EXPERIMENT 1 TO LEARN ELEMENTARY LAYOUT DRAWINGS OF UTILITIES

Structure

1.1 INTRODUCTION

Following definitions will be useful in understanding the practical.

- **Layout:** It is a procedure in which position of various parts is fixed according to a plan. This forms the basis for design.
- **Design**: Specific planning or modeling using some established principles or rules.
- **Utilities**: Systems, which provide service to production or processing.

First major step in establishing a dairy plant is the site selection. The governing factors of site selection include manpower availability, raw material supply, road or railways, local environment, water and electricity supply and town planning. The major utilities of a dairy plant are water, compressed air, steam, electric power and refrigeration. Once the main processes in a dairy plant are fixed, they are scheduled. From scheduling charts, the utilities loads are worked out with time. Based on that the detailed design/selection of equipment and construction of additional infrastructure is decided.

1.2 OBJECTIVES

We will be able to

- understand the layout drawings of a dairy and its utilities
- draw a simple layout drawing of a dairy and its utilities
- know the space requirement of different equipment and utilities

1.3 EXPERIMENT

i. Principle

Following general principles should be followed in preparation of lay out of utilities.

- For small dairy plants, the utilities may be located in the main building and for large dairy plants a separate building for utilities is recommended.

ii. Requirements

Milk processing plant of your area
Layout drawings of dairy plant and utilities section of a dairy plant.

Dairy plant utilities

Utility	Purpose	Equipment and additional infrastructure needed
Water	Floor washing, cleaning the equipment and pipelines, feed water for boiler	Water softener, storage tank, distribution system
Electricity	Running machines, lighting, ventilation, process control	Main switch room
Steam	Heating in heat exchangers, hot water production.	Boiler, fuel storage tank
Refrigeration	Cold storage, chilling of water	Compressors, condensers
Compressed air	Pneumatic controls, pneumatic conveying, agitation in tanks and pneumatic tools.	Compressor, air filters

iii. Procedure

- Study some of the elementary drawing of dairy plant layout and study the location of utilities.
- Visit a dairy plant and actually see the location of utilities.
- Interact with the staff of dairy plant to know the advantages of layout they adopted.

iv. Observations

- Draw the block diagram of the plant showing the administrative section, production section and utilities section of the dairy plant visited. Example layouts are shown in figure 1 and figure 2.

v. Results

- Elementary lay out drawings of dairy plant visited and its utilities.

1.4 PRECAUTIONS

- While preparing layout drawings, the arrangement of different section should be such that the chance of microbial or other contamination of raw materials and products is minimized.
- The piping and cables of utilities should be as short as possible to economize both initial cost and operating costs.
- All utilities should have easy accessibility for maintenance purpose.
- The utilities should be located and maintained in such a way that they do not act as source of microbial or other contamination in processing section.
- Noise and smoke or dust producing equipment should be located opposite to the prevailing wind direction so that they will be carried away from processing section.

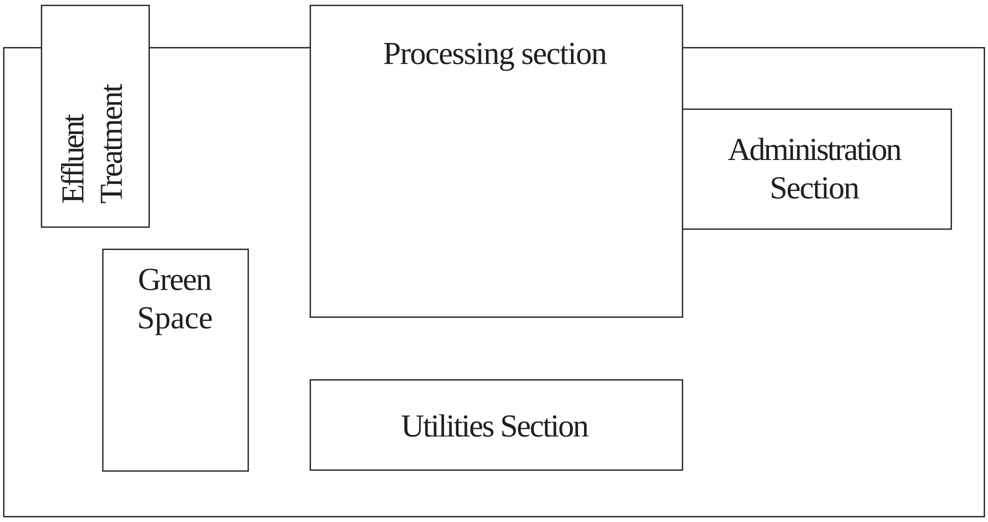


Fig. 1: Elementary layout drawing of a dairy plant

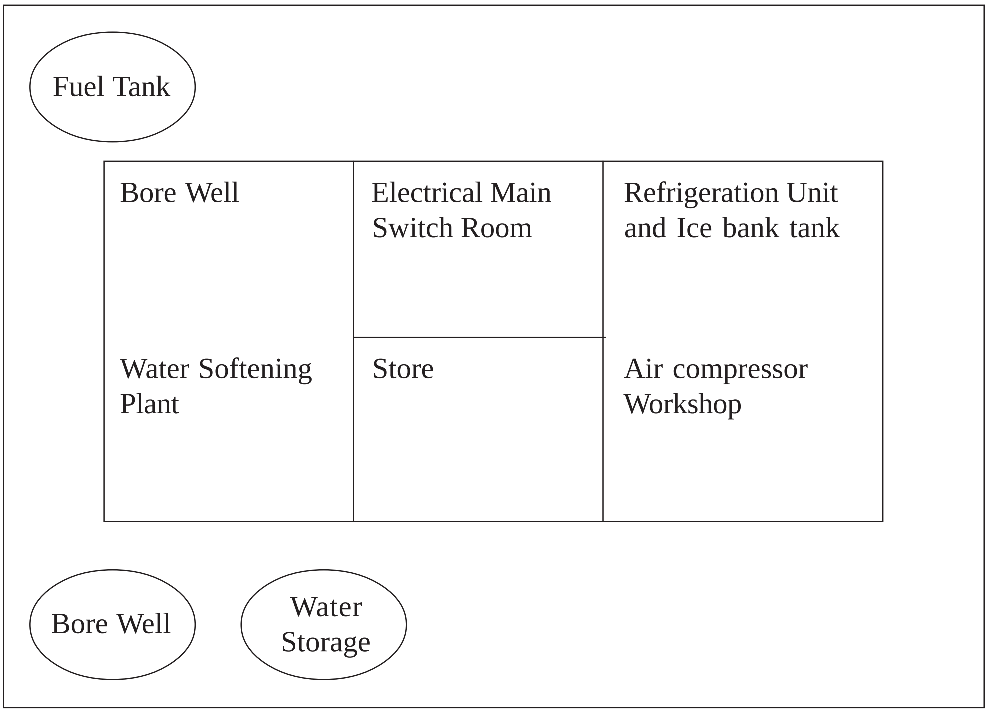


Fig. 2: Elementary layout drawing of utilities of a dairy plant

EXPERIMENT 2 STUDY OF VARIOUS WORKSHOP TOOLS

Structure

2.1 INTRODUCTION

"Workshop Tools" is basically a broad term covering a wide range of general purpose and special purpose tools used in various applications. We know that the function of tools is to facilitate that work which cannot be done by hands only. There may be a number of tools for use in a number of different applications. But here our purpose is to study some general workshop tools used in routine repair and maintenance of dairy equipments, pipes and fittings etc. in a dairy plant. Tools are essential in carrying out any dismantling/ assembling and maintenance job of dairy equipments. One cannot attend even a small repair job without the use of tools. Hence a dairy operator/ maintenance staff must be well familiar with some general workshop tools, their names, identification, types, use and care to be taken etc.

2.2 OBJECTIVES

We will be able to

- identify different workshop tools by their proper name
- know the types and range of size available for different tools
- understand the specific use of each tool
- take the proper care while keeping and using a tool

2.3 EXPERIMENT

i. Principle

The principle of working of general-purpose workshop tools is very simple and also common in some sense. These convert the available motion and force of hands of a worker into required motion and force to carry out a particular mechanical operation like tightening a screw or nut bolt, beating, cutting, filing, grinding, punching etc.

ii. Requirements

General workshop tools of each type and size as mentioned below:

1) Vice
2) Hand Hacksaw
3) File
4) Hammer
5) Chisel
6) Pulley Puller
7) Oil Can
8) Sniper
9) Screw Driver
10) Pliers
11) Double End Spanner Set
12) Ring Spanner
13) Box Spanner
14) Pipe Wrench
15) Adjustable Wrench
16) Ratchet Wrench
17) Allen Key Set

iii. Procedure

1) First of all note down the names of different tools displayed on a workbench and draw a neat sketch of each.
2) Try to understand the working function and method of application of each tool.
3) Study the different shapes, different types and range of size of tools displayed.
4) Understand the use of a particular size and type of tool in any specified situation by using these on a dummy work piece.

iv. Description Of Tools:

1) **Vice**: It is used for holding the work piece tightly while performing the mechanical operations like cutting, filing, and drilling etc. on the work piece. Its main body is generally made of cast iron. It consists of one fixed jaw and another movable jaw moved by handle and spindle. It is generally of four types: a) Bench Vice b) Pipe Vice c) Machine Vice d) Hand Vice
2) **Hand Hacksaw**: It consists of an adjustable steel frame in which a hacksaw blade is fixed. It is used for cutting of metals. The blade is made of 'High Speed Steel'. It consists of cutting teeth on one edge or both edges. The blade is specified by its length, width and TPI (teeth per inch) the value of which is generally 14 to 32.
3) **File**: It is used for filing of metal jobs to finish their surface to the required size and shape. It is made of 'High carbon Steel'. On its surface parallel cuts are made which help in tearing/ filing the surface of job. Depending on the direction of cuts, files are of two types as single cut and double cut. Depending on the size of cuts, files are named as rough files, smooth files and dead smooth files etc. Depending on the shape these are divided as flat file, round file, half round file, triangular file and square file.
4) **Hammer**: It is a very simple tool, which is used for beating of metal job. It consists of a solid block of steel in which a wooden handle is fixed. Depending

on the shape of this block, hammer is of various types such as ball peen hammer, cross peen hammer and straight peen hammer. Its size depends on its weight.

5) **Chisel**: It is used for cutting of different shapes of metals by beating with hammer. It is made of carbon steel. Its cutting edge is hardened and tempered and shaped at an angle of 60° to 70°. The cutting edge can also be of some other shapes. Depending on this shape, chisels are of different types as flat, cross cut, diamond point and round chisel.

6) **Pulley Puller**: It is used for dismantling of a pulley from its shaft for some repair purpose. It is fabricated of cast iron. It consists of two or three flexible legs connected to a central frame in which a spindle with outer threads moves. When the spindle is tightened on the shaft the legs holding the outer edge of pulley pulls it outwards.

7) **Oil Can**: It can be of different designs. Its purpose is oiling the moving parts in equipment.

8) **Sniper**: It is like a scissor. It is used for cutting of thin sheets of metal.

9) **Screw Driver**: As the name suggests, it is used for opening or tightening of screws. On the head of a screw a square recess is made in which the flat edge of screwdriver fits. The handle of screwdriver is made of wood or some insulated plastic. It is generally of two types: a) Flat screw driver b) Philip Screw Driver

10) **Pliers**: It is used for many purposes like opening and tightening of nut bolts, scratching of insulation from electric wires, cutting of wires etc. It is of different types: a) Combination Plier b) Side cutting Plier c) Round nose Plier d) Long nose Plier

11) **Double End Spanner**: It is a very simple and most suitable tool for screwing and unscrewing a nut or bolt with hexagonal head. Its both ends have different sizes and are bent at an angle of 15°. It is suitable where there is less space on the top of nut as it can fix on from the side due to its open ends. It is available in a set of 6 or 10 pieces for operating on different sizes of nut/ bolts.

12) **Ring Spanner**: Its function is also the same as that of double end spanner. The difference is that its ends are of ring shape and fix on the nut or head of bolt from the top. The shape of rings is specially designed which prevent it from slipping over the nut/ bolt. It is also available in a set of different sizes.

13) **Box spanner**: Its function is also the same as that of double end spanner and ring spanner. The difference is that it is used where there is no space to operate simple spanners. By using box spanner one can apply force on the nut from any direction depending on the space available. Its one end exactly fits over the nut and on the other end a handle is fixed.

14) **Pipe Wrench**: It is used for screwing or unscrewing a pipe. It has one fixed jaw and other movable jaw, which can be adjusted according to the size of pipe. The jaws have knurled surfaces, which help in holding tightly the pipe surface. It is also available in different sizes.

15) **Adjustable Wrench**: It is a universal type tool and very handy because it can be singularly used for operating different sizes and shapes of nut/ bolts. It is possible because of its adjustable jaw operated by a screw. Therefore it is also called adjustable screw wrench. It is available in different sizes like 100mm, 150mm, 200mm & 250mm.

16) **Ratchet Wrench**: It is generally used for fast opening or closing any service valve in the industry. On its one end there is a fixed cut spanner connected to

the handle through a ratchet gear. Due to ratchet, spanner acts in only one direction and in the other direction it slips. So, we need not to detach the spanner from the valve stem again and again for operating the valve.

17) **Allen Key Set**: It is a hard steel rod of hexagonal shape cross sectional area and bend at 90° in the shape of letter 'L'. It is used for screwing the L-key shape bolts. It is available in different sizes depending on its thickness.

    Note: For figures of tools, please refer to your theory notes of block no.4 (Electrical Engineering. and Safety Devices)

v. Observations

1) Note the names, types and sizes of various workshop tools displayed.
2) Observe their method of application and utilities in various types of repairs.
3) Observe the importance of keeping all the tools in good working condition and measures to be taken for that.

vi. Results

At the end the students will be well familiar with various types and sizes of general-purpose workshop tools. They will understand their importance in the routine repair and maintenance of the plant. They will be able to decide on that what type and size of tool should be used in a particular repair job. They will know the proper use of tools. They will understand the importance of keeping the tools in good working condition.

2.4 PRECAUTIONS

1) Follow the instructions of practical teacher carefully.
2) Do not mishandle any tool and don't play with it as a toy.

EXPERIMENT 3 STUDY OF DIFFERENT SANITARY S.S.PIPES, FITTINGS AND GASKETS

Structure

3.1 INTRODUCTION

A milk processing plant has network of pipelines. Sanitary stainless steel pipes are required to supply/transport milk from one equipment to other or even from one section to other. During milk/product supply it is ensured that pipes do not add any contamination, thus milk is protected during its movement. The word "Sanitary" carries specific objectives. Only milk pipeline requires being sanitary. Hence all care is taken during selection of material, machining, installation etc. Sanitary pipe thus offers I) Easy assembly and dismantling for cleaning. II) Self-draining slope to ensure minimums hold-up when not in use. III) Minimum corner, bends, sharp edges etc to avoid pressure loss or danger to operator. IV) No Blind pockets to avoid contamination etc.

Similarly pipe fittings required for control of milk supply. Fittings are various types such as Tee. Bends, union, elbows etc and valves such as two-way and three way for supply & control. Gaskets become the integral part of each joint. These help in preventing leakage and also absorbed some vibration/noise of equipment. The material of gasket should also have longer life and should not add to any contamination.

3.2 OBJECTIVES

After doing this practical we will be able to

- identify various types of pipes and fitting used in a dairy plant.
- understand the sanitary features of pipes and fittings
- know the purpose of each pipes fitting and gaskets.

3.3 EXPERIMENT

i. Principle

1. Quick and easier assembling and dismantling features.
2. Easily accessible for handling, operation and maintenance, and readily cleanable.
3. The material chosen must not have any action upon the product, not mix with

the product or alter composition, flavors or appearance of the product.

4. After assembling of equipment, the pipe threads are not exposed to the product.
5. After assembly inner surface be smooth and even with self-draining slope.
6. Gaskets required for joints be bare minimum and made from non-toxic material.

A whole range of pipeline fittings are available such as bends, tees and reducers, all of which are designed to be interchangeable. Piping should be in good alignment and well supported to prevent sagging. Self-draining slope of 25mm per 3 meters be maintained. Objective is to eliminate or minimize the dead ends to avoid microbial contamination.

Each fitting offers specific purpose on a service pipeline. We should try to learn and distinguish the application of individual fittings.

ii. Requirements

1. A set of various pipes, such as cast Iron, mild steel, stainless steel of varying sizes for identification.
2. A set of pipe fitting required for water steam and milk pipe lines. e.g. union, bends, elbow, valves, tee, reducers etc.
3. A set of insulating material for chilled water line, steam line with aluminum cladding.
4. Pipeline supports, clamps etc.

iii. Procedure

Pipe and fitting of various service supply line are different in their appearance, installation and operation. All pipes and fitting for water supply and transport have blue colour code. Steam line is marked with yellow colour Refrigeration pipes and fittings are indicated with red marking. Milk pipelines are of stainless steel, hence no colour code is given.

The learners should identify the pipes and fittings used for different products. They should observe specific features of material, design, operation, maintenance and control.

iv. Observations

The purpose of this practical is very specific. The learner should identify the pipe and fittings with respect to their application. They may observe the appearance in terms of fabrication/machining. A milk pipe and fitting offers clean and smooth surface as compared to water supply lines. Inside finish of individual fitting will be much different in each eases. Milk line will have clear finish with no obstruction. Assembling and dismantling is much easier. Only hand assembling may be sufficient. The material of construction for each pipe and fitting is different.

v. Results

Learner will learn different colour codes of pipes. They will be able to distinguish between pipes for different products. They should also identify various fittings and their role in the handling of product. The sanitary features of milk pipe and fittings are of special interest. Learner will be able to appreciate the importance of these features, required for better hygienic control and quality milk processing.

Proper selection of pipe and fittings, and knowledge of hygienic features improves the efficient working/operations.

3.4 PRECAUTIONS

1. While disassembling and reassembling no hammering or pressure is required. This will protect the gaskets provided within joints.
2. During operation or flow of milk, there could be vibration/leakages due to improper alignment, which should be removed.
3. Regular support to the pipe line will facilitate proper slope, avoiding accumulation of product.
4. Never dismantle the line during its use.

EXPERIMENT 4 DISMANTLING AND ASSEMBLING OF MILK PUMPS

Structure

4.1 INTRODUCTION

Pumps are used to supply milk from one equipment to another. In most of the cases fluid from a lower level is lifted to higher level or to create more pressure in the line. Most of the pumps used in Dairy plants are centrifugal type pumps. A centrifugal force is created by rotating a part called “Impeller”. A low pressure is created at the inlet or suction end and high pressure at the outlet or delivery end of the pump.

A centrifugal pump consists of impellers, casing (usually volute type), drive shaft, seal, inlet and outlet ports. The shaft receive power from a motor either directly connected or through a coupling.

For more viscous products like ghee, cream, or ice-cream-mix etc positive displacement type pumps are employed. Milk pumps are centrifugal pumps. A dismantled diagram is given for convenient learning. (Figure.)

4.2 OBJECTIVES

We will be able to:

- identify various sanitary pump used in dairy plant.
- dismantle and reassemble a milk pump.
- maintain proper functioning of milk pump.

4.3 EXPERIMENT

i. Principle

Mechanical energy is added to fluid (milk) by rotating impeller within volute casing generating a centrifugal force. This further creates suction in the centre and pressure at the discharge out let, causing fluid to flow. The part coming in contact with milk are hygienically designed and fabricated. Because of simplicity, the pumps are easily dismantled for clearing and repairs.

The construction facilitates quick reassembling without much effort. Practically no spanner or hammering is required.

ii. Requirement

1. A centrifugal milk pump
2. Sanitary spanner
3. Spare clamp gasket
4. Spare pump seal

iii. Procedure

Stepwise procedure is given below.

1. Switch-off the power supply.
2. Routine operation in shut down mode.
3. Dismantle the suction and discharge milk line connection.
4. Opening of clamp ring provided on the pump casing.
5. Part 1 and 2 of figure can be removed.
6. Unscrew of nut no 3 provided on the impeller.
7. Remove nut and the impeller.
8. Remove pump seal and the housing gasket for cleaning.

For reassembly reverse order will be fallowed. To unscrew clamp and impeller nut, mild pressure through a sanitary spanner may be applied.

iv. Observation

A plant operator needs to open/dismantle the pump if there is leakage or giving vibration. One is required to observe the cleanliness of pump casing, impeller, pump seal etc. Also if undue wear is observed in the seal, the same requires adjustment, repair or even replacement. Some time impeller may also indicate sign of damage such as pitting. If so the impeller may need repair. Often the casing gasket, pump seal, pipeline gasket develop wear, causing leakage or the noise. Pump may not be supplying proper amount fluid or at reduced pressure. Matter requires reporting to the technical group.

v. Results

Though dismantling and reassembling, one can understand the construction details of a pump. The smooth fabrication and ease in handling will strengthen the knowledge of hygienic design aspects. The regular check-up will lead to quality improvement and efficient running of whole system. The degree of cleanliness will indicate the effectiveness of cleaning method being used in the plant.

4.4 PRECAUTIONS

1. Ensure switching-off of electrical supply line.
2. Before dismantling milk supply operation must be shut down.
3. Keep enough spare parts before dismantling to ensure quick reassembly.
4. Do not hammer or apply force during dismantling or assembling.
5. Ensure cleaning cycle is complete and no detergent remains in the pipe line.

EXPERIMENT 5 STUDY AND SKETCH THE DETAILS OF MILK TANKER, STORAGE TANKS AND SILOS

Structure

5.1 INTRODUCTION

Milk is transported through milk tankers from chilling center network. These tankers are insulated and mounted on truck chassis. The inner wall of these tankers is made of stainless steel, hygienically designed and fabricated. A thick insulation is provided covered by outer layer and necessary fittings outer layer may be of stainless steel or mild steel in some cases. Insulation does not allow the rise in milk temperature. These tankers are of 4,000 to 12,000 L capacity with single or double compartments. Two compartment facilitate collection of two types of milk and also reduces the surge, agitation and churning of milk during transport. Manholes with sanitary covers are provided for each compartment. Fill connections, vents and cover assembly is provided for inspection, loading and cleaning etc. Rubber gasket and locking device is provided for tight seal. Similarly outlet valve, hose, railing are provided for unloading cleaning purpose. Storage tanks are required with-in the dairy plant for storage of raw, pasteurized or processed milk. These may be cylindrical, rectangular, horizontal or vertical type, and made of stainless steel. Necessary fittings/ accessories are provided for inspection, control and cleaning. Tanks are insulated with minimum 5 cm insulation. An oval shape manhole with gasket is required for manual cleaning.

Silos are usually vertical tank for capacities beyond 10,000 litres. These occupy less space and mostly installed outside Dairy building. To facilitate control an access is provided from within the Dairy building. These have provisions for mechanical cleaning, control, milk stirring, milk weighing etc. Some times chilled water-cooling or even refrigerant cooling is also provided as per the need of Dairy plant. However, while fabricating, installation all hygienic cares are taken as in other dairy equipments.

5.2 OBJECTIVES

We will be able to:

- identify various types of milk tanks and their accessories.

- know the hygienic feature of milk tank, tankers and silos.
- understand the operation cleaning and maintenance aspects.

5.3 EXPERIMENT

i. Principle

Milk received from the collecting center or chilling center is required to be stored under chilled condition. All other processing within dairy takes longer time. There is need to provide bulk transport up to dairy plant and within the plant for subsequent operation. During this handling no outside contamination should reach into the milk. Also chilled condition prevents multiplication of microbes. The size and shape of milk tanks, tanker and silos are decided primarily based on the need. Circular/cylindrical shape offers greater mechanical strength. The rectangular shape utilizes better space of the Dairy plant. Elliptical shape, especially for tankers offers lower center of gravity considered good during transport. The material of construction, quality fabrication helps in hygienic design of the equipment.

ii. Requirement

1. Milk tank, tanker and silos.
2. Various types and size of these tanks.
3. Various fitting and accessories mounted on tanks, tankers and silos.
4. Visit to Dairy plant.

iii. Procedure

The learner, while examining tank, tanker and silos must ensure that the units are not in operation or in use. The fittings or mountings may be opened for study. No tool or external pressure will be required.

iv. Observations

One should make a diagram and write maximum possible technical details. The shape, size and the list of all accessories are to be noted. The function or the purpose of each mounting be noted and explained. The manhole shape, its locking arrangement, the shape of gasket and their functions be highlighted. Cover, agitator, gauges, vent, valves, sight glass, light glass, adjustable legs, self-draining slope, ladder, spray ball etc be noted. The milk inlet has special feature. Try to find explanation of such design. One should also observe how these units are cleaned and put into operation again. The hygienic features of design must be noted. How the clean surface is achieved.

v. Results

1. The Geometry of this equipment with specific reason.
2. The hygienic design aspect will be appreciated.
3. A neat sketch with fitting will ensure clarity of these equipments.
4. Use of individual mounting will be known..
5. The location of agitator and its operation will provide reason for its use.
6. Side foamless entry of milk and the relation of air vent will be known.
7. Purpose of insulation and temperature indicator/recorder will be known.
8. Degree of cleanliness will explain the beauty of design and fabrication.

5.4 PRECAUTIONS

1. Ensure that this equipment do not have milk inside.

2. Agitator must be switched-off.
3. Only clean tank, tanker and silo are studies.
4. For better understanding the operation be observed again during its use.
5. All electrical connection to load calls of silos is switched off.

EXPERIMENT 6 TO STUDY DIFFERENT TYPES OF THERMOMETERS, PRESSURE GAUGE AND FLOW METERS

Structure

6.1 INTRODUCTION

During the operation of equipment and machinery in a dairy plant, the plant operator has to keep a constant watch on various machine parameters and process variables, such as, temperature, pressure, flow rate etc. For indicating these variables and parameters several devices and instruments are installed on the equipments. The satisfactory operation *of* the equipment depends upon the reliability of these instruments.

The fundamental purpose of measurement of process variable is to improve the quality of product by processing it under the optimum processing conditions. All the milk processing equipment are designed to operate under given set of machine parameters such as speed, pressure or vacuum, flow rates and heat exchanger temperature. The efficiency of these equipments is maximum, if they are operated under the parameters for which they have been designed. It is thus of importance to understand the working of the devices used to measure the important process variables.

6.2 OBJECTIVES

After doing practically we will be able to

- identify different types of thermometers
- know about Pressure gauge
- understand working of flow meters.

6.3 EXPERIMENT

i. Principle

a) Glass Thermometer

The mercury in glass thermometer utilizes the volumetric expansion of mercury with temperature as a mean of indicating temperature.

It has a bulb formed by a glass envelop. This bulb contains mercury. Bulb is attached to the stem, which contains a fine capillary tube in it. Bulb of the thermometer is inserted into the hot medium whose temperature is to be measured. As the heat is transferred from hot medium into the mercury in the bulb, the mercury expands. This expansion pushes a thread of mercury into the capillary. The glass of the thermometer is generally shaped as to magnify the apparent width of the thread of mercury. A temperature scale is put on the stem of thermometer, which indicates the temperature being measured.

b) Liquid Gas Expansion Thermometer:

Liquid Expansion Thermometer utilizes the volumetric expansion of liquid caused by temperature changes to measure the temperature. The commonly used expanding material in the liquid expansion type thermometers is ethyl alcohol. Gas Expansion Thermometer operates on the principle that the pressure of gas varies directly as the temperature, if the volume is kept constant.

The basic construction of these thermometers is same. They have a bulb, which contains either a liquid or gas. A metal capillary is connected to the bulb on one end and to a receiving element at the other end. The receiving element is usually a bourdon tube or pressure spring. The bulb comes in thermal equilibrium with the medium and transfer heat to the fluid inside the bulb. With this heat a pressure is developed in the fluid and the capillary connected to the bulb transfers this pressure to the receiving element, that is, the pressure spring. The pressure spring converts this pressure into a motion that moves the pointer on a scale to indicate the temperature.

c) Electrical Resistance Thermometer:

This type of thermometer is based on the principle of change in electrical resistance of a substance with temperature.

Usually the material of a resistance thermometer is metal but non-metallic material may also be used. The industrial resistance thermometer employs platinum, nickel or copper. In processing industries the platinum-resistance element is used. An electrical resistance thermometer bulb could be made up in many forms. The element may be made up of a strip of very thin foil or a coil of very fine wire wound on a frame. The industrial resistance thermometer is of a probe type.

d) Bourdon tube type pressure gauge:

It employs a Bourdon tube element for direct indication of pressure. The bourdon tube element can be of ‘C ‘type, spiral type or helical type. One end of the ‘c’ type bourdon tube element is sealed at its tip, while the other end is connected to the process pressure, which is to be measured. When the pressure is applied to it, the tube tends to straighten up and results in a motion of the sealed tip end of the tube. The extent of movement of the tip of tube depends upon the amount of applied pressure. The movement of sealed end of the bourdon tube is thus an indicator of the applied pressure or vacuum. The metallic materials used for construction of bourdon tube include brass, bronze, phosphor bronze, beryllium-copper alloy, alloy steel or stainless steel. The non-metallic materials are leather, neoprene and rubber.

e) Rotameter:

Rotameter is a type of area flow meter. It operates on the principle that the variation in area of the flow stream required to produce a constant pressure differential at a restriction of flow is proportional to the flow rate.

It consists of a tapered metering tube and a float which is free to move up or down within the tube. The shape of the float is of bob-shape or inverted cone shape so to provide constant viscous drag at all flow. The metering tube is mounted vertically with the smaller end at the bottom. The fluid whose flow rate is to be measured enters the tube at the bottom, passes around the float and moves out of the tube at the top. When the fluid enters the tube, it raises the float. The float moves up or down in the tube in proportion to the fluid flow rate. Every float position corresponds to one particular flow rate. The tapered tube is made up of Pyrex glass. The float is made up of dense material such as silver or tantalum.

ii. Requirements / Apparatus

1. Mercury in Glass Thermometer
2. Liquid / Gas Expansion Thermometer
3. Electrical Resistance Thermometer
4. Bourdon-tube type Pressure Gauge
5. Rotameter (Flow meter)

iii. Procedure

i) Study the cut models of the Mercury in Glass Thermometer, Liquid / Gas Expansion Thermometer, Electrical Resistance Thermometer, Bourdon-tube type Pressure Gauge, Rotameter (Flow meter) in the laboratory and observe their principle of working.

ii) Examine the devices and note down their components and the sub-components.

iii) Dismantle and assemble all the given devices and study their internal construction.

iv) Note down the specifications of above devices and learn how to write down their specifications.

v) Visit the dairy plant and observe the location of different pressure gauges, thermometers and flow meters installed on various equipment.

vi) Note down the mode of installation of these devices on the equipment.

vii) Draw the sketches mentioned in the column 11.4 in your practical record note-book and write their technical details/ specifications.

iv. Results

Note down the following:

i) Actual size, shape and physical appearance of various measuring devices used on a milk processing equipments.

ii) Need and importance of various indicating / control devices fitted to various equipments.

iii) How and where these devices are installed on the plant and machinery in a milk processing plant.

6.4 PRECAUTIONS

i) The technical data sheet and the instructions under ‘operation’ should be studied before proceeding.

ii) Do not unscrew or remove any device from the equipment or machine.
iii) Do not operate any valve attached to the device when the plant is in operation.
iv) Dismantle any device only under the supervision of expert instructor.
v) Keep safe distance from equipment and machinery in the dairy plant.
vi) Do not touch the hot surfaces and the pipelines.
vii) Follow the instructions of the plant operator while observing the metering devices in the plant.

EXPERIMENT 7 STUDY OF REFRIGERATION SYSTEM: COMPRESSOR (RECIPROCATING), CONDENSERS (SHELL & TUBE, ATMOSPHERIC) AND EXPANSION DEVICES (THERMOSTATIC EXPANSION VALVE/ CAPILLARY TUBE)

Structure

7.1 INTRODUCTION

A refrigeration system is a name given to all those equipments/ machinery, which work together and produce refrigeration. For example, a refrigerator unit or a milk chiller or a cold storage of Dairy Plant, all are named as a refrigeration system. A refrigeration system has a major role to play in Dairy Industry or we can say that a refrigeration system is an important and integral part of Dairy Industry.

There can be numerous types of refrigeration systems depending on different size, design, application, capacity of cooling or low temperature to be maintained, etc. But the principle of refrigeration in all these equipment is mostly common and that is 'vapour compression refrigeration'. Because of common principle of working, the basic major components of refrigeration systems are also same, i.e., compressor, condenser, expansion valve and evaporator. Our purpose here is to physically examine some common types of major components of any refrigeration system of a dairy plant. After physically examining, we can actually identify these major components and their sub-parts and hence understand their construction, working and actual position in the system. This type of study is highly important not only in strengthening and supporting the theoretical knowledge but also in the efficient operation and maintenance of a refrigeration system.

The type of compressor, usually used in any refrigeration system of a dairy plant is of reciprocating type. In this type when an electric motor rotates the main shaft of compressor, a piston reciprocates i.e. moves up and down in the cylinder of compressor. While moving down, the piston sucks the refrigerant vapours coming from the evaporator through suction valve and while moving upward, it compress (increase the pressure of) these vapours and discharge them to condenser through discharge valve. In this way, the basic working of a reciprocating compressor is exactly same as that of a cycle pump. We can thoroughly understand the principle of working by physically examining the fixed and moving parts in an actual compressor.

The role of a condenser is to reject heat of compressed refrigerant to atmosphere by providing large area for heat exchange. It is named as condenser because by rejecting latent heat of refrigerant it condenses the refrigerant i.e. converts it from vapour to liquid state. In a large size refrigeration system, which is generally there in a Dairy Industry, either shell or tube type or evaporative type, also called as atmospheric condenser is used. Shell and tube type condenser is most satisfactory condenser in case there is no scarcity of cooling water. But its initial cost is high with separate cooling tower. On the other hand, when there is water shortage and cooling tower is being used, then generally the evaporative condenser is more suitable especially in case of large plants. Here we will study both types of condensers and understand their work of heat exchange.

Regarding expansion valve, thermostatic expansion valve is most commonly used in a mid size refrigeration system. In small unit generally capillary tube is preferred because of its low cost, simple working and no maintenance required, etc.

7.2 OBJECTIVES

We will be able to:

- identify the major components i.e. compressor, condenser and evaporator of a refrigeration system and also their sub-components.
- understand the constructional design of each component.
- know the function of each component and sub-component in the complete working of refrigeration plant.

7.3 EXPERIMENTS

i. Principle

Any type of vapour compression refrigeration system has the same principle of working. A fixed quantity of refrigerant, which is any suitable gas is filled in the closed system of four components, i.e., compressor, condenser, expansion valve and evaporator connected to each other through tubes. When the compressor is run, the refrigerant starts flowing through the system i.e., the system starts its working. The compressor continuously sucks low pressure, low temperature refrigerant vapours from the evaporator and pump these to condenser at high pressure and high temperature condition. While flowing through the condenser, the high temperature vapours release their heat to atmosphere and condense to high-pressure liquid state. After condenser this high-pressure liquid enters the expansion valve where it is throttled to low pressure. On throttling the pressure and temperature of refrigerant decreases and when this low pressure, low temperature throttled liquid flows through evaporator, it sucks heat and produce cooling. On absorbing heat in evaporator all the low-pressure liquid evaporates to low-pressure, low-temperature vapours, which are again sucked by compressor. In this way all these processes go on continuously and as long as the compressor runs, the system produce cooling around the evaporator.

ii. Requirement Of Machinery/ Instrument & Materials

i) Reciprocating compressor

ii) Evaporative condenser

iii) Shell & tube type condenser

iv) Thermostatic expansion valve with capillary and filler bulb

v) Capillary tube

vi) Workshop tools kit

iii. Procedure

i) Study of Compressor:

It is the main component of a Refrigeration System. It may be of many types but a reciprocating compressor is commonly used for different cooling applications in a dairy industry. The principle of working has already been explained in theory. Here our purpose is to physically study the compressor by adopting following steps:

i) First of all note down the make, size and specifications of compressor shown. Also note down its capacity to produce cooling in tons.

ii) Identify the various parts and connections of compressor, which are visible from outside.

iii) Identify various inside parts also if it can be partially dismantled.

iv) Note down the type of refrigerant for which the compressor is meant.

v) Note down the name and type of lubricant being used in compressor and also identify the required level of oil through sight glass.

vi) Identify the mounting/accessories being used on compressor like compressor gauge, safety valve/ switches, etc.

vii) Draw a neat diagram of compressor showing various parts and connections.

viii) Try to understand that how by running of compressor, piston moves up and down and how by this reciprocating action of piston and operation of valve, the refrigerant vapours are sucked and compressed.

ii) Study of Condenser:

(A) Shell & Tube Condenser:

i) First of all note down the make, size and specification (whatever available) of the condenser.

ii) If it is not in use, can be partially dismantled by opening up the end plate of condenser.

iii) Note down the material and size of shell and tubes.

iv) Note the number of turns or passes of tube in the shell.

v) Draw a neat diagram of condenser.

vi) Try to understand the direction of flow of refrigerant and cooling water and the process of heat exchanger through wall of tubes in shell and tube condenser.

(B) Evaporative Condenser:

i) Check and note the number of water re-circulating pumps being used.

ii) Note down their size, specifications and power rating.

iii) Note down the size and material of condenser tubes

iv) Note down the number of tubes in the one coil and also the number of coils.

v) Note the total flow rate of cooling water over the coils by adding up the discharge of each pump.

vi) Also calculate the total water carrying capacity of pump.

vii) Draw a neat sketch of condenser.

iii) Study of Expansion Valve:

(A) Thermostatic Expansion Valve

i) Take a thermostatic expansion valve and dismantle it by opening up screws and bolts.

ii) Identify its various parts, i.e., diaphragm, valve and valve seat, spring and adjusting screw, etc.

iii) Identify the capillary and feeler bulb attached with it.

iv) Draw a neat sketch of valve.

(B) Capillary Tube

i) Note the inner and outer diameter and length of capillary tubes available. Also note the material of tube.

iv. Observations

i) Observe and understand that how by running of compressor, piston moves up and down and how by the reciprocating action of piston and operation of valve, the refrigerant vapours are sucked and compressed.

ii) Observe and understand the direction of flow of refrigerant and cooling water and the process of heat exchanger through wall of tubes in shell and tube condenser.

iii) Observe and understand the process of heat exchanger in evaporative condenser. The latent heat of refrigerant vapours is transferred to water layers on outside surface of tubes. And the water layers are cooled by increased evaporation due to large area of contact with air.

iv) Observe the construction of different parts of thermostatic expansion valve, their linkage with each other and their working by sensing of the pressure in feeler bulb attached with evaporator tube..

v) Observe physically that the thin cross-sectional area and large length of capillary tube offer resistance to flow of refrigerant liquid. Due to this resistance, the pressure decreases on the other end of tube and it can be used as an expansion valve.

v. Results

After physically studying the components of refrigeration system, the students will be able to know:

i) Construction and function of each sub-part in a compressor, condenser and expansion valve.

ii) Position and importance of each part and sub-part of a refrigeration system.

iii) Need for automatic controls of major components of refrigeration system.

7.4 PRECAUTIONS

i) Study of refrigeration plant should be undertaken in the presence of Instructor/ Practical Teacher and under his instructions and guidance.

ii) Don't touch and disturb any part in the plant of your own.

iii) Listen carefully the instructions of practical teacher and follow them accordingly.

iv) Do not dismantle any part without the permission of operator/ plant in charge.

EXPERIMENT 8 STUDY OF PARTS AND OPERATION OF A COLD STORAGE PLANT AND ICE BANK

Structure

8.1 INTRODUCTION

The cold storage is a highly essential part in a dairy industry for safe storage of dairy products. In the cold storage, favorable conditions of temperature and humidity are maintained so as to retard spoilage and preserve the freshness and eatable quality of dairy products. It may be of varying size depending on the quantity of products to be stored and also the storage time. It is an insulated room used as a storage cabin in which low temperature/ cold is maintained with the help of a refrigeration system. The evaporator or evaporating coil of refrigeration system is situated inside the cold room to maintain cold conditions. All other components, i.e., compressor, condenser, expansion valves etc. are situated outside the cold room. When refrigeration plant is run, the evaporating coil situated inside cold storage produces cooling around it. To spread this cooling of evaporator in whole inside space of cold storage, an air diffusing system is used. In this system, a fan or blower force the room air to flow over the cooling coil and then spread it in the whole room thus increasing heat transfer. As the plant is continuously run, it pumps out the inside heat of cold room and of products stored within. By pumping out the heat and preventing the natural inflow of heat from outside by insulation, the temperature inside the cold storage falls down, making the safe environment for stored products.

An ice-bank unit is also commonly used in a large size dairy plant. An ice-bank unit is nothing but a large size tank filled with chilled water and ice. Here also the normal water filled in tank can be chilled or formed to ice by the application of a refrigeration system. The evaporating coil of refrigeration system is directly dipped in water where it absorbs heat from water and converts it to ice. This ice-bank unit can supply a large amount of chilled water for various applications in plant. Ice-bank unit is generally operated by the same refrigeration system by taking a part of compressed and condensed refrigerant and expanding it in the cooling coil dipped in water. Thus there is no need to install separate compressing and condensing unit. This combination of one or more cold storage and an ice-bank unit run by a common refrigeration system is usually kept in dairy industry. Our purpose here is to visit a working refrigeration plant and study of its different parts and their operation.

8.2 OBJECTIVES

We will be able to:-

- know the arrangement of refrigeration components in a cold storage plant.
- understand the importance and method of cold air diffusion inside cold storage.
- understand the role of insulation.
- operate and use of an ice-bank unit.

8.3 EXPERIMENTS

i. Principle

The principle of production of cooling is same as of vapour compression refrigeration system. However, different methods are used to spread this cooling from evaporator to dairy products in a cold storage and from evaporator to water in an ice-bank unit. In a cold storage an air diffusing system is used which force the room air to flow over cooling evaporator coil and diffuse this cold air in the whole space. In an ice bank system, an agitator is generally used to spread cooling in all directions in water thus increasing the rate of ice formation.

ii. Requirement of Machinery/ Instrument and Materials

1) A cold storage plant in working condition.
2) An ice-bank unit in working condition.

iii. Procedure

i) Study of cold storage plant:

i) Visit to a working cold storage plant after taking legal permission of authority.
ii) Inquire and note down the capacity of plant and refrigerant being used. Also note the horsepower of compressor motors.
iii) Identify the various components and sub-components of cold storage and its refrigeration system.
iv) See the pipe connections between components and draw a refrigerant flow diagram of the plant showing different components.
v) Enter the cold room and study the air diffusing system. Also check the type of insulation around the cold room.
vi) Understand the procedure of loading and unloading in cold store.
vii) Note down the reading of different indicating devices, indicating pressure and temperature at various points.

ii) Study of Ice-Bank Unit:-

i) Visit an ice-bank unit of dairy plant after taking legal permission of concerned authority.
ii) Identify the various components and sub-components of ice-bank unit and its refrigeration system.
iii) Inquire and note down the capacity of ice-bank unit. Also the capacity of compressor motors in horsepower or KW.

iv) Identify the pipe connections between components, and draw a refrigerant flow diagram (line-diagram) showing all the major components.

v) See the working of agitator and the circulation of chilled water within the ice-bank tank. Also note the HP of agitator motor.

vi) Note down the specifications of chilled water supplying pumps and their positions near the ice-bank.

iv. Observations

1) Observe and understand the flow of refrigerant through refrigeration system and the change in its conditions while flowing through different components by reading the various indicating devices positioned at various points.
2) Observe the air diffusion/ circulation system within the cold storage.
3) Observe the process of ice-formation in ice-bank unit and importance of circulation of water by agitator motor.
4) Finally observe and understand completely the whole operation of cold storage and ice-bank unit in a dairy plant.

v. Results

The students will be able to know the:

1) Actual size, shape and physical appearance of various components of cold storage and ice-bank unit.
2) Need and importance of various indicating/ control devices fitted in the cold storage and ice-bank unit.
3) Importance of the effectiveness of heat exchange processes occurring in condenser and evaporator.
4) Importance of providing insulation around cold room, ice-bank tank and also pipes carrying low temperature refrigerant.
5) Type and method of insulation provided.
6) How the cold storage is useful in safe storage of dairy products.
7) How an ice-bank unit is useful in a dairy plant and how it can maintain supply of chilled water by melting of ice formed around cooling coil even when refrigeration plant is not working.

8.4 PRECAUTIONS

1) Study of refrigeration plans should be undertaken in the presence of Instructor/ Practical Teacher and under his guidance.
2) Don’t touch and disturb any part in the plant of your own.
3) Listen carefully the instructions of practical teacher and follow them accordingly.
4) Do not dismantle any part without the permission of operator/ plant in charge.

EXPERIMENT 9 STUDY DIFFERENT PARTS AND LEARN THE OPERATION OF PLATE CHILLER AND BULK MILK COOLER

Structure

9.1 INTRODUCTION

Raw milk is cooled to 4°C to avoid spoilage. Provision is made to cool it as soon as milk is collected. If the provision of cooling is not there, the milk is transported quickly to a chilling center or a milk plant. The plate type chillers are available at the chilling center or at the reception dock of milk plant. The Bulk milk cooler is usually available at the collecting center.

The Bulk milk cooler has provision to store milk and cool it. It consists of a jacketed vat. The inside wall is of stainless steel and hygienically designed, while the jacket has provision to circulate chilled water or have refrigerant circulation. The unit has milk measuring provision, agitator, dial thermometer, lids, adjustable legs etc. some unit has integrated refrigeration system while others may have separate ice-bank unit for supply of chilled water.

Plate chillers are usually for high capacity operations. These are very efficient in terms of cooling rate. The construction is such that a thin layer of milk is passed through parallel plates. Due to high velocities and thin layer faster cooling is achieved. The unit occupies very little space, but does not store milk like Bulk milk coolers. A separate chilled water supply arrangement is provided, normally installed at service section of the dairy plant.

9.2 OBJECTIVES

We will be able to:

- know common types of milk chilling systems.
- understand the sketch of plat chiller and bulk milk cooler, alongwith their fittings.
- identify the hygienic feature of these coolers.
- learn the operation, cleaning and maintenance.

9.3 EXPERIMENT

i. Principle

Very high cooling rate is achieved in the plate chiller. It is due to very small thickness of plate and also small layer of cooling medium between the plates. Also the higher velocities of milk flow and chilled water flow offers greater turbulence. Higher turbulence facilitates greater exchange of heat. Another feature of flow is the direction. Flows on both sides of plates are reverse to each other. This counter-current flow further improves the heat transfer efficiency. In some cases more quantity of chilled water is supplied (some times 2-3 times the milk flow) to obtain further improved heat exchange. Thus plate chillers are most efficient chilling systems.

In Bulk milk cooler milk slowly cools to 4^{o}C, but the storage facility makes it a compact unit. Cooling is achieved through indirect cooling across the vat inner wall.

ii. Requirement

i) One plate chilling system.

ii) One Bulk milk cooler.

iii. Procedure

In a plate chiller, milk is supplied through a milk pump. The chilled water is switched on first. The chilled water temperature is 1^{o}C at the inlet while it may exchange heat and get heated to 15^{o}C at the exit. It is recirculated through an ice-bank system. Milk flows in alternate channel. After cooling, the cleaning is done in-line without dismantling.

Learner should understand the flow cycle and operation of valves. Once in a month plates are opened for cleaning. Plate gaskets may also indicate sign of damage after a year or so. The same be replaced.

Milk is received in a batch the bulk milk cooler. It is measured and dumped. The refrigeration system is switch-on as soon as milk is poured in. Bulk milk cooler normally stores milk for over night. It is cleaned/washed before fresh milk is taken again.

iv. Observations

i) Plate chiller should not indicate any leakage, either of chilled water or of Milk.

ii) Temperature of outgoing chilled milk and incoming chilled water should be noted.

iii) Bulk milk cooler should be clean before dumping the milk.

iv) Temperature of stored milk be noted.

v) For ice-bank type unit the chilled water temperature should be noted.

v. Results

i) Chilled milk temperature should be around 4^{o}C.

ii) No leakage around plate chiller.

iii) Chilled water supply temperature should not be above 1^{o}C.

9.4 PRECAUTIONS

i) Ensure cleaning of plate chiller, before fresh milk is supplied.

ii) Chilled water line is switch-on first.

iii) Bulk milk cooler be cleaned at the end of operation.

iv) Inner surface be any smooth covered.

v) While unloading milk into Bulk milk cooler the can should hit or rest on the body of bulk milk cooler.

EXPERIMENT 10 STUDY OF WATER SUPPLY SYSTEM AND WATER SOFTENING PLANT

Structure

10.1 INTRODUCTION

Large quantity of water is needed for many operations in dairy plant such as steam generation, for cooling and heating in heat exchangers and for cleaning and washing. Water supply system includes the source of water supply, wells, piping, pumps, storage and distribution structures. The general source of water supply for a dairy plant is groundwater. Tube wells are constructed by professional bore well drillers to harvest the groundwater. Water is pumped out from the wells by pumps (mostly submersible type pumps). This water flows through the connected piping to different processing and purification units such as sedimentation, filtration, disinfection, water softening. The treated water is then stored in storage tank and distributed to the point of use through distribution system. The distribution system mainly consists of network of piping. Read thoroughly Unit 1 (Tube well, water storage and supply) and Unit 2 (Water quality, water treatment and Purification) before performing this practical. In this practical you will visit a water supply system, draw its flow diagram, note down the capacities of pumps, dismantle and assemble a submersible/ centrifugal pump, determine the free residual chlorine available in water sample and perform regeneration of ion exchange water softening plant. The amount free chlorine available is useful in checking the adequacy of disinfection as well as to determined whether dechlorination is required.

10.2 OBJECTIVES

We will be able to

- know a flow diagram of water supply system and list various components
- dismantle and assemble the submersible/centrifugal pump to see its parts
- determine the residual chlorine in water sample by orthotolidine test
- perform regeneration of ion exchange water softening plant and test for hardness.

10.3 EXPERIMENT

i. Principle

Orthotolidine Test: In this test orthotolidine indicator is added to water sample. Within 5 seconds the free chlorine reacts with indicator and gives an yellow colour. The combined residual chlorine takes time to react and the reaction is complete after 5 minutes. So the colour after 5 minutes indicates the amount of free chlorine and combined chlorine present in water sample. These colours are compared with colours on colour chart or disc provided by supplier to get the concentration of chlorine. This type of test usually detects 0.1 to 1.0 ppm chlorine with an accuracy of 0.1 ppm.

Regeneration of water softener: Initially, the zeolite bed is complexed with sodium ion. During the softening, the calcium and magnesium ions from water are taken up by zeolite and sodium ions are released into water to form sodium salts.

The softening reactions may be written as follows:

$$\begin{array}{lll} Ca^{++} & (HCO_3)^-{}_2 & \\ \quad | & SO_4^{--} + Na_2^+Z^- & \\ Mg^{++} & Cl_2^- & \end{array} \qquad \begin{array}{lll} Ca^{++} & & 2Na{+}HCO_3^- \\ \longrightarrow & | \; Z^- + & Na_2^+SO_4^{--} \\ Mg^{++} & & 2Na{+}Cl^- \end{array}$$

After some use the water softener looses its ability to produce soft water.Then the unit is regenerated. During the regeneration, the calcium and magnesium ions from zeolite are displaced by excess sodium ions in salt solution and the displaced calcium and magnesium form salts with chlorine. The regeneration reaction is as follows:

$$\begin{array}{ll} Ca^{++} & \\ & | \; Z^- + Na_2^+ Cl^- \\ Mg^{++} & \end{array} \longrightarrow \begin{array}{ll} Ca^{++} & \\ & | \; Cl_2^- + \quad Na_2^+ \; Z^- \\ Mg^{++} & \end{array}$$

Where Z = zeolite radical.

ii. Instruments/Chemical/Machinery Requirements

Water supply system, submersible/centrifugal pump, water softener, saturated sodium chloride solution (10-15%), orthotolidine indicator, test tubes, kit for hardness determination.

iii. Procedure

i) Draw the flow diagram of water supply system.

ii) Note down the specifications and capacities of pumps and dosing pump of chlorine.

iii) Dismantle a submersible/centrifugal pump, draw sketches of parts and assemble the pump.

iv) Draw schematic diagram of water softener with valves to control flow direction. Following general description of water softener gives the structural details. It is basically a cylindrical tank with connected piping. A plate with holes is located near the bottom of the tank. Small filters are fitted in to these holes to seal them. These filters are like funnels with top closed. Very narrow slots are provided on the sides through which the soft water enters in to the filters. The collected water will flow out through the pipe at the bottom. The filters are fitted such that the outlets of filters will be connected to under drain pipes below the plate and slotted inlets will be above the plate. A layer of fine gravel is provided to surround the filters. Zeolite is packed above this gravel layer up to two thirds of the tank. Rest one third on top is occupied by water and water distribution system. Hard water enters the tank from top and slowly flows downwards through zeolite bed. By the time the water reaches the bottom, Then the soft water flows through the gravel pack which retains fine particles of zeolite and others. The clear water then enters the filter through the slots on side and flow into under drai pipes below the plate. The water collected in under drains sflows out through the outlet of water softener. The water softener unit is connected with a net work of pipes, valves to change the direction of flow, tank to prepare sodium chloride solution for regeneration, a pump for circulating the sodium chloride solution.

v) **Orthotolidine test**: Take 100 ml water sample in a test tube. Add 1 ml of orthotolidine solution to it. The compare colour formed after 5 seconds and after 5 minutes with colours on chart/disc.

vi) **Regeneration of water softener:** The softener is regenerated by following sequence of steps.

a) Reverse the flow direction and backwash the resin with treated water to remove solids that have accumulated on the resin bed surface. The beads are suspended in the upward flow that will loosen any packed bead clumps.

b) Now introduce a sodium chloride salt solution (10-15%) on top of the resin and allow it to flow downwards. The salt will remove calcium and magnesium ions and replace them with sodium ions. This leaves the resin in the sodium condition. The completion of regeneration is checked by measuring hardness with commercially available kits. The hardness of effluent from the softener should be zero after complete regeneration.

c) In the final step, rinse the resin to remove excess salt and calcium and magnesium chlorides. The softener is ready for reuse.

viii. **Hardness determination by hardness kit:** The hardness kit consists of thre or four reagents. These reagents are added to the sample of water coming out from softening plant during regeneration in a sequence specified by the supplier of the kit. The colour formed is compared with chart provided by supplier to know the hardness.

iv. Observations

i) In orthotolidine test, the free available chlorine concentration is noted from the chart after comparing the colour formed in 5 seconds. Again compare the colour formed after 5 minutes and note down concentration of free and combined chlorine in the water sample.

ii) In hardness test, add the reagents in given sequence and compare the colour formed with colours on chart to determine hardness in ppm of calcium carbonate.

v. Results

The amount of free available chlorine in water sample is ____________.

The residual free available chlorine in disinfected water should be in the range of 0.1 –0.2 ppm.

The hardeness of the sample is ____________________ppm of calcium

Carbonate. It should be zero if the regeneration is complete.

10.4 PRECAUTIONS

i) In orthotolidine test, the water sample should not be stored at all. The chlorine gas easily escapes from the water; hence the sample should be tested immediately.

ii) In backwashing of water softener, the flow rate should not exceed the maximum limit set by the supplier. Excess velocities might carry away the zeolite beads from the water softener.

EXPERIMENT 11 STUDY THE CONSTRUCTIONAL DETAILS OF FIRE TUBE AND WATER TUBE BOILERS

Structure

11.1 INTRODUCTION

Boiler occupies such an important place in dairy plant that much of plant's successful operation depends upon its unfaltering performance. The safety and satisfactory working of a boiler largely depends upon the reliability of several component units, which are mounted on the body of the boiler. Knowledge of different types of boilers helps in understanding operation of a boiler and effective utilization of steam in a milk processing plant. It is also essential for all the dairy workers to become acquainted with general construction of the boiler, for overall safety and precautions.

11.2 OBJECTIVES

After completing this exercise we will be able to

- understand the constructional details of Fire-tube and Water-tube boilers
- know working of a steam boiler

11.3 EXPERIMENT

i. Principle

Boiler is a pressure vessel in which steam is generated. Heat is produced in the boiler by burning of fuel. This heat is transferred to the water contained in the boiler and the water evaporates to form steam. The steam is generated at a desired saturation pressure. The boiler maintains the required pressure in the shell. The construction and appearance of a boiler depends upon the arrangement made for the burning of fuel and the mod e of this heat transfer to water.

ii. Requirements / Apparatus

i) Models of fire tube and water tube boilers.

ii) Boiler installed in a dairy plant

a) Steam Boilers:

The function of steam boilers is to furnish the supply of steam at the required pressure, of quality as nearly dry as possible. They are also called as steam generators. Heat is produced in the boiler by burning of fuel. This heat is transferred to the water contained iri the boiler and the water evaporates to form steam.

b) Types of Steam Boilers:

Boilers are of two types

i) **Fire-tube type:** In the fire-tube boilers, the hot fuel gases from the furnace are made to pass through the tubes and water surrounds these tubes. The number of tubes varies as per the capacity and design of the boiler. A boiler with large number of tubes is known as multi-tubular boiler. This type of boilers cannot be used to work under very high pressures and are usually made for smaller capacity.

ii) **Water-tubes type:** In the water-tube boilers the hot gases travel from the furnace to the chimney through the space outside the tubes in the chamber, while water, which is to be heated, is circulated through the tubes. Since the amount of water contained in the tubes is small the heating in these boilers is efficient and the evaporation is faster. These boilers require more attention and the cleaning of the tubes is difficult.

The efficiency in well-designed boilers of both types is about the same. Water-tube boilers take up less space than fire-tube boilers of the same power.

c) Components of a steam Boiler:

a) **The Fuel Space:** It consists of the furnace chamber and the passage of hot gases as they flow through the boiler. The fuel is burned in the furnace chamber or the firebox. If the fuel is solid fuel such as coal, placing it over a grate burns it. If the fuel is liquid or gas it is burned with the help of a burner. The combustion of fuel is maintained by steady supply of air to the furnace, which is done by a blower or by a high chimney attached to the boiler.

b) **The Water Space and The Steam Space:** The water and steam in the boiler is contained in the metallic water drums and the tubes. The water space is the volume of the drum or shell that is occupied by the water. The level at which water stands in the boiler shell is known as water level. The steam space is the volume of the entire shell not occupied by the water.

c) **The uptake and chimney:** The uptake is the tube that starts from the top of the boiler firebox and passes through the shell and connects the base of the chimney. A fire-hole is provided in front of the boiler slightly above the grate. A manhole is provided in the shell to have an access for cleaning. A mud-hole is provided to drain the mud that settles down in the boiler.

iii. Procedure

Follow the following steps in the sequence they are mentioned to study the construction and working of the different types of steam boilers, provided as the laboratory models and the boiler installation in a dairy plant.

i) Study the cut models of the fire-tube boiler and the water tube boiler.

ii) Observe the components parts of a steam boiler, viz., the flue space, the water space and steam space, the uptake and chimney.

iii) Observe carefully the flow path of hot gases and water/ steam in the fire-tube boiler and the water-tube boiler and note down the difference in the two types of boilers.

iv) Visit the boiler installation in a dairy plant.

v) Study the technical data sheet of the boiler installed in the dairy plant. Observe the working of the boiler.

vi) Note down the starting-up and the blow- down procedures being followed by the boiler operator.

vii) Observe the different piping connections provided with the boiler and the purpose of each valve fitted to the pipelines.

viii) Note down various accessories attached to the boiler installation.

ix) Observe the working of feed water pump and the fuel burner provided with the boiler.

x) Record the location of different boiler mountings fitted on the boiler.

xi) Draw the sketches mentioned in the column 11.4 in your practical record note-book and write their technical details/ specifications.

iv. Results

We will be able to know the:

i) Actual size, shape and physical appearance of different types of boilers used in a dairy plant.

ii) Need and importance of various indicating / control devices fitted to the boiler.

iii) The starting-up and the blow- down procedures being followed by the boiler operator.

11.4 PRECAUTIONS

i) The technical data sheet and the instructions under ‘operation’ should be studied before proceeding.

ii) Do not unscrew or remove any mounting without the approval of the boiler operator.

iii) Do not operate any valve attached to the boiler while the boiler is in operation.

iv) Keep safe distance from equipment and machinery.

v) Do not touch the hot surfaces and the pipelines.

vi) Follow the instructions of the boiler operator while observing the boiler in operation.

11.5 RECORDS

Record the sketches, description and observations on all the above devices in your record book.

EXPERIMENT 12 STUDY OF DAIRY EFFLUENT PLANT

Structure

12.1 INTRODUCTION

All the waste from a dairy plant finds its way into wastewater. Most of this waste is organic matter and it pollutes the environment if disposed without treatment. There are statutory limits on the level of pollutants in treated wastewater for disposal. Wastewater treatment plants are designed to achieve the pollutant levels below these limits. The treatment processes can be categorized as physical, chemical and biological processes. The type of impurities present in wastewater forms the basis for the selection of treatment processes. Since the major components of dairy wastewater are biodegradable organic substances, the biological treatment is more important in treatment of dairy wastewater. To increase the efficiency of biological treatment, the load of organic substances should be decreased as much as possible by using physical and chemical methods in pretreatment. Read thoroughly Unit 3 (Wastewater treatment, reuse and disposal) before performing this practical.

12.2 OBJECTIVES

We will be able to

- draw flow diagram of a wastewater treatment plant
- know the purpose and principle of operation of each unit of a wastewater treatment plant

12.3 EXPERIMENTS

i. Principle

In dairy wastewater treatment system, initially screens, grit chamber and grease trap are used to remove rags, leafs, waste packaging material, coarse grit and free-floating oil and grease. Then the wastewater flows in to an equalization tank with mixing provision where variations in flow rate and organic matter content are reduced. The well-mixed wastewater is then subjected to biological treatment.

The biological processes used could be aerobic, anaerobic or a combination of both.

The break down of organic matter in wastewater by microorganisms in the absence of dissolved oxygen is classed as anaerobic digestion. Some of the organic matter is used in cell growth and major part is converted in to methane and carbon dioxide. Upflow Anaerobic sludge Blanket (UASB) reactor is the most commonly used anaerobic system. Though the actual processes are in fact much more complex, the anaerobic digestion has two stages.

Satge I: In the first stage a group of microorganisms breaks down carbohydrates, fats and proteins into simpler substances such as alcohols and volatile fatty acids. Some of the substances are used as food by the organisms while the other substances are used in next stage.

Stage II: Mostly, the lower volatile fatty acids (acetic, propionic, and butyric acids) produced in stage I will be converted to methane and carbon dioxide by a different group of organisms.

In aerobic process, the microorganism use the organic matter and dissolved oxygen for cell growth. This cell mass is settled in the secondary clarifier. That means the aerobic process converts the organic matter into easily settleable cell mass called sludge. Some of the active sludge from secondary clarifier is recirculated in to aeration tank to maintain activity of biomass. The excess sludge from secondary clarifier and UASB reactor is dried in drying beds.

ii. Instruments/Chemical/Machinery Requirement

Wastewater treatment plant

iii. Procedure

- Visit a wastewater treatment plant.
- Draw the flow diagram or schematic diagram of the plant. Though there may be some variations, the following description traces the flow of wastewater through different units commonly found in a wastewater treatment plant.

Wastewater is led to a screen chamber for retaining leafs, rags and coarse matter. Three inclined screens with different sizes of openings shall be provided for screening. After screening the effluents are led to a grit channel for removal of grit particles present in the effluents. Two grit channels shall be provided which are to be used alternately. After the removal of grit the effluents are led to an oil and grease trap. Free floating oil and grease shall be retained here. The grease trap shall be cleaned periodically by operating the cleaning mechanism provided or manually. Wastewater free of grit, oil and grease is then taken to equalization tank to attenuate variation in waste flow rate and organic matter concentration.

Equalized wastewater is pumped at a constant rate from the equalization tank. Two pumps are generally provided with one as 100% stand by. The wastewater is subjected to bio-chemical treatment in two stages. The first stage of the treatment is an anaerobic system (UASB). After anaerobic treatment further polishing treatment of the wastewater is done in an aerobic process (activated sludge process). Oxygen to the wastewater in the aeration tank shall be supplemented by means of fixed type low speed surface aerator. Following biochemical oxidation the wastewater is led to secondary clarifier for solid – liquid separation. A peripheral drive clarifier mechanism is provided in the secondary clarifier tank to enable scrapping and collection of sludge. Active sludge from the secondary clarifier is recirculated to the aeration tank by means of the sludge recirculation pump to maintain the desired concentration.

Excess sludge from the secondary clarifier and the sludge to be wasted from the anaerobic system shall be applied on sludge drying beds for dewatering and drying. Dried sludge cakes can be either used as fertiliser or disposed off as land fill in low lying areas without posing any problem. Overflow from the secondary clarifier shall be within the stipulated limits for discharge of trade effluents into inland water bodies. The treated wastewater shall be discharged via. A terminal manhole provided with a "v" notch to enable flow gauging and sampling. The treated wastewater can also be profitably used for purposes like gardening and irrigation.

iv. Observations

a) **Screen chamber:**

Duty	: To arrest large size floating matter.
No. of units	: One
Size	: 0.35 m. wide x 1.5 m long x (0.5m + freeboard)
Material of construction	: Reinforced cement concrete (RCC)
Screens	: Three inclined type screens with spacing between bars as 50 mm, 25 mm, 10 mm
Material of construction	: Mild steel flats of 10 mm thick

b) **Grit channel:**

Duty	: To remove grit particles present in the combined effluents.
No. of units	: Two
Size	: 18.0m. long x 0.60m wide x (0.5m +freeboard)
Effective volume	: 3.35m^3 (each)
Material of construction	: RCC

c) **Oil and Grease traps**:

Duty	: To enable separation of free floating oil and grease.
No of unit	: One
Size	: 1.75m. wide x 16m long x (2m depth + free board)
Effective volume	: 56 m^3
Material of construction	: RCC

d) **Equalization Tank:**

Duty	: To attenuate variation in waste flow rate and characteristics
No of units	: one

Size	:	9.25m. dia. x (3m depth+ 0.5m free board)
Effective volume	:	200 m^3
Material of constrution	:	RCC
Air blower for mixing	:	One, 3 HP, 60 cfm at 5 psig
Pumps for wastewater	:	2 Centrifugal pumps (one stand by) 165 m^3/hr at a head of 9 m water column

e) **UASB Reactor:**

Duty	:	To anaerobically bio- degrades the waste.
No. of unit	:	One
Size	:	15.2m. dia. x (5.5m SWD + 0.5m FB)
Effective volume	:	990 m^3
Material of construction	:	RCC

f) **Aeration Tank :**

Duty	:	To provide oxygen to the wastewater.
No. of unit	:	One
Size	:	14m. dia x (3.5 m depth + 0.5m free board)
Effective volume	:	538 m^3
Material of construction	:	RCC
Surface aerator	:	20 HP motor + 20:1 reduction worm gear

g) **Secondary Clarifier Tank:**

Duty	:	To enable solid-liquid separation.
No. of unit	:	one
Size	:	14.25m. dia. x 3m. average depth.
Material of construction	:	RCC
Clarifier	:	Clarifier mechanism connected to drive unit with motor and worm gear for speed reduction.
Return sludge pump	:	2 Centrifugal pumps (one stand by) 60 m^3/hr at a head of 4 m water column

h) **Sludge drying bed :**

Duty	:	To dry the sludge from treatment plant.
No. of unit	:	Three
Total Effective volume	:	216 m^3
Material of construction	:	Brick work and plain cement concrete
Sludge filtrate pump	:	2 Centrifugal pumps (one stand by) 60 m^3/hr at a head of 6 m water column

v. Results

Visually observe the turbidity of wastewater from equalization tank and final effluent at the discharge point. The final effluent is clear water.

12.4 PRECAUTIONS

1. Maintain proper level of Mixed Liquor Suspended Solids (MLSS) in aeration tank. Typical values of MLSS are in the range of 1000-6000 mg/L.
2. Maintain slightly alkaline conditions in UASB reactor to promote growth methane forming bacteria.

EXPERIMENT 13 STUDY THE DIFFERENT PARTS OF SINGLE PHASE AND THREE-PHASE INDUCTION MOTORS

Structure

13.1 INTRODUCTION

All the induction motors, whether single phase or three phase, consist of essentially two parts, the stator or the stationary part and the rotor or rotating part. As discussed in unit 03 under the block no. 04, the stator is connected electrically to the supply whereas the electrical energy will be transferred to the rotor through magnetic induction. Both the rotor and stator are built of laminated sheets pressed together and riveted. The laminations are normally 0.03 to 0.06 cm thick and insulated by varnish or enamel coating. Fan blades are used for cooling purpose, on the ends of the rotor for force circulating of air through the motor to keep the temperature with in permissible limit. Different parts of single phase and three phase induction motors will be described along with constructional detail in procedure given below.

13.2 OBJECTIVES

We will be able to learn the

- dismantling of induction motors.
- constructional features of single phase and three-phase induction motors.
- the basic difference in single phase and three-phase winding.
- different types of rotors.
- assembling of induction motors.

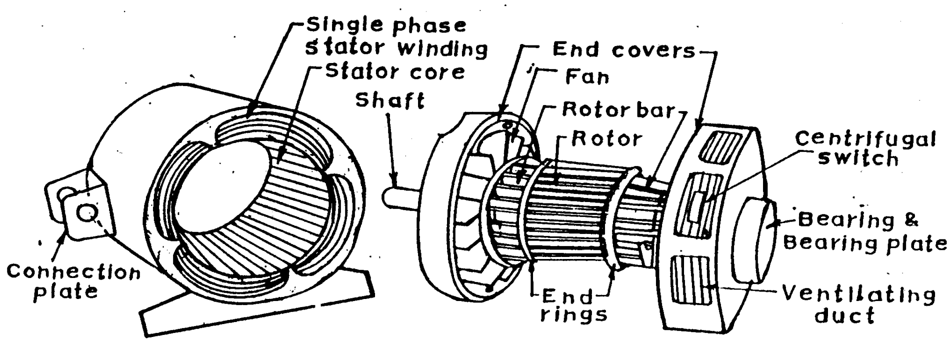
13.3 EXPERIMENT

i. Principle

The working principle of single-phase and three-phase induction motor is given in brief. For detailed study, you may refer to unit no. 03 under the block no. 04.

However, the principle of working of both the motors are given below.

A. **Single-Phase Squirrel Cage Induction Motor:** Single-phase squirrel cage induction motors works on the same principle on which the poly-phase (Two or three phase) induction motor works, i.e. "whenever a short circuited conductor or coil is placed in a rotating magnetic field, the conductor tends to move." The magnetic field produced by the stator current is fixed in space instead of rotating, but its magnitude is changing sinusoidally. Such a field is equivalent to two field equal and opposite in magnitude, rotating in opposite direction at equal speed, each being half of the maximum value of alternating field. So the single-phase motors are not self-start in first instance and are made self-start by splitting the magnetic field produced into two fields having an angle of phase difference between them. Different methods are adopted to make the single-phase motors self-start.



DIFFERENT PARTS OF A SINGLE PHASE SQUIRREL CAGE INDUCTION MOTOR

B. **Three-Phase Squirrel Cage Induction Motor: -** When stator winding of a three-phase induction motor is connected across the three phase electric supply, a rotating magnetic field will be produced. This rotating magnetic field, when links with the short-circuited rotor bars, an electro-motive-force (E.M.F.) will be induced in the rotor bars. This induced electro-motive-force will circulate a heavy eddy current in the rotor bars and produced its own magnetic field. By Lenz's law this induced current will oppose the cause producing it i.e. relative motion of the stator field. The combined interaction of both the magnetic fields (Stator and Rotor) will produce a net resultant moving force (Torque) in the rotor. As the current in the rotor bars is set up entirely by effect of electromagnetic induction from the stator, hence the name "Induction Motor". The main parts and their use are detailed below, along with figure: -

ii. Material Required

The following material is required for the study of different parts of three phase and single-phase induction motors.

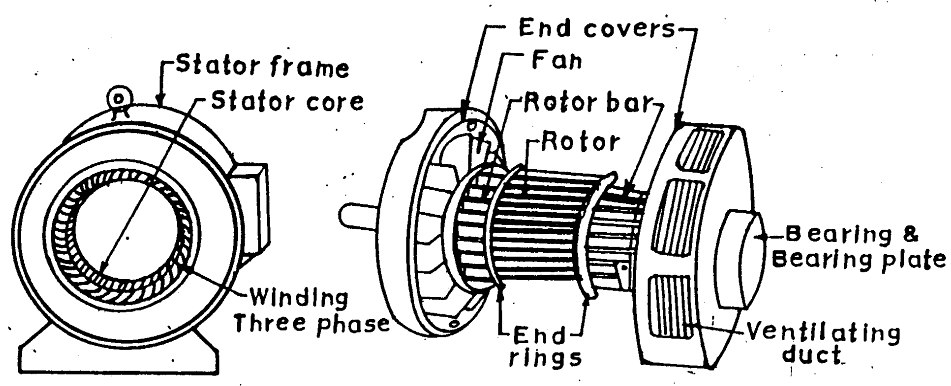
a) Single-phase squirrel cage induction Motor.
b) Three phase squirrel cage induction motor.
c) Insulated Screw-driver heavy duty 20 Cm.
d) Insulated combination Plier 20 Cm.
e) Double Ended and ring spanner sets.
f) Wooden Hammer (Mallet).
g) Ball peen Hammer ½ Kg.
h) Cold Chisel 10 Cm.

iii. Procedure

The different parts of a single-phase and three-phase squirrel cage induction motor and method of assembling and dismantling the same, is given below.

A. **Single-Phase Squirrel Cage Induction Motor: -** The constructional detail along with description about the different parts is given below.

B. **Three-Phase Squirrel Cage Induction Motor: -**



DIFFERENT PARTS OF A THREE PHASE SQUIRREL CAGE INDUCTION MOTOR

C. **Description of Different Parts of Motors:** The following are the main parts of single phase and three-phase induction motors, described in brief. For detailed study, you may refer to unit no. 03 of block no.04.

i) **Stator Frame (Body): -** The stator frame or body is made up of close-grained alloy cast iron. All the different parts of the induction motor detailed below will be accommodated in the frame of the motor depending upon the type of motor. Centrifugal switch and capacitors are the parts pertaining to the single-phase induction motors only. Rest of the parts are common to both the motors.

ii) **Stator: -** As the name indicates, it is the stationary part of the induction motor and made of silicon steel strips of thickness, varying from 0.3 to 1.35 mm. These strips are combined together, which are called laminated strips and the combination is known as laminated core. These laminated stampings/strips are slotted to receive the winding. These slots may be of open or semi-closed types, to facilitate the winding. The same stator can be used for single-phase induction motors also. If the stator carries three-phase winding and is fed from three-phase electric supply, it is known as three phase stator where as the stator carries single winding is known as single phase stator.

iii) **Rotor: -** The rotor is the rotating part of the motor and made of silicon steel strips. The thickness of these strips varies from 0.3 to 1.35 mm, as in case of stator. These strips are clamped together to form rotor core, called as laminated core. This laminated core is slotted to totally closed type, to receive rotor winding. In large capacity motors thick aluminum bars are inserted and are short-circuited with end rings. Now a day, melted aluminum is filled in these slots, which works as short-circuited winding. This winding is known as squirrel cage winding.

iv) **End Covers: -** As the name indicates these covers are used to cover the ends of the motor and are made of cast iron. These end covers are fitted with the stator frame with the help of nuts and bolts. The ball bearings are fitted in the end covers to keep the rotor exactly in the centre of the stator, so that it can move freely.

v) **Shaft and Bearings: -** Mostly ball bearings are used in large capacity motors where as the bush bearings is used in small capacity motors because the noise level is high in ball bearing as compare to bush bearings. The main purpose of bearings is to keep the rotor exactly in centre and ensure free movement for the rotor. The shaft is a long circular bar, made of mild steel. The rotor assembly and cooling fan is securely keyed to the shaft of the motor.

vi) **Cooling Fan:-** In general, the fan is used to cool down the temperature. When the motor runs on load, the heat is produced in the motor winding as well as in the core due to copper and iron losses respectively. So, the fan serves the purpose of transferring the heat from inside to outside of the motor by forced air circulation. It sucks the air from the atmosphere through the air ducts and discharge back to atmosphere after cooling the winding and core of the motor. In large capacity

vii) **Winding: -** The winding of induction motor is the main part of the motor. In below standard and low capacity motors, it may have aluminum winding but normally it is made up of copper. The type of winding depends upon the speed, type of supply (Single phase or three phase) and type of starting device used especially in case of single phase winding.

viii) **Centrifugal Switch: -** As the name indicates, it is a switch, which switch-on and switch-off on the principle of centrifugal forces. When the motor is at stand-still position, the switch contacts remains closed, keeping the starting winding in the circuit and it cut-off the starting winding out of circuit when the motor attains more than the 80 % of the rated speed. When the motor is switched off, the starting winding is again inserted into the circuit by switching on the centrifugal switch.

ix) **Capacitor:-** Capacitor works as a starting device in single-phase induction motors by producing an angle of phase displacement between the starting and running winding of the motor.

D. **Dismantling and Assembling of Motors: -**

While assembling and dismantling of single-phase and three-phase squirrel cage induction motors, following sequence of operation may be observed.

i) Make of one mark of identifications on one side and two on the other sides of end covers and fan cover etc. on both the sides of the motor, with the help of cold chisel and ball peen hammer.

ii) Remove the fan cover fitted on the outer frame by unscrewing its screws.

iii) Remove the fan mounted on the same shaft by unscrewing the screws and key should be removed carefully, followed by slight outward hammering from all sides. While doing so, rotate the fan by hand so that the fan may slides out of the shaft.

iv) Remove the bearing plate cover by unscrewing the screws, on both sides of the motor. This will disengage the inner bearing plate from the end covers and helps the end cover to slides out from the motor shaft.

v) Now un-tighten the end cover bolts with the help of spanner from both sides of the motor.

vi) Hammer the one of the end cover gently with the help of cold chisel and ball peen hammer and try to push it out. Rotate the end cover with hand for equal out side push. Hence the end cover will gets removed from the stator frame as well as from the motor shaft.

vii) Now remove the other end cover along with rotor, by slightly hammering the end cover. While removing, care should be taken that so the squirrel cage rotor or its shaft etc. did not damages the winding of the stator.

viii) The bearings can be taken out by bearing Puller.

ix) In case of single-phase induction motors, the starting winding may have been connected with the centrifugal switch fitted on the motor shaft. So, first disconnect the starting winding connection from the switch and the remove the end covers of the motor.

x) For assembling the motors, adopt the reverse sequence of operation as explained above.

iv. Observations

The following observations must the observed carefully and draw respective sketches.

a) Draw the sketches of different parts of the motor such as fan cover, end cover, fan, bearings and bearing plate, rotor and rotor shaft, stator and stator winding etc.

b) Observe the following constructional features of the motor.

   i) Stator and stator winding.

   ii) Rotor and rotor bars short-circuited with the end rings.

   iii) Stator core and rotor laminated insulated core riveted and pressed together to make single unit.

   iv) Type of stator frame (Enclosure).

   v) In case of the single-phase induction motor, the construction of centrifugal switch.

   vi) Identification of starting and running winding.

   vii) Starting mechanism used such as capacitor etc. and its capacity.

   viii) Terminal box and plate must be observed carefully and note down its various features such as number of phases (Single or three phase), B.H.P capacity, speed of motor and connections of winding etc.

v. Results

The students will be able to know the

i) The procedure for assembling and dismantling of single phase and three-phase induction motor.

ii) Different precaution to be observed before, during and after dismantling and assembling the induction motors.

iii) Different winding such as three phase winding, starting winding and running winding etc.

13.4 PRECAUTIONS

The following precautions must be observed while assembling and dismantling the three phase induction motors.

i) Do not forget to make marks of identification on the end cover, fan cover and stator frame etc. especially in case of single-phase motors having centrifugal switch. Otherwise proper and accurate fitting will not be possible.

ii) While removing the end covers, hammer it gently. As the end covers and stator frame are made of cast iron, which is brittle in, nature will develop cracks and may finally leads to break.

iii) The rotor should be removed carefully from the stator; otherwise it may damage the stator winding.

iv) Avoid application of any metal tool with stator winding.

v) The bearings should be removed with the help of bearing Puller only. Pulling out of the bearing by hammering should be avoided.

vi) While mounting the fan on the shaft, the key should be fitted in proper place and tight the bolt tightly.

vii) During the assembling of the motor mark of identification should be carefully observed.

EXPERIMENT 14 STARTING OF 3 PHASE SQUIRREL CAGE INDUCTION MOTORS BY DIRECT ON LINE AND STAR-DELTA STARTER

Structure

14.1 INTRODUCTION

As the name indicates **"Starter"** is used to start and stop the motor. The starter is also used to protect the motor and other connected equipment from sustained overload, under voltage, single phasing etc., and also provide automatic control when ever require. We know that the motor acts as a transformer with secondary winding (Rotor winding) short-circuited, when the motor is at stand-still position. When the motor is started from stand-still position, high starting current will circulate in the rotor winding and simultaneously the stator will start drawing heavy current from the supply mains. As a result of this heavy current, the system or line voltage will be drastically reduced, which is objectionable from safety point of view. The other sensitive equipments connected with same line may trip on low voltage. Therefore, large capacity motors (Above 5 H.P.) should be connected through such a mechanism, which can reduce the starting voltage. If the starting voltage is reduced, the starting current drawn by the motor will be reduced automatically and thus the line voltage will remains almost constant.

14.2 OBJECTIVES

We will be able to learn the

- the different parts of Direct on line and Star-Delta starter.
- wiring of Direct on line and Star-Delta starter.
- working of Direct on line and Star-Delta starter.

14.3 EXPERIMENT

i. Principle

The working principle of Direct On Line (DOL) and Star-Delta starter is explained below in brief. For detailed study of these starters, please refer to theory of block no.4.

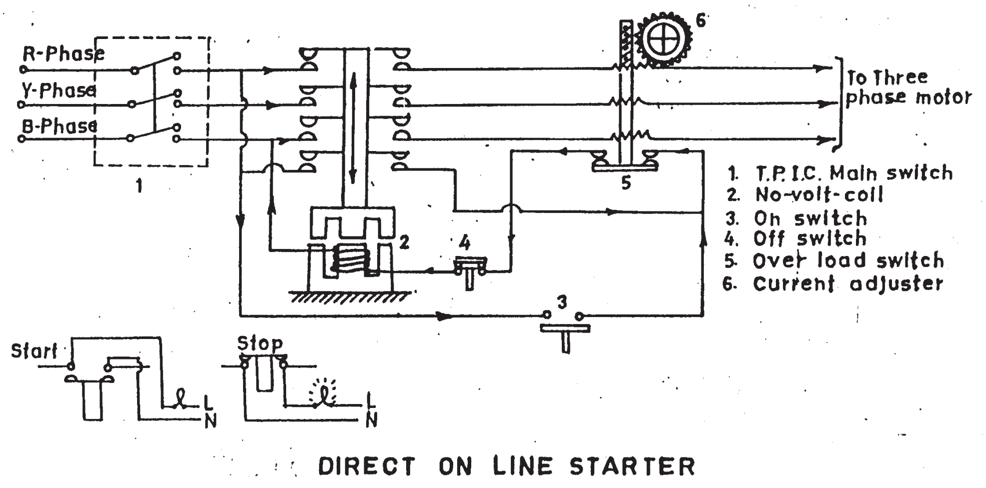
A) **Direct On Line (D.O.L) Starter:** The Direct On Line starter is used to connect the motor winding terminals in delta connection directly instead of connecting in star first and then is delta position, as in case of Star-Delta starter. When the on switch (Green Button) is pressed, the No-Volt-Coil (N.V.C.) will become an electromagnet and pulls down the plunger down ward position. As a result of it, the motor winding will connect across the three-phase supply and motor start running.

B) **Star-Delta Starter:** The Star-Delta starter also works, almost on the same working principle with difference of connection of motor winding terminals. In this type of starter, the winding terminals are connected in star when the handle is pressed to down ward position and motor starts running. When the motor picks up more than 80 % of the rated speed, the handle is pushed to up ward direction. As a result of it the winding terminals gets connected in delta position and motor will stats running at its full rated speed. Secondly, the **No-Volt-Coil (N.V.C.)** will gets connected across the two-phase supply and keep on holding the handle in this position after acting as a electromagnet.

ii. Material Required

The following material is required for starting the three phase induction motor with Direct On Line (DOL) and Star – Delta starter.

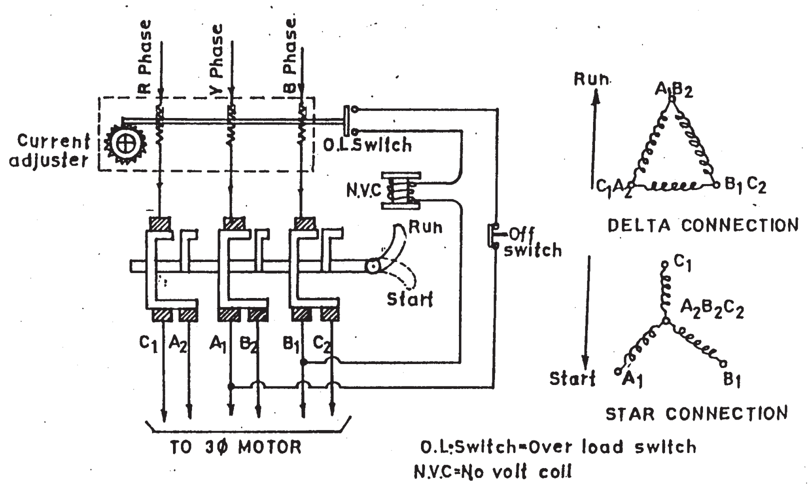
i) Three-phase squirrel cage induction motor 7.5 H.P.
ii) Direct on line starter.
iii) Star-Delta starter.
iv) Triple Pole Iron Clad (TPIC) Main Switch 63 Amp.
v) Voltmeter 0 – 500 Volts.
vi) Am-meter 0 – 100 Amp.
vii) Insulated combination plier 15 Cm.
viii) Insulated screw Driver 30 Cm.
ix) Series test lamp 100/200 Watt.
x) P.V.C. wire 7/22.
xi) Hand Gloves.
xii) Wire stripper



Direct on Line (D.O.1) Starter

iii. Procedure

The following procedure should be adopted to connect a three-phase squirrel cage induction motor with Direct On Line and Star Delta Starter. To study in detail, please refer to unit no. 03 of block no. 04. The circuit diagram starters and sequence of operation given below:



STAR DELTA STARTER

i. First of all find the phase sequence of winding i.e. C_1 A_2, A_1 B_2, and B_1 C_2 terminals of the three-phase induction motor, with the help of series test lamp.

ii. Open the starters connect the "M" terminals with motor and connect the "L" terminals with three-phase supply. Direct on line starter and Star Delta starter with motor as shown in figures above.

iii. Connect an Ammeter in series of one of the phase and voltmeter across any two phases, to monitor the current drawn by the motor and applied voltage.

iv. Switch on the green button in case of D.O.L. starter to run the motor directly in star or delta position as recommended on motor connection plate.

v. And when the handle is pressed to start position (Star), the motor's out put terminals A_2, B_2 and C_2 gets short circuited with a thick copper strip on the handle while the other terminals A_1, B_1 and C_1 gets connected across the supply and the motor will continue to run in star position.

vi. When the motor picks up more than 75 % of the rated speed, the handle is switched over to run position (Delta). Now the motor terminals C_1 A_2, A_1 B_2, and B_1 C_2 will get short circuit and the motor will continue to run delta position, because the handle will remain hold in this position with the help of no volt coil.

iv. Observations

The following points must be observed carefully during the working of the motors.

i) Observe the starting and running current drawn by the motor.

ii) Observe the input voltage to the motor with the help of voltmeter and it should be around 440 volts.

iii) The motor should not make any abnormal sound or hum during the operation.

v. Results

The student will be able to

i) Check the motor's phase sequence test.

ii) Connection of motor with starters.

iii) Observe the normal and abnormal sound of the motor.

14.4 PRECAUTIONS

The following precautions must be observed while connecting and running the three-phase induction motor with the help of D.O.L. and Star Delta starter.

i) All the connections should be tight.

ii) The fuse wire of main switch or rating of MCB should be of proper size.

iii) Before connecting the motor on supply, check the leakage current or earth fault with the help of series test lamp.

iv) Phase sequence test should be conducted carefully.

v) Connect the T.P.I.C. main switch, Starters and motor with proper earth wire to avoid leakage current accidents.

vi) Connection plate should be carefully examined to connect the motor in Star or Delta position.

EXPERIMENT 15 STUDY OF DIFFERENT SAFETY MEASURES TO BE ADOPTED IN A DAIRY PLANT

Structure

15.1 INTRODUCTION

The industrial safety is basically a broad term covering a wide range of general purpose and special purpose of safety measures to be adopted in the operation, repair and maintenance of various dairy equipments. As we know, with the advancement in the operation of sophisticated dairy equipment, there is a drastic enhancement in the quality and quantity of dairy products. On the other hand, the threat to the human life also increased due to the ill implementation of safety norms. The first aid measures should be well known to all the workers of the dairy and a first aid kit should be placed at easy approachable place with **+ (Positive)** sign on the box.

If safety norms are strictly adopted the chances of accidents occurrence are reduced and hence the threat to the man, machine, material could be avoided. This result in increase in production and hence overall cost of the product will be reduced. Secondly, there is saving in man-hours, loss of human life and property of the industry. So, each and every person responsible for the operation, repair and maintenance of dairy equipment directly or indirectly, should be well versed with different safety measures to be adopted. The endeavor should be, to make them safety conscious so that it becomes a part and parcel of their regular working. The following are the safety measures, which should be adopted strictly.

1. Safety measures against material handling accidents.
2. Safety measures against electric shock accidents.
3. Safety measures against fire accidents.

15.2 OBJECTIVES

We will be able to

- know the importance of various safety measures to be adopted in a dairy industry.

- protect the worker against accidents and ensure safe and better working atmosphere for them.
- know the operation and routine maintenance of fire fighting equipment.

15.3 EXPERIMENT

i. Principle

The principle of different safety measures to be adopted in any industry should be human friendly. Priority should be given to save human life as compared to other losses; because the property loss can be compensated where as human loss can never be compensated. So all the safety measures should be implemented carefully.

ii. Procedure

A) Safety measures in material handling accidents:

With the advancement in technologies, the conveyors or lifts etc. are to be used for transporting the material from one place to another. But some time we have to handle the material manually if there is any problem in the transportation system. In both the circumstances, the chances of accidents are there, if proper safety measures are not adopted in true spirit. So the following points should be kept in mind while handling the material.

i) The path should not be slippery.

ii) The worker should wear a proper and tight dress while on duty.

iii) Proper protective clothing like, gumboot, leather hand gloves, helmets and goggles etc. should be wore by the workers.

iv) While handling the material, the hand and gloves should be free from the oil and grease etc.

v) Worker should be properly trained and have habit to work safely.

vi) Riding on conveyor should be strictly prohibited and standing instructions to this effect may be displayed at proper place.

vii) The worker should be trained to handle the material manually as well as by conveyor or other suitable means.

viii) Before handling the material it should be properly inspected for pinches and shear point if otherwise it may injures to the worker handling it.

ix) The worker should be aware about the moving parts of machines while handling the material. The moving parts should be properly covered with a cage guard.

x) The material, which have slipper, surface such as oily or greasy ones, should be wiped off before handling.

B) Safety measures against electric shock accidents:

Accidents through electric shock are more than the accidents of any other kind. Because when the mechanical injury occurs to worker, we can see and can prevent if we are little bit cautious where as the electric shock accidents occurs at once. Secondly, the intensity of electric shock is of great concerned because the muscular system of the respiratory system gets paralyses by contracting the respiratory system, which may lead to the death of the electric shock victim. The intensity of electric shock depends upon the effective voltage, body resistance of the victim and supply frequency. Higher the effective voltage and frequency, greater the intensity of electric shock i.e. more chances of fatal accidents. The following are the point, which should be kept in mind and to be adopted by the worker for safe working.

i) Only authorized and trained persons who are well versed with the electrical circuit diagram should be allowed to work with electrical system.

ii) All the persons should wear proper and tight dress along with other protective items such as leather hand gloves, helmet, gumboot and safety belt etc. while discharging their duties.

iii) All the electrician tools such as combination pliers, screwdrivers, meggar, earth tester, clip-on meter and millimeter etc. should be insulated properly.

iv) Unauthorized person should never be allowed to temper with control panel, cable, wires and equipments etc.

v) All the broken accessories should be replaced promptly such as switches, sockets, fuses holders and fan regulators etc. otherwise it may the cause of electric shock.

vi) An authorized person should replace fuses and miniature circuit breakers with proper rating.

vii) Screwdriver and combination pliers should never be used as hammer and these should have proper insulation.

viii) Inflammable material should never be kept near the control panels and metering system where the chances of fire are more.

ix) Danger plate or signboard with proper indications and instruction should be displayed on the machine or on the wall near the machine and metering section.

x) Always work with proper permission. Switch off the supply and a notice to this effect should be hanged on the I.C.T.P main switch or circuit breaker that ***"Do not operate, men at work".***

xi) All the persons associated with electric work should put on proper and tight dress and shoes have rubber soles.

xii) All the portable appliances, electric tools etc. should be checked proper for earth resistance at regular intervals.

xiii) Periodic inspection charts should be prepared and displayed in regional and English language to detect the damaged wires, main switch blades, earth wires and leakage currents etc.

xiv) As for as possible the wiring should be underground.

xv) The test lamp should consists of two lamps connected in series of same watt and operating voltage.

xvi) While carrying out electrical repair of electric heater, kettle, fan, geyser etc. these should be earthed properly.

C) Safety measures against fire accidents:

The following safety measures should be adopted for providing safe and tension free working atmospheres to the worker, by preventing the chances of fire accidents.

i. All the doors and windows should be open outward, so that in case of fire, the people may exit with few seconds to avoid human loss along with loss of property.

ii. Fire fighting equipments should be kept at a safe and convenient place, easily accessible to all.

iii. Effective alarming system should be installed and checked for its effective working at regular intervals.

iv. Bucket filled with sand and water should be placed in the corridor or any other convenient place near the possible accidents place if space requirement permits.

v. Never use water to extinguish the electric fire. Sand can be thrown on the electric fire. Carbon dioxide may be used for fighting such electric fire.

vi. Every person employed in the industry should be trained to fight with fire accidents and they should be aware of the location of fire fighting equipment.

vii. All the inflammable and explosive material should be stored in a cool and dry place at a distant place. The inflammable liquid such as petrol, diesel and kerosene oil may be kept in a closed container.

viii. Any kind of material should not be allowed to store on the way to exit.

ix. Smoking, open fire and sparks etc. should be strictly prohibited near the inflammable material and a signboard to this effect should be displayed.

iii. Observations

The following are observations, which should be taken carefully.

i. Observe the location of all fire fighting equipments in the industry.

ii. Whether the fire alarming systems are in proper working condition or not.

iii. Sand and water buckets are filled with sand and water respectively.

iv. All the electrician tools are properly insulated. The insulation may damage due to improper handling or worn out due to aging. It should be replaced immediately.

v. Observe the location of first aid kit and ensure that the medicines should be sufficient and there should be updated at regular interval.

vi. The worker should observe the location of various tools and the various methods of upkeep.

iv. Results and discussions

The workers and other people of the industry will understand the importance of different safety measures. How we can save the man material and other property loss of the industry? Apart from the above, importance of first aid kit and first aid in case of accidents. The workers also understand the various safety measures and how it may be implemented.

15.4 PRECAUTIONS

In addition the following precautions should be taken carefully while working in the dairy industry.

i) The intensity of light should be within comfortable zone according to the requirement of job. It should not be too low that the operator may feel stress on eye and it should not be too high that the operator may face glare.

ii) The work place should have natural air circulation and if possible the provision of natural light should be ensured.

iii) If any accident occurs, the first aid should be given to the victim without any delay according to condition of the patient and in the mean time either we should call the doctor or rush the patient to the near by hospital.

iv) In case of fire accidents, before starting extinguishing the fire, ensure what type of fire it is. If any electric wire, cable, control panel and motor etc is in contact with the fire, the water should not be used to extinguish the fire. Sand or carbon dioxide cylinders should be used.

v) In case of fire, the fire-fighting department should be informed and asked for help.

vi) Avoid further spreading of fire by isolating the nearby inflammable material or by any other means.

vii) The eyes should be protected from the flying particles such as carbon particles in the smoke.

viii) No person should be asked to lift or carry any material excess to his capacity, which may lead to serious injury.

ix) Untrained persons should not be allowed to work on hazardous jobs.

x) The working tools should be handled carefully. Loose handling of tool may lead to serious accidents.

EXPERIMENT 16 TO STUDY THE CONTROL AND SAFETY MOUNTINGS OF A STEAM BOILER

Structure

16.1 INTRODUCTION

The boilers are fitted with various mountings for safety and for complete control of process of steam generation. These components or elements function with the boiler as a whole and contribute their individual share in the task of steam generation. The safety and satisfactory working of boiler largely depends upon the reliability of these mountings.

According to Indian Boiler Regulations the mounting fitted to the boiler must include two safety valves, a fusible plug, a feed check valve, a blow off cock, an attachment for inspectors test gauge a manhole or mud hole. These mountings are fitted on the body of the boiler itself. It is essential for all dairy workers to get acquainted with general features of these mountings for overall safety and precautions.

16.2 OBJECTIVES

After completing this practically the we will be able to :

- identify various boiler mountings essential for safety and control of boiler operation.
- understand the purpose of their installation and their location on the boiler
- know the principle of working and general constructional features of different boiler mountings.

16.3 EXPERIMENT

i. Principle

i) **Safety valves:** The function of safety valve is to prevent the building up of excessive pressure in a steam boiler. The safety valve is set at or below the maximum safe pressure for the boiler. It is generally placed on the top of the boiler. It blows off the steam when the pressure of steam in the boiler exceeds the working pressure.

There are four types of safety valves:

a) Dead weight safety valve

b) Lever safety valve

c) Spring loaded safety valve

d) High steam and low water safety valve.

The above-mentioned classification of the first three safety valves is based on the method of loading the valve, while in the fourth type; it is based on its mode of operation. The safety valve is connected directly to an independent nozzle on the boiler without any intervening valves of any description. According to IBR Act two safety valves are required to be fitted on the boiler.

ii) **Water Level Indicator:** The object of this mounting is to indicate the level of water in the boiler and to enable the attendant to regulate the supply of feed water. It is mostly placed in front of the boiler from where it easily visible to the attendant. According to IBR Act two water level indicators are required to be fitted on the boiler.

iii) **Pressure Gauge:** Pressure gauges for steam boilers are usually of the bourdon type. The best working pressure for a gauge is half that of the maximum graduation. The pressure gauge is fitted in front off the boiler in such a position that the operator can conveniently read it. It is connected to the steam space by a siphon pipe.

iv) **Fusible Plug:** This device is intended to operate when the water level in the boiler falls too low. It permits the discharge of steam into the furnace and quenches the fire. A fusible core is designed to melt and allow the escaping steam to sound a warning of low water. Thus the fusible plug is mounted at the required lowest safe water level in the boiler.

v) **Steam Stop Valve:** This valve is bolted to mounting block on the top of the boiler and through it passes the principal supply of steam from the boiler to the steam pipeline.

vi) **Feed Check Valve:** It is fitted to the boiler slightly below the working level of water in the boiler. It consists of two valves combined in one valve. One is the feed valve and the other is check valve. The feed valve is operated by hand and its function is to allow or stop the supply of water to the boiler. The check valve is automatic in operation and its function is to prevent the water escaping from the boiler in case of failure of the feed pump.

vii) **Blow of cock:** It is located at the lowest water space of a boiler to serve three purposes;

a) To remove the precipitated sludge or loose scale.

b) To permit the rapid lowering of the boiler water level if it has become too high accidentally.

c) As a means of removing water from the boiler system so that fresh water may be added to keep concentration of solids in the boiler water very low or when required periodical inspection of the interior may be carried out.

viii) **Manhole:** It is provided on the boiler shell at convenient position so that a man can enter through it inside the boiler for cleaning and inspection purposes. A manhole cover fitted from inside the manhole closes the opening.

ii. Requirements / Apparatus :

i) Safety valves

ii) Water level Indicator
iii) Pressure Gauge
iv) Fusible plug
v) Feed check valve
vi) Steam Stop Valve
vii) Blow off cock

iii. Procedure

Make sketches of the followings:

i) Line Diagrams of the above mentioned boiler mountings.
ii) Diagram of a boiler indicating the location of these mountings.

(You might take the help of figures provided in the theory material of the related topics or the suggested textbooks)

Procedure to Study

i) Study the cut models of different boiler mountings and observe their components parts.
ii) Observe the principle of operation and the functioning of these mountings.
iii) Study the fittings and mountings in original and compare them with their cut models.
iv) Visit a boiler plant and observe and record the location of these fittings on the boiler.
v) Draw the sketches of these mountings on your record book.

iv. Results

Record the sketches, description and observations on all the above devices in your record book.

i) Actual size, shape and physical appearance of different types of boilers mountings used in a dairy plant.
ii) Observations on various indicating/control devices fitted to the boiler.

16.4 PRECAUTIONS

i) The technical data sheet and the instructions under 'operation' should be studied before proceeding.
ii) Do not unscrew or remove any mounting without the approval of the boiler operator.
iii) Do not operate any valve attached to the boiler while the boiler is in operation.
iv) Keep safe distance from equipment and machinery.
v) Do not touch the hot surfaces and the pipelines.
vi) Follow the instructions of the boiler operator while observing the boiler in operation.

UNIT 1 MATERIALS THEIR CHARACTERISTICS AND SELECTION OF EQUIPMENT

Structure

1.0 OBJECTIVES

After reading this unit, we should be able to:

- identify various materials used in fabrication of dairy equipment and machineries
- specify the important properties of material and their selection for milk and milk products
- protect plant and machineries and give them long working life
- select proper material required for dairy plant
- describe the major specification of equipment before purchase
- determine and select appropriate service equipment.

1.1 INTRODUCTION

Equipment and machineries used for milk handling processing plant require special characteristics. They are required to handle and process an edible food material and hence should not react with it. They are required to work under hot and humid environment, hence, should be non-corrosive. They are also required to handle chemicals during washing, hence, should have enough protection against any damage.

Milk utensils in our villages are commonly made of earthenware or they are zinc plated or galvanized iron or made of brass, or copper. Modern dairy utensils are, however, made of tinned iron, aluminum alloys, or stainless steel. The product contact surfaces are increasingly being made of stainless steel (common 18-8 stainless steel refers to 18% Chromium and 8% Nickel).

The final choice will, however, depend on the ease of fabrication, availability and the overall cost. From the point of fabrication, the machinability and weld ability are the main factors and, therefore, should be kept in mind. Other properties like specific weight of the material, thermal conductivity and expansion, resistance to corrosion, brittleness and hardness are also important. All of these have bearing on the selection.

1.2 TYPES OF MATERIALS

Materials required for fabrication are classified into (i) metals and (ii) non-metals. Metals are further grouped as (i) ferrous and (ii) non-ferrous. Ferrous metals, containing iron as major constituent along with other elements, hence, vary in their strength, machining properties, etc. Wrought Iron is the purest form of iron, having minimum carbon and other contents. It can easily be machined and welded and can be used for high temperature applications such as steam supply lines, heating coils, exhaust lines, etc. Similarly, cast iron is different having carbon-content 2.5 to 4% and can be casted through mould into any shape. However, it is tough towards machining and welding. Furnace bars, jaws of crushing and grinding machine, bases of pillars, etc. are usually made of this type of iron. Let us discus in detail.

i. Steel

Steel is an iron alloy with carbon between 0.5 to 2.0%. In addition small amount of phosphorus, sulphur, silicon and manganese are added to change their uses. Mild steel with 0.05 to 0.3% carbon is most commonly used steel. Vessels, pipes and fitting are generally made of this iron. This type of steel can be most easily fabricated and machined. Medium carbon steel with 0.3 to 0.5% carbons improves the strength. Hence, shafts, springs, bolts, etc. are made from this material. High carbon steel with carbon content above 0.5% to 2% is very hard. Therefore, cutting tools like blades, saw, chisels, etc. are made of this type of iron.

ii. Alloy Steel

Alloy steel is special steel having selected properties. They are made by adding nickel, chromium, silicon, manganese, molybdenum, titanium, etc. They become highly corrosion resistant and are used for heat exchangers, milk pipelines, and all dairy equipment. Special mention may be made of stainless steel with 18% chromium and 8% nickel. This steel is best as corrosion resistant steel. The sheets are furnished in several degrees of polish covering the range from plain finish to a mirror finish. The No. 4 is finish considered good for general daily use. There are over 100 types of stainless steels. Austenitic stainless steel with American Iron and Steel Institute (AISI) 300 series is most common S.S. used for fabrication of Dairy Equipment.

iii. Non-ferrous Metals

Non-ferrous metals such as aluminum and its alloys are used selectively. Milk cans are usually made of aluminum due to its lightweight. Ladders, door and windows and some frames are also made of aluminum. Aluminum is chemically rather stable to milk and milk products. Its greatest fault is its vulnerability to attack by alkaline detergents. The surface gets pitting type corrosion causing small roughness hence cannot be cleaned easily. Copper-zinc alloys are used for tubing, bushes, and heat exchangers. It is not a very common metal for dairy industries.

iv. Non-metal Materials

Certain non-metal materials commonly used in the dairy industry include glass, rubber, plastic, etc. These are used in very small quantity for special applications such as hose pipe for water, gasket material for plates, flanges or bolts. Glass is used for viewing inside any vessel. Most commonly used synthetic rubbers are neoprene, nitrile, butyl, silicone, fluro-elastomer or viton for sealing or gaskets. These materials do not react with milk or milk product and offer leak proof joint packing. Certain plastics used in dairies are crates, conveyors, and packaging material. Wood is normally not recommended due to its porosity and its vulnerability to microbial attack. It is mostly used as building material.

Check Your Progress 1

1. What is steel?

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2. What do you understand by alloy steel?

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2. Write importance of aluminum in dairy industry?

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4. Where and why rubber and plastic are used in the dairy plant?

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1.3 PROPERTIES OF MATERIAL

The basic properties are categorized under chemical, physical and mechanical groups. Chemical properties such as composition of material and structure help in understanding the degree of strength given to material through various heat-treatments. Physical properties help in understanding possible applications, such as, selection on specific weight, thermal conductance of heat, etc. The mechanical properties help in the design and fabrication of equipment.

Strength of material indicates the capacity of material to withstand external force, hence, tensile and compressible stresses. Stiffness and rigidity is a measure to resist deformation. Ductibility is measure of elongation; hardness represents the surface characteristics against scratch.

Material of construction should not react with milk and milk product and should be durable. Usually equipment is constructed with more than one metal or alloy due to requirement of strength, function, economy or hygiene. The materials must meet following conditions as far as possible.

1. Non-toxic, non-flavour imparting and should not affect the keeping quality of the product.
2. Insoluble in the product and non-absorbent quality.
3. Resistant to corrosion.

4. Easy to clean and attractive.
5. Strong and lightweight.
6. Good heat conductor.
7. Low cost and easily available.
8. Easy in manufacturing.

Check Your Progress 2

1. Why should we learn about the properties of materials?

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2. Describe four important properties of material.

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3. What are the important characteristics of materials?

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1.4 CORROSION AND ITS PREVENTION

After having learnt about materials used for the fabrication of dairy equipment, it is now important to learn as to how to increase the life of machine and equipment. Metals employed for their fabrication becomes unstable and tend to react with environment within the dairy plant. Dairies have hot and humid environment and equipment come in contact with detergents and other chemicals used for their cleaning and sanitization. Corrosion is a process of electro-chemical decay. The amount of corrosion will depend on the type and composition of materials. Corrosion will be greatly affected by the presence of moisture or water, the temperature of surroundings and the chemical nature of the product in contact. Two dissimilar metals if used during construction, the corrosion will be fast. Non-metals are considered corrosion resistant. Now question is that how to prevent or reduce the corrosion. It can be done by:

Protective coating on metals/equipment: Most of the equipment are generally made from stainless steel, which does not need any protective coating. But certain frames, supports or the components of equipment are made from other metals. These could be protected by metallic coating such as hot-dipping, electroplating, metal spray coating, or cladding/ covering with soft metal like thin aluminum sheet. Some inorganic chemicals like anodizing treatment for aluminum cans are also made. Painting the surface does involve organic coating. Synthetic resins in oil or solvent give a continuous inert film on surface.

By selecting non-corrosive metal as far as possible.

By engineering design of components: Avoid in-built stress or loading during fabrication. Like no dead corners, avoid undulation or pits, self-draining slopes, rounded corners, no over hung parts/ component, inbuilt thermal expansion joints, appropriate gaskets and packing materials, etc.

Control of process environment: As already explained, avoid moisture accumulation around equipment, especially near its base and foundation. Avoid condensation, seepage, leakage, etc. Keep the surrounding dry as much as possible.

Some general life giving practices to be followed: Use only soft brush (fibre brush) during manual cleaning of surfaces, remove all accumulated milk residues, use only recommended detergents and keep the surface dry whenever the equipment is not in use.

Check Your Progress 3

1. What is corrosion?

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2. How do we prevent corrosion of metals?

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1.5 CHOICE OF MATERIALS

By now we have studied the specific characteristics of various metals and non-metals: The mechanical and corrosive properties will help in selecting material for specific conditions that prevail inside a dairy plant. One must analyze the economics of material selected. A high material cost may be accompanied by ease in fabrication, hence, significant saving of labour during fabrication, or owing to long life of equipment. Sometimes compromise is made to select inferior material due to high cost of better material. Certain equipment are made with combination such that a good material is placed on the joint of product contact, while non-contact part could be made with other materials. Example is milk tank or milk tanker. Inner wall is made of stainless steel while outer jacket could be made with mild steel. Such type of grafting can be done with proper understanding only.

1.6 SELECTION OF MILK HANDLING AND PROCESSING EQUIPMENT

It is very important to select the best equipment at a reasonable cost. To do we must know the capacity of dairy plant, each process involved and purpose of this individual equipment. We should also know the period of operation or running of the equipment. The location of plant also affects the selection. In order to determine the capacity, one must know the products to be manufactured and their process of manufacture. We can then develop a product flow line diagram of each product.

This will enable us to know how the milk will be handled at various stages of processing, thus, the capacity of each equipment involved can be determined. An example is given here.

i. A Simple Example

Suppose a dairy unit is to receive 10,000 litres of milk per day, 60% of milk in the morning and 40% in the evening. Normally evening milk is chilled and stored for processing in the morning. Also it is assumed that milk will be received through milk cans, and only butter and standard pasteurized milk will be manufactured. Let us make a product flow line diagram (Figure-1.1) and decide capacities of individual equipment.

Milk Reception: Milk must be received inside the dairy within 3-hours of its arrival at the receiving point, accordingly milk reception rate is decided to be 2000 L/h. Normally 2-3 cans in a minute are to be received by an operator. Hence, a weighing machine of 250 kg is selected. Every two to three minutes the milk will be released into dump tank. In about 20-30 minutes one dump tank will get filled. Hence, the capacity of 1000 litres is enough. There may or may not be need for the second dump tank, indicated as dotted lines and shown as optional arrangement.

Milk Handling: Milk from dump tank must be removed quickly to enable the receiving of fresh raw milk. To do so a high capacity milk pump is needed to unload. Therefore, a 5000 litre/hour capacity is good enough. The empty cans are sent for cleaning through a rotary can washer. The capacity of can washer will be same as that of can reception rate. Milk while pumping is required to be chilled on line. Therefore, a plate chiller of 5,000 L/h is selected. The chilled raw milk will be stored in raw milk storage tank (usually insulated). Only one tank of 5,000 litres is selected.

Milk Processing: As soon as milk reaches raw milk storage tank, the pasteurization through a HTST (High Temperature Short Time, will be explained in Unit-2) is also followed. At this point milk passes through a centrifuge machine to remove excess of milk fat as indicated in the diagram. The standardized and pasteurized milk is stored for subsequent filling through a pouch-filling machine, while the cream is stored in a vat (Ripening Vat cum Batch Pasteurizer). This vat will have about 500 kg of Cream; hence, a cream pasteurizer of same size is selected. Cream after ripening is transferred into butter churn for making Table Butter and the butter is stored in the cold store. Similarly, standard pasteurized milk filled in pouches is stored in crates and are stacked in a separate cold store.

Sizing of Equipment: The size of individual processing equipment is easily determined. The actual capacity will finally be decided looking at the availability of equipment in the market. For example milk-weighing machines are of 250 and 500 kg capacity. Selection is to be made accordingly. Dump tank is normally of 1000 and 2000 litres capacity. Likewise all the equipment indicated in the diagram are selected, based on the product flow line diagram and the availability of equipment with the manufacturer i.e. in the market.

ii. Some General Aspects of Equipment Selection

The surface finish of equipment should be No 4. And the thickness of metal used is such that no dents or cracks are formed while working with it. All equipment should have self-draining slopes. The dismantling and assembling type joint and fittings are preferred. No threaded constructions are permitted. All connections made on the equipment are such that no projections are towards product side. All equipment should be at least 10 cms. above the floor level to permit cleaning of floors.

Fig. 1.1: Product Flow Line Diagram

Check Your Progress 4

1. Describe the importance of proper selection of dairy equipment.

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2. What is product flow line diagram?

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3. What is sizing of a can washer?

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1.7 SELECTION OF UTILITIES

After selection of equipment, the requirement of heat i.e. the steam, chilled water, i.e., refrigeration, electricity for various pumps and drives, the water and compressed air, etc. can be calculated. Most often the utilities required for each equipment are available from the equipment supplier. In certain cases, it may be calculated. Again with the help of previous example of equipment selection, we shall do estimation of steam requirement, i.e., sizing the Boiler.

Steam Requirement: Steam is most convenient source of heat in the dairy plant. The demand of heat/steam will be based on established data of product flow line diagram. Let us draw a chart indicating each operation on time scale as given below (steam load with period of operation).

Process/Period → ↓	0 — 6 — 12 Noon — 18 — 24
o Can washing through Rotary Can washer 200 kg/h	8 to 11 hrs; 18 to 20 hrs
o Steam for Pasteurizer 300 kg/h	8 to 15 hrs
o Crate washing 50 kg/h	9 to16 hrs
o Floor cleaning etc. 50 kg/h	6 to 17 hrs; 18 to 21 hrs
o Cream pasteurizing 20 Kg/h	11 to 13 hrs

Steam Load Calculation: With the help of this simple chart, we can develop Figure-1.2. To do so, we take a graph paper and mark the time/period on abscissa from 0 to 24 hour basis. We may further indicate 2-hourly mark. Similarly, on ordinate side, we plot steam load by marking scale 0 to 700 kg at 100 kg mark difference. Now with the help of available information, the steam requirement is plotted. Steam requirement starts from 6 hrs at the rate of 50 kg/h for floor cleaning; hence, X is marked in figure-1.2 at each point on chart. The 2nd requirement is at 8 hrs for can washer and the pasteurizer. Since the three operations are at same time, the total load at 8 hrs will be 50+200+300 kg/h, i.e., 550 kg/h. This steam load will be up to 9 hrs. At 9 hrs, another operation will need 50 kg/h up to 16 hrs. At 11 hrs, the washer operation will be over, hence steam load reduction to the tune of 200 kg/h, but the cream pasteurizer will need 20 kg/h. Therefore, the drop will be 180 kg/h. The load at this point will be 420 kg/h up to 13 hr. At 13 hr, the load of cream pasteurizer will be phased out and the load of 400 kg/h will continue till 3 p.m. From 3 p.m. steam for pasteurizer will be shut down and thereby the load will level off to 100 kg/h only up to 16 hr, further reduce to 'O' by 17 hrs. Similarly, the evening operation of can washing and floor cleaning will need steam from 18 hrs to 21 hrs on time scale.

Sizing of Boiler: With the above estimation, we know the maximum/peak load requirement, which is 600 kg between 9 hrs to 11 hrs. Hence, the boiler capacity must be minimum of 600 kg/h. Now the choice is to have either one boiler of minimum 600 kg./h capacities or to split load into two, of 300 kg/h each. By having one boiler, the initial capital investment will be less but we have no alternate boiler to act as standby. The standby boiler helps during sudden failure or breakdown.

Other utilities: Similarly, we should plan load requirement of refrigeration compressors with one standby, one standby tube well for water supply, one air compressor for air supply and so on. Similar provisions are made at critical points wherein we expect sudden failure.

While estimating maximum load about 20% additional load as safety margin should also be added. This is done to compensate for loss in efficiency of equipment while in use. We have suggested earlier that the size of equipment will depend on its availability in the market. In this case, Boiler of 300, 500 and 1000 kg/h are available. Hence, the most appropriate decision will be to go for two Boilers of 500 kg/h capacities. This way the 2nd Boiler will require running only during peak load.

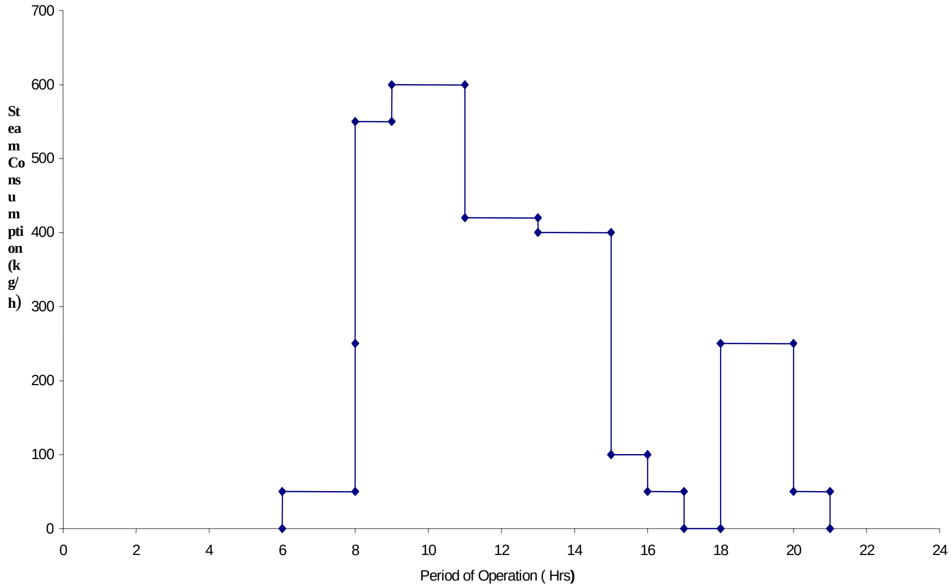

Fig. 1.2: Steam Load Diagram with Period of Operation

Check Your Progress 5

1. What are the utilities of a dairy plant?

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2. Prepare steam requirements on time scale for the can washing operation.

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3. Explain as to how you can prepare a steam load diagram for evening hours, i.e. 18-21 hours.

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1.8 LET US SUM UP

Milk utensils in our Indian villages are made of earthenware; zinc plated or galvanized iron, brass or copper. All these do affect the quality of milk and milk products and, therefore, the modern dairy utensils/equipment are made of tinned iron, aluminum alloys or stainless steel. The processing equipment are primarily made from stainless steel.

The selection of material becomes very important mainly with the view that these metallic elements should not enter into the milk and milk products. The concentration of copper affects the hot milk or cream especially when washed with alkaline solution. The tin coating is also not very resistant to abrasion. These two elements influence the flavour. Similarly iron reacts with milk salts or lactic acid and gives bitter flavour and some times toxic salts. Aluminum is rather chemically stable for milk and milk products. Its utmost advantage is that of its being lightweight and its insolubility into milk and is a good conductor of heat. Hence, it is one of the accepted metals. Apart from milk cans, the railings of the staircase, ladder and other support structures, which are not directly coming in contact with the hot milk, are made of aluminum.

Brass is also not a desirable element as it affects the flavour. The choice, therefore, rests only with zinc nickel and chromium based metals known as stainless steel. As discussed, stainless steel containing 18% chromium and 8% nickel is the most popular and exhibits anti-corrosion properties. It is known as type 302. The alloy with a maximum 0.08 percent carbon is available under the designation 18-8-5 type 304. However, the surface of the equipment made of stainless steel should also be clean and kept dry. Saline solutions (salt in water) should not be used with stainless steel.

Dairy equipment is, therefore, preferred to have the product contact surface made of stainless steel. While fabricating the equipment, the great hygienic care is taken to avoid any rough corners or dead ends with pockets, etc. to avoid corrosion. Dairy plants mostly have hot-humid climate, care must be taken for all those components and parts of the equipment, which are made of other than stainless steel, and are vulnerable for corrosion. The methods of avoiding corrosion and enhancing the life of the equipment have been discussed in detail.

In order to select appropriate size of milk processing equipment and its utilities, the description has been made with examples to calculate the size of equipment required. For this purpose, the capacity of the dairy plant and the various products to be made must be decided in advance. This decision will help us to formulate a product flow line diagram, which will give sequence of operation and the equipment required in the dairy plant. The same product flow line diagram will also provide the guidelines to decide the capacities of individual equipment. After having done the exercise of sizing the equipment, the various utilities required for the dairy can be worked out as explained through Figure-1.2. The designing of a dairy plant where we have to decide the size of various plants and machinery is also a matter of experience and not purely through calculations. The safety provision, standby and the availability of equipment in the market will ultimate decide the size of utilities required. By proper analysis, one can also plan purchase of equipment in phased manner. There could be a possibility that some equipment are required immediately while others could be deferred and purchased later. This will help in reducing the initial cost of a dairy plant.

1.9 KEY WORDS

Ferrous metals	:	Are those containing iron as a major constituent.
Strength	:	Capacity of material to withstand external Load
Stress	:	Load per unit area
Deformation	:	Change in original size or shape
Rigidity	:	Ability of material to resist
Yield stress	:	It is the maximum stress when further loading will break the material
Ductility	:	It is a measure of the deformability of material
Hardness	:	The resistance of surface to scratching
Machinability	:	Ability of material for easy fabrication
Alloy steels	:	Mixture of selected elements with main metal
Non-toxic	:	Non poisonous
Conductor	:	To facilitate heat or electricity flow
Humidity	:	Moisture content
Detergent	:	Chemical used for clearing
Cladding	:	Thin metal sheet cover for protection
Thermal expansion	:	Increase in length or volume due to increase in temperature
Reception Dock	:	Place in the Dairy plant where milk is received
Dump tank	:	A container in which milk is unloaded or received in bulk
Rotary Can	:	It is circular shaped can washer and received discharges cans in rotation
Vat	:	A small milk receiving container
Batch Pasteurizer	:	A container with provision of heating and cooling to handle milk in one go
HTST	:	It is high temperature short time type of continuous pasteurization unit
Grit No. 4	:	Grinding grade of surface finish

1.10 SOME USEFULL BOOKS

Ahmad Tufail. (1990). *Dairy Plant Systems Engineering.* Kitab Mahal Publisher, Allahabad.

Warner James N. (1976). *Principle of Dairy Processing.* Wiley Eastern Limited Publisher, New Delhi.

1.11 ANSWERS TO CHECK YOUR PROGRESS

Your answers should include the following points:

Check Your Progress 1

1) i. Names of various types of steels
   ii. Carbon content in various steels
   iii. Uses of various steels in fabrication
2) i. Different elements added to make alloy steel
   ii. Description of stainless steel composition
   iii. Uses of stainless steel in dairy industry
3) i. Advantages of aluminum as metal used in dairy application
   ii. Different uses of aluminum in dairy
4) i. List different non-metals used in a dairy plant
   ii. Use of rubbers as a part of equipment
   iii. Application of plastics in dairy
   iv. Name the equipment made of plastic materials

Check Your Progress 2

1) i. Different properties of material
   ii. How properties help in selection of a material
2) i. Various mechanical properties of metals
   ii. Effect of different metal properties on equipment fabrication
3) i. Reasons for choice of materials for equipment fabrication
   ii. Importance of materials in their selection

Check Your Progress 3

1) i. Definition of corrosion
   ii. Factors affecting corrosion of metals
2) i. Various types of protective coatings used on equipment
   ii. Precaution during fabrication of equipment
   iii. Precaution in upkeep and care of equipment

Check Your Progress 4

1) i. What information about the dairy plant be made available before selection of equipment
   ii. Various products to be made and their method of manufacture
2) i. Procedure for making a product flow diagram
   ii. Milk availability at various stages of handling/processing
   iii. Various stages of handling in each sections of dairy plant
3) i. Rate of receiving milk cans at the reception dock
   ii. Capacity of operator to handle can in a minute
   iii. Operation of can-washer

Check Your Progress 5

1) i. Various inputs required for running of an equipment

   ii. Duration of running of individual equipment every day

   iii. Quantity of utilities/services required for each equipment

2) i. To estimate hourly requirement of specific utility

   ii. Rate of Cans handling by the Can-washer

3) i. To allocate value in Abscissa and ordinate

   ii. To plot value on abscissa and ordinate scale

   iii. To join points and interpret the figure.

UNIT 2 DAIRY EQUIPMENT FOR FLUID MILK PROCESSING

Structure

2.0 OBJECTIVES

After reading this unit, we should be able:

- specify the important features of a milk processing plant
- identify the requirement of facilities in a collection and chilling center
- determine the space requirement and the types of equipment needed at reception dock
- characterize the equipment for pasteurization and sterilization of milk
- identify the need of a homogenizer, cream separator and clarifier
- distinguish the types and advantages of filling units
- specify the clean-in-place cleaning system.

2.1 INTRODUCTION

In the unit I, we have learnt the types and characteristics of materials used in the construction of dairy plant and equipment. It has given us idea of the type, shape and look of machineries used in the dairy plant. We have also learnt the importance of the material of construction of equipment in relation to the milk and milk products. We also made an attempt to plan for a dairy and sizing of equipment.

In this unit, we shall learn about the hygienic and sanitary features of a dairy plant and its operation. We will study different types of milk processing plants and factors affecting location of plant. Dairy plants are well supported by a network of milk collection and chilling centres to ensure un-interrupted milk supply. We will learn the requirements in a collection centre through a layout diagram.

We can then work out the area and the equipment needed for a collection centre. As soon as the milk reaches a milk processing plant, the manner it should be received at the reception dock will be discussed. This will enable us to learn the types of equipment required and the need for large open space. The type of flooring and other civil construction will also be discussed briefly.

Milk thus received needs further processing. Pasteurization process is the first treatment given to save milk from spoilage. We will learn as to how milk is pasteurized. Some time long shelf-life milk may be in demand. A brief description of milk sterilization will be made to explain the plant and machinery needed to produce such milk.

During pasteurization of milk, the fat content is adjusted as per consumer's need. To standardize the fat content, cream is partially separated by a centrifuge called cream separator. Also some plants may need to remove dust and other undesirable particles from milk. A clarifier is employed for the purpose. How these centrifuges operate will be discussed in this unit. Similarly, we will also learn the importance of a homogenizer, the equipment employed to reduce the size of a fat particle.

After milk is pasteurized, standardized, cleaned and homogenized, it is to be filled in some container. We will learn the working of filling machines. At the end all these machines require cleaning. It is possible to clean them without opening or stoppage. Therefore, a method of clean –in- place will be discussed.

2.2 THE DAIRY PLANT

Building and equipment are important components of a dairy processing plant. This plant is required to handle a highly perishable food product that must be protected against spoilage. The sanitation of the surroundings, interior of the building and equipment must protect the product.

i. Location of a Dairy Plant

A dairy plant is located at a place where raw milk is easily available and which has got proximity to a good market for its produce. The area should be well drained and no flooding around. It shall have good roads, potable quality water, enough electrical supply, good sewage disposal or own effluent treatment plant, adequate labour, availability of building material, spares and service facilities. Land availability must allow future expansion. Orientation of dairy building should not allow dust into the building, hence direction of wind is important. Access to road must be considered while fixing the position of dairy plant.

ii. Space Requirement

Building area depends on the capacity of the plant and the product to be manufactured. Usually manufacturers of the equipment do specify the space required. Allowance for working spaces of 5 times the actual area occupied by equipment or not less than one-meter space around each of equipment is given. As a thumb rule 25% additional space is reserved for store and office facility. Some space for future expansion is also planned. Similarly space for cold storage is estimated based on the quantity of product to be stored. The height of cold storage is governed by the mechanical provision of cooling system and height of stocking of products.

iii. Dairy Floors

Design and construction of dairy floor requires very special attention. The product handling is usually in cans or crates by trolleys, therefore durable floor material is required. Metallic tiles with cement concrete are preferred. Spillage of product and frequent cleaning require an acid resistant material like *kota*-stone with acid resistant cement. Slope of floors vary for different sections of dairy plant. In processing area maximum slope is given, as more drainage is required during washing and cleaning. Normally 2cm for every one meter, i.e., 2% slope is provided. One drain for every 10-meter distance, with minimum one drain in every section is provided. Drains do not permit insect or off odour to enter inside plant, hence, water trap type drains are provided.

iv. Dairy Walls

We know that a dairy plant provides hot and humid environment inside. The wall surfaces are protected up to 150 to 200 cm from floor against moisture. Hence, glazed tiles are preferred up to this height. Corners/ turns are protected with metallic strips to safeguard against mishandling of trolleys/cans if they strike during movement. Similarly, ceiling is kept plain having smooth surface with minimum projection of beams, etc. to avoid harbouring dust and dirt. Light fixers are imbedded into the ceiling. Doors and windows should facilitate easy cleaning. A dairy plant will have milk receiving area, processing rooms, stores, laboratory, office, wash or dress room, staff room, utility/service house, garage, workshop, etc. The space for each will depend on the handling capacity. Some time service/ utility house is separated from processing area to avoid contamination. Similarly office area and laboratory is separated to avoid hot and humid conditions and noise.

v. Ventilation

Hot and humid condition within milk processing area is reduced by better ventilation. Natural light is encouraged to reduce electrical load. Also enough protection against insects, dust and flies is ensured as milk and milk products attract a lot of these insects and flies during processing/handling.

vi. Plant Surrounding

Environment outside dairy plant is equally important. There should be minimum pollution of air, noise and water. Plant should give aesthetic look to give positive public image. Proper planning to release smoke, wastewater and dairy waste is done to promote better public health/welfare. This will also help meet strict government restrictions.

vii. The Master Plan

For a new dairy plant, a master plan must be prepared to link it with existing road, if any. Movement of traffic within the premises, parking, landscape, location of public amenities, security, sewage line and disposal, housing tube wells, electrical sub station etc. are pre-decided. A detailed layout of facility within plant is then planned. The total planning requires good knowledge of engineering and product processing.

Check Your Progress 1

1. Describe factors before selecting location of a dairy plant.

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2. What are the requirements of a dairy floor?

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3. Write various sections of a dairy plant.

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2.3 MILK COLLECTION OR CHILLING CENTRE

The success of a dairy plant will depend on the uninterrupted supply of good quality raw milk. One must plan as to how and how much milk will be procured. A milk producer may deliver milk to a dairy plant directly or through a contractor. Milk must be chilled to 4^{o}C within 3-4 hours of its milking and pasteurized as early as possible, to protect it. If there is over 500 to 1000 litres of milk available in the producer's village, it is wise to set up a collection point called as collection centre. It will not be profitable to develop a collection centre for milk less than this quantity. This collection centre must have a provision of weighing milk, examining it organoleptically, test for acidity and milk fat content and storage. These tests form the basis of payment to the producer. If the milk is required to be stored, then a provision of cooling milk is a must. The centre then is provided with appropriate housing, light, ventilation and protection against flies. After necessary recording, milk is sent to processing plant. Figure-2.1 depicts a simple layout of a collection centre. If the quantity of milk received exceeds 1000 litres, a chilling centre is planned. Chilling centre has fairly good facility of handling larger quantity of milk.

Fig. 2.1 Milk Collection Centre

2.4 MILK RECEPTION AND STORAGE

Raw fresh milk is received at the processing plant in cans directly from a producer or from a collection centre. The milk-receiving platform at dairy plant is elevated to facilitate convenient handling of cans. Also the space planning is such that cans are received and stored at the platform/ dock for unloading. Cans are emptied one by one into a weighing unit comprising of a calibrated weigh balance and weigh bowl (figure 2.2). Normally it takes 20-30 seconds to handle one can. Hence, 2-3 cans will be handled in a minute. Accordingly milk reception rate will be 100 litres of milk/minute; hence, around 6000-litres milk can be received in an hour. This simple calculation will help in deciding the equipment required for further handling as was discussed in the unit-1.

Fig. 2.2 Weigh Machine with Bowl

i. Reception Dock

Milk reception dock will have a weighing machine, a can steaming block, can washer, temporary storage after weighing called as dump tank, a high capacity milk pump (Figure-2.3) for pumping milk from this tank to a chiller (Figure-2.4). This cools the milk on line before it reaches into a storage tank. The chiller is usually a plate heat exchanger type unit, which cools milk almost instantaneously. The section also has a small laboratory to conduct platform test and recording of the milk being received.

Fig. 2.3 Milk Pump

Fig. 2.4 Plate Type Chiller

ii. Storage Tanks

The raw milk storage tanks are usually double walled horizontal stainless steel tanks (figure-2.5). These are insulated tanks, to prevent increase in the temperature of chilled milk. These are from 2000 litres to 10,000 litres in size, depending upon on the planned capacity of dairy plant (Fig. 2.5). This may or may not be installed at the reception dock.

iii. Can-steaming Blocks and Can Washer

A can-steaming block is provided to sterilize the can. Inverted can is placed over this unit and steaming is done to a cleaned can. This unit is used in addition to can washer A Rotary can washer is also shown in figure-2.6. Inverted cans are placed after milk is emptied into weighing machine. Inverted can moves in a round and cleaning is done during various stages of can washer rotation. A can washer has provision for ordinary water wash, detergent wash, hot water wash and rinsing. Hot clean can should come out of this unit. All spray nozzles are maintained to give

Fig. 2.5 Horizontal Insulted Milk Storage Tank

high-pressure spray. Also the strength of detergent and its temperature is maintained for better cleaning (Fig. 2.6).

After the milk is received, clean warm water is supplied through same route as that of milk. Detergent washing is also carried out followed by ordinary water wash to ensure complete cleaning of all equipment used at the reception dock. Finally, do not forget to drain this equipment and dry them, and also clean the floor and surroundings.

Plan view

Fig. 2.6 Rotary Can Washer

Check Your Progress 2

1. Name the facilities available at the collection centre?

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2. Make a list of the equipment used at reception dock.

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3. Give the flow route of milk within the reception dock.

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2.5 PASTEURIZER AND STERILIZER

i. Pasteurizer

We will now study two types of pasteurizers commonly used in a dairy plant (i) Batch and (ii) Continuous type.

Batch/Holding type Pasteurizer: It is also called as Low Temperature Long Time (LTLT) Pasteurizer. Batch process is mostly preferred where small quantity of milk is handled. In this method milk is generally heated to $63^{o}C$ and held for 30 minutes and then cooled to $5^{o}C$ or below. Here indirect heating is done by means of hot water. A typical batch type pasteurizer is shown in figure-2.7. In this a double-walled vat is used for pasteurization. Milk is kept inside the vat and heating medium (hot water or steam) is circulated through the jacket or space between two walls. The outer wall is insulated to reduce heat loss. The heat exchange takes place through the wall of inner lining. The milk is moved gently with an agitator. In this type, the heating and holding is done in same vat. Circulating chilled water in place of hot water also cools milk at the end. From energy use point, this is not an efficient equipment.

Continuous type Pasteurizer: The other most common method is High Temperature Short Time (HTST) or Flash pasteurization (Figure-2.8). In this process, milk is heated to above $72^{o}C$ temperature for a period of about 15 seconds in continuous manner and promptly cooled. It is a plate heat exchanger type assembly, having different sections such as heating, regeneration and cooling, in a single compact equipment assembly. This type of pasteurizer is equipped with different accessories like float control balance tank (FCBT), filter, pump, hot water mixing battery, flow diversion valve (FDV), temperature indicator and recorder, etc., to ensure uninterrupted flow of milk by continuous operation. Hot water at a $90\text{-}95^{o}C$ temperature is used as heating medium and chilled water at $1\text{-}2^{o}C$ temperatures is

Fig. 2.7 Batch-Type Milk Pasteurizer (LTLT)

used as cooling medium. This is energy efficient system but expensive in terms of initial cost. Fig. 2.8

Fig. 2.8 Continuous Pasteurizer (HTST)

ii. Sterilizers

In the process of sterilization, all the microorganisms are supposed to be destroyed. The milk is heated to 109-115^{o}C for 20-40 min, in bottles and in a batch while 135-150^{o}C for 2-6 sec only in the continuous type of systems for large capacity operations. Sterilized milk is then aspectically filled in sterile containers. This milk can be stored at room temperature for 3 to 6 months. Usually this system is very expensive.

Batch sterilizer: In this sterilizer, milk is filled in the glass bottles and capped. These bottles are placed in baskets or carriage and locked in stationary autoclave. Autoclave is a high-pressure vessel, stationary or mobile, hooked with steam connection on heating. Heat is transferred uniformly in the bottle for better treatment. Also these autoclaves are made to revolve to facilitate faster heating. It takes little long to bring the desired temperature. Thereafter, the temperature is maintained for 20-40 minutes to achieve sterilization. After this holding, the steam/condensate is drained and bottles are allowed to cool slowly. Final temperature of the bottle/milk is brought down to 30-36^{o}C. The sterilizer has thermometer, steam pressure gauge, convenient loading and unloading provision. For better results, these instruments should be maintained properly.

Check Your Progress 3

1. What are the time temperature combinations of Batch and HTST Pasteurizer?

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2. What are the time and temperature combinations of sterilization process?

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3. List the components of HTST Pasteurizer.

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2.6 HOMOGENIZER AND CENTRIFUGES

Homogenizer breaks the fat globules. Large size fat globules have tendency to float and form a cream line on the surface making milk a non-homogenous product. After homogenization the milk globules number increases 10,000 times and the size is reduced $1/10^{th}$ of the original, usually less than 1 mm size and hence the tendency of rise of fat globule is considerably reduced. This equipment is also employed for preparing reconstituted milk, ice-cream mix, etc. The main reason is to make a homogenous product.

From technological angle, there are tremendous improvements in the quality of milk and ice cream. In this equipment (Figure-2.9) the milk is passed through a small opening under very high pressure. This generates the velocities of the order 100 to 250 m/s, resulting in high shear stresses. These shear stresses break up the fat globules. Fig. 2.9

Fig. 2.9 Homogenizer

i. Homogenizer

The are various types of homogenizer, based on the type of homogenizing head. Also the operation could be in single stage or in two stages.

Two-stage operation is considered most efficient because the sheared globules have little chance of getting mixed again. They remain dispersed. In general the homogenizer consumes very high electrical energy. The initial cost of machine is also high, as the material of construction requires special material, which is very hard and hence, expensive. A homogenizer comprises of a homogenizing head, homogenizer triplex pump, high capacity motor, power transmission mechanism, and a pressure gauge.

ii. Centrifuges

Fresh raw milk contains fat 4.5% or above. It also gets contaminated with dirt, straw, etc., even leucocytes (udder cells) gets into the milk during milking. Both of these could be removed by centrifugation process.

Cream separator: It is equipment, which operates continuously and imparts centrifugal force to the incoming milk stream. A simple hand operated unit is shown in figure-2.10. The milk gets distributed in thin layers between the discs. The fat (cream) being lighter phase will travel towards the centre while skim milk, which is heavier, will travel towards the periphery. Both of these streams are so directed that the cream and skim milk be collected through separate outlets. The cream, which is rich in fat %, could be further tuned by the adjustment of cream outlet screw. Greater restriction at the exit will result in a rich cream i.e. cream of higher fat %. The cream separator has bowl, milk pan, cream pan and the drive unit. The bowl normally revolves at the speed above 3000 RPM. The bowl, which is the main part, comprises conical discs, disc-holder, parting disc, cover, nut, etc. An assembly of parts of two bowls is depicted in figure-2.11 with various flow streams.

Fig. 2.10 Hand Operated Small Cream Separator

Clarifier: It is similar to the cream separator. Its function is to remove extraneous elements such as dirt, chaff and leucocytes cells, etc. These are heavier and the undesirable elements. By centrifugation these particles are collected at the periphery. There is enough space (residue space) provided in the bowl, which accumulates these particles until the unit is stopped and cleaned. In case the residue level is high or the operation is required for longer duration the residue needs continuous removal. Therefore, modern separators have been provided with clarifiers to remove sludge in continuous manner.

Fig. 2.11 Two Bowl with Flow Streams

Cream separator and the clarifier could also be an integrated unit. The modern centrifuge has provision to remove cream or adjust the amount of fat required and also to remove dirt.

Check Your Progress 4

1. Give the working of a homogenizer.

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2. What is the principle of centrifugation?

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3. Give advantages of homogenization.

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4. Describe the differences between a separator and a clarifier.

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2.7 PACKAGING AND FILLING

Milk is filled in bottles and the plastic pouches. As shown in figures-2.12 and 2.13, the filling in bottle is done under gravity or the vacuum and only fixed volume will be filled. The cleaned empty bottles are placed on the pedestal, which lifts the bottle against the filler valve. As soon as the bottle joins the valve, milk starts flowing into the bottle for a fixed time. After filling, the bottle is lowered and removed from the pedestal and capped. Machine is integrated with the continuous pasteurizer.

Filling in the plastic pouches is accomplished by a special filler (figure-2.14). The plastic film roll is placed on the filling machine. The film is drawn into the machine and it form into a cylinder with closed bottom; the milk is released in this cylinder for a fixed duration under constant flow. Thus only fixed amount of milk will be discharged. Subsequently, the cylinder will be sealed from the top, forming a complete filled pouch. The machine has adjustment for regulating the quantity of milk.

Fig. 2.12 Low Vacuum Filling System Valve

Fig. 2.13 Vacuum Filler

Fig. 2.14 Pouch Filling System

2.8 CLEAN IN PLACE (CIP) CLEANING SYSTEM

It is a process that combines high velocity scrubbing and chemical actions of the circulating detergent solutions to remove the deposits from milk handling equipment. The clean-in-place (CIP) system of cleaning eliminates the dismantling and reassembling process for the equipment for the cleaning purposes. This reduces the human effort involved and economizes on labour, time and energy.

The CIP System consists of storage tanks for water, alkali and acid detergents, pumps and interconnecting pipelines for solutions. Pressure jets, perforated spray balls are employed in conjunction with CIP system for creating effective turbulence for proper cleaning of storage tanks as shown in figure-2.15.

Storage tanks have the provision for heating of the solutions. Equipment to be cleaned is connected with this system and different solutions are circulated through the equipment for a definite period of time in a sequence decided as per the cleaning cycle. The time of circulation, temperature and the concentration of cleaning solutions and the turbulence required for physical action depend upon the type of deposits in the equipment.

Addition of higher amount of detergents or unnecessary increasing the cleaning time does not remove additional deposits from the surface. Also sometimes higher temperatures of detergent solutions may fix the deposits more firmly on the milk process equipment.

The detergent solutions are reused as many time as possible. The concentration of the detergents is constantly monitored. For conservation of water, an additional tank is provided which collects the final rinsed water, which is used for pre rinse in the next cleaning operation. Cleaning of large vessels and storage tanks is not satisfactorily achieved by using circulating system alone.

Fig. 2.15 CIP Cleaning System

2.9 LET US SUM UP

If some one is interested in setting-up of a milk processing plant, apart from the capacity of milk handling, one should know the location/ place where this factory is to be constructed. Though the potential of raw milk availability and consumption of its produce are significant, the environmental factors, geographic and topography of land, availability of construction material and equipment, skilled and unskilled labour, power supply, drainage system, surrounding land scape, network of road etc. play very important role in selecting the location. Milk is highly perishable product and therefore the rate at which it should e received and handled is very important. Similarly the construction of floors, walls, ceiling, door and windows, drains and dust proof environment inside the dairy plant become significant.

To increase milk procurement and uninterrupted supply, the collection centres are planned. Some minimum facilities are created at these centres to protect milk. However, milk must reach processing plant within 3 hours of its milking, else it should be cooled to 4^oC or less.

Mode of milk collection is important in selection of equipment and so is the space requirement at reception section. Milk received at the reception is handled fast and stored for subsequent processing.

Milk containers (cans) should be cleaned and sterilized before these are returned to producers. Reception section should be dust and fly proof. It should be kept clean and dry when not in use.

We have learnt the process of pasteurization and sterilization. An attempt has been made to explain the different types of equipment available in the market. The selection of equipment depends on the scale of milk handling.

Usually these operations are carried out throughout the working shift. All equipment must be cleaned and kept dry when not in use. All pressure and temperature gauges are calibrated regularly, as the pasteurization and sterilization temperatures and pressures are very critical.

The importance of homogenization has been discussed. Although this equipment is expensive but improves the quality of milk and milk products significantly. Similarly, we have learnt the application of centrifuges. Clarifiers remove the dirt while cream separator helps in adjusting the fat content.

This adjustment is needed as per the requirement of the product. Homogenizer works under high pressure, milk must be filtered to avoid any damage to the homogenizer, and similarly centrifuges revolve at high speeds. The assembly of bowl and its cleaning is very important. Both of these equipment require special maintenance precautions.

Fluid milk after pasteurization, standardization and homogenization, etc; requires filling into glass or plastic packages. You have seen these filling machines. This filling process may cause further contamination. The choice of filling container and its size is governed by the market demand. Currently, smaller packets in plastic pouches are common. Only flavored sterilized milk is sold in glass bottles. Large-scale operations and equipments are not discussed.

At the end of processing, all equipment and plants be cleaned and sanitized. The design and construction of equipment and the dairy plant is such that cleaning and sanitization is performed easily. Condition of hot and humid environment is not allowed to hinder the hygienic requirement.

Self-draining type floors, no place for accumulation of dirt or water, no corners or crevices, prevention of rodents, pest and insects, are parts of a well-constructed and maintained dairy plant.

2.10 KEY WORDS

Hygienic features	:	In-built shape or construction facilitates better cleaning microbial free conditions.
Layout diagram	:	Plan of space showing placement of equipments and facilities.
Pasteurization	:	It is a process of heating and cooling to destroy pathogenic organism.
Sterilization	:	Process of destroying all types of organisms.
Centrifuge	:	An equipment facilitating high-speed rotation of material to induce separation under centrifugal force.
Standardization	:	To provide predetermined % fat in the milk.
Clean-in-place	:	A method to circulate detergent/water for cleaning without its dismantling
Perishable food	:	Food that gets spoilt fast
Ventilation	:	Exchange of air from enclosed room
Pollution	:	Contamination of environment
Master plan	:	Overall plan depicting details of individual Buildings
Organoleptically	:	Method of examination by looks and taste
Dump tank	:	Container to receive milk installed below floor level
Instantaneously	:	Quickly
Regeneration	:	To exchange heat energy between hot and cold Stream
Fat globules	:	Fat particles
Homogenous	:	Uniform product
Shear	:	Relative motion between layers of individual Particles
Triplex pump	:	Three positive pumps operating at 120^0 apart in one Rotation
Leukocyte cell	:	Muscular cells of the udder

2.11 SOME USEFUL BOOKS

Ahmad Tufail. (1990). *Dairy Plant Systems Engineering*. Kitab Mahal Publisher, Allahabad.

Anantakrishnan. C.P. and Simha N.N. (1987). *Dairy Engineering Technology and Engineering of Dairy Plant operation*. Laxmi Publications, Delhi

Kessler H.G. (1981). *Food Engineering and Dairy Technology*. Verlag A. Kessler, P.O.Box 1721, Dairy Engineering Division-8050, Freising (Germany)

Warner James. (1976). *Principles of Dairy Processing*. Wiley Eastern Ltd. Publisher, New Delhi.

2.12 ANSWERS TO CHECK YOUR PROGESS

Check Your Progress 1

1) i. Type of land, its area and surroundings
   ii. Raw material and labour availability
   iii. Nearness of market, roads and waste disposal facilities
2) i. Method of moving material on floors.
   ii. Construction and quality of floor
   iii. Importance of slope and drain design
3) i. Names of rooms with their specific requirements.
   ii. Main rooms and attached facilities.
   iii. Importance of separating individual sections.

Check Your Progress 2

1) i. List of equipment and instruments provided at a collecting centre
   ii. Construction of centre with type of floor, wall, ceiling etc
   iii. Use and importance of individual equipment
2) i. Need and importance of individual equipment
   ii. Space requirement of individual equipment
3) i. Name equipment's sequence involved from beginning of milk intake
   ii. Function of each equipment at different stages of operation

Check Your Progress 3

1) i. Batch and continuous pasteurizer operation
   ii. Importance of heating and holding in each.
2) i. Batch and continuous sterilizer operation
   ii. Importance of heating and holding in each
   iii. Difference between pasteurization & sterilization
3) i. Identification of all parts of HTST.
   ii. Functions and importance of each part.

Check Your Progress 4

1) i. Various parts of a homogenizer
   ii. Sequence of flow of milk with the equipment
   iii. Mechanism of fat particle breaking
2) i. Effect of centrifugal force
   ii. Separation of fat and skim milk
   iii. Effect of high speed on fat separation
3) i. Why homogenization is done
   ii. Two stage operation of homogenizer
4) i. Difference in the construction of the bowls for the separator and clarifier.
   ii. Separation of fat, skim milk and dirt
   iii. Functions of separators and clarifiers.

UNIT 3 DAIRY EQUIPMENT FOR PRODUCTS PROCESSING

Structure

3.0 OBJECTIVES

After reading this unit, we should be able to identify:

- equipment required for the manufacture of butter and cheese at small and medium scale
- various types of ice-cream making equipment in use
- machines and equipment needed to produce condensed and dried milk
- different *ghee* making equipment
- *khoa* making equipment available in the country
- equipments needed for mechanized manufacturing of *Dahi* and *Lassi.*
- mechanization of acidic coagulated products.

3.1 INTRODUCTION

In the Unit, we have learnt as to how a dairy plant should be planned for processing of fluid milk, and how selection of various equipment for pasteurized and standardized milk should be done. The usefulness of clarification and cream separation to produce good quality standardized fluid milk has been discussed. Importance of homogenization and in-line filling has been explained. How a fluid milk plant is cleaned without opening the equipment has also been explained in brief. Certain aspects of building construction such as type of flooring, walls, ceiling, ventilation and flies control have also been discussed.

In this unit 3, we will learn about equipment required for the manufacture of milk products. Milk products are made in every country and therefore, a simpler classification is done as western and indigenous milk products. The equipment required for the western milk products like butter, ice-cream, cheese and milk powder will be discussed. The emphasis will be given on small level operation, while a passing reference will be made for large-scale operations. Similarly, indigenous milk products such as *ghee*, curd, *lassi*, *khoa*, etc. will be discussed in detail.

Attempt will be made to compare certain similarities of western and indigenous milk products like Butter Vs *Makhan*, Ice-cream Vs *Kulfi*, Cheese Vs *Paneer*, Curd Vs Yoghurt, etc.

In order to generate interest for readers, some basic principles involved in the manufacture will be discussed. Smaller equipment will need little care and maintenance, while the larger equipment will need more attention. Important aspects of maintenance will be explained along with the discussion on individual equipment.

Every equipment has some unique features or specific requirement for its safe and uninterrupted operation. Wherever it is considered appropriate, a brief observation is made so that learner will take care during the selection of particular equipment.

Since products vary from place to place and require regional attributes, it may not be possible to recommend any single equipment. After attaining the knowledge, you can select your own manufacturing strategy.

3.2 BUTTER AND CHEESE MAKING EQUIPMENT

Butter is the name given by western countries. In India, this product is referred as '*Makhan*', the country made "*desi*" butter. The process line at domestic level varies and also the compositional parameters. The *Makhan* is usually freshly made and consumed. The leftover, if any, is stored for manufacture of *ghee*. As the cream availability increases, the butter quantity manufacture exceeds the domestic level handling. Cream is, thus, handled through larger containers called ageing vats.

i. Cream Ageing Vat

It performs the batch type pasteurization as discussed in unit-2. This tank has provision to store cream at 4^{o}C; hence, cream collected is stored overnight, pasteurized and then put into the churn.

ii. Churn

The churns are of cylindrical, conical, dice and top shaped containers (Fig.3.1). They are made of stainless steel food grade AISI-304. Provision is made for slow revolution with changed direction of rotation. The churns are 1/3rd to ½ filled with cream. During rotation the fat particles colloid with each other and form clumps. Care is taken that the temperature of cream/fat is maintained, i.e., the chilled water is sprayed over the churn during summer. The concussion is better achieved if the temperature of cream/ fat remains between 45 to 55^{o}F. The cylindrical churn will have internal baffle to break the motion of cream along with the cylinder body, while in other shaped churns, such provision may not be required. The churn will have a complete geared drive system to obtain different speeds, water spray mechanism to maintain temperature and guard rail to protect workers. Churn under rotation creates vibrations due to uneven shape and load; hence, proper foundation is essential. To facilitate operation, the churn is provided with an outlet in the form of manhole, buttermilk drain, sight glass, etc.

iii. Butter Trolley

Butter prepared in the churn requires unloading. Hence, a hygienically designed stainless steel open type trolley is required. The size of trolley should be such that it should accommodate all butter from the churn. If the quantity of butter made is less, one may collect butter in other containers, provided they are clean and designed to handle food products.

Fig. 3.1 Type of Metal Churns

iv. Continuous Butter Manufacturing Equipment

If the quantity of cream availability further increases, a continuous butter-making machine could be used. Most common and convenient machine is "CONTIMAB" (Fig.3.2). Although there are two other types of continuous equipments available in the market. In this machine all steps required in butter making such as churning, working, salting, etc. are done in a continuous manner. The cream of 30 to 40% richness keeps flowing into a cylindrical churn. The churn delivers clumped fat mass into the working zone, while the buttermilk is drained. During working, the texture modification, moisture regulation, colour addition, salt mixing etc. are obtained. The end product in the form of rectangular slabs comes out of the plant. It is, then, hooked with at appropriate packaging machine.

Fig. 3.2 Continuous Butter Churn

v. The Cheese Making Equipment

These are cheese vat, knife, curd mill, hoops and press, etc. The cheese vat is used for coagulation and cooking and is made of stainless steel in rectangular shape as shown in Figure 3.3 and 3.4. This vat is jacketed allowing space for circulation of hot water between the inner and outer containers. It may or may not have an agitator as shown in the diagrams. During coagulation and cooking, agitator is used for uniform dispersion of coagulant. The whey is drained and the curdled mass is placed in cheese hoops for further matting and drainage of secondary whey. The pressure is applied through a cheese press on these hoops for expulsion of whey, thus, the block of curdled mass is obtained .It is then waxed and stored for ripening. After ripening, cheese of different flavours is prepared for further processing as per the manufacturing requirements.

Fig 3.3 Jacketed Vat

Fig. 3.4 Vat with Agitator

Check Your Progress 1

1. What are the functions of cream aging vat?

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2. Explain the operation of churn.

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3. What equipment are needed for cheese making?

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3.3 ICE-CREAM MAKING EQUIPMENT

Ice-cream and other frozen products manufacturing equipment may be classified as batch freezers, hand operated, *kulfi* maker, direct expansion type batch freezers and continuous freezers, etc.

i. Hand Operated Unit

It is shown in figure-3.5, has a wooden cylindrical case to accommodate broken ice+salt, a mix can and dasher assembly. The mix-can is made of either aluminum or mild steel with tin coating. This is designed such that it is pivoted in the bottom and has a geared drive system. The dasher remains stationary to facilitate scraper of frozen mass and keep mix moving for better freezing efficiency. This unit is commonly used at domestic level.

Fig. 3.5 Hand Operated Freezer

ii. *Kulfi* Maker

Little larger scale operation is through a kulfi maker. In this traditional method, the prepared mix is filled in the metal containers usually cone/square shaped. The size of containers is such that the quantity is served once. These containers are placed in a clay pot or a metallic container, which is large enough to accommodate the broken ice. Salt is added to lower the freezing point, thus causing faster freezing. This type of kulfi maker is very common at entrepreneur level. Care is taken to seal the container to the extent that the brine water does not leak through in the product.

iii. Direct Expansion Type Freezer

The batch freezers are the most common units shown in figure.3.6 and 3.7. These are cylindrical in shape with one jacket for refrigerant and the other for insulation. The cylinder acts as an evaporator of a refrigeration system. It is made of stainless steel. Normally, this is of 6 kg and 12 kg mix holding capacity. After freezing, the volume of mix gets doubled as the air gets incorporated. The mix is agitated by the dasher. The dasher does two jobs, firstly to remove frozen mix from the inner shell and second to agitate the mix such that the mix does not freeze into one solid mass.

During agitation a filtered atmospheric or pressurized air is sent into the mix. The air gets trapped causing overrun of frozen mass. This increase in volume is called overrun.

Fig. 3.6 Batch Type Ice Cream Freezer

Fig. 3.7 Scraper and Freezer Body

Fig. 3.8 Diagram of a Continuous Ice-Cream Freezer

Continuous type freezer: As the scale of production increases over 500kg/h, the continuous or instant freezers are used. The mix is continuously pumped into the freezer cylinder and the frozen mass is discharged from the machine as shown in figure.3.8. The principle of freezing is the same, however improved automation and control are necessary. The desired amount of overrun and degree of freezing can be adjusted with these controls (Fig.3.9). Pumping of mix is half the volume of the ice-cream outlet pump. Similarly, the dasher design is such that the mix flows from one end to outlet without backward flow.

In both the freezers, the frozen mix coming out is in flowable state. It is soft at –10^{o}Cand served as softy. The frozen product is filled into cups/bricks and put into hardening freezers for hardening and is served to consumers as ice cream. Soft serve freezers or softy plants are like batch freezers where soft frozen mix is directly drawn into edible cones or cups. Once the mix is frozen, the dashers keep rotating and the refrigerant is switched off. This way, the mix keeps in a flowable state and the temperature is between -5^{o} to -10^{o}C, no hardening is required.

Fig. 3.9 Freezer with Accessories

Check Your Progress 2

1. Give the important parts of a batch freezer.

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2. Explain the working of a continuous freezer.

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3. How soft and hard ice-cream are obtained?

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3.4 EVAPORATORS AND DRYERS

We know that the milk has around 85% water; hence, it can be condensed manifolds by reducing the water content for the preparation of special dairy products like condensed milk and milk powders. Milk is normally surplus during winter months, while there is shortage during summer months. By reducing the bulk the shelf life of the milk is also enhanced. This process will help in augmenting the supply during lean months.

i. Milk Evaporators

These are the equipment to concentrate milk usually up to 40% total solids. This is done by boiling the milk under vacuum. When the milk is boiled under atmospheric pressure, it boils at 100.5^{o}C. This temperature is so high that most of the nutrients will be lost. When the milk is boiled under vacuum, the boiling occurs at much lower temperature say around 60^{o}C. At this temperature, most of properties of milk are retained while the water gets evaporated. Milk evaporators are mainly of two types.

Batch-type Milk Evaporator: It is also called as vacuum pan as shown in figure 3.10. It is like a storage vat with provision of indirect heating and vacuum. Milk remains in the container for longer duration. Initially, a large amount of milk is loaded and slowly the batch gets concentrated. It is then cooled and stored. Since the evaporation occurs under vacuum the chemical properties of milk remain unchanged and only partial water is removed. Fresh milk is loaded and the heating tubes are submerged. Steam heats tubes are surrounded by milk and vapours formed. A vacuum device removes these vapours. Concentrated milk is taken out from the bottom outlet.

Fig. 3.10 Batch Evaporator

Continuous type: As the capacity of handling increases, there is need to get concentrated milk out in the continuous manner. Also in the batch system, the milk residence time is very high. It does affect the quality of the product. Long tube (rising or falling film) type equipment are available in the market. These units are very tall and sophisticated in terms of their operation and control. The residence time of milk during evaporation is very short, i.e., usually few seconds only. Thus, the product quality is superior. Milk travels from one heat exchanger (calendria) to another in a continuous flow. The flow of milk is such that the velocity of milk is very high giving very high rate of heat transfer. Whole system is under vacuum. Milk flow inside the tube could be either in rising or in falling manner. Accordingly, the evaporator is named. Another way of classifying is, the number of heat exchangers involved. Single, double, triple or even multi-stage systems are available. This helps in economizing the steam consumption. Figure 3.11 shows a classical single effect evaporator. Product enters the heater, and the heated milk is directed into a large calendria for evaporation. The concentrated milk falls into the vapour separator, from where the vapours are either recompressed with help of thermo-compressor or sent into condenser cum ejector system.

ii. Dryers

Drum dryer: It has drums heated internally with high-pressure steam. These drums revolve with low speed in the direction indicated in figure 3.12. The milk is supplied through feed pipe. It gets filled in between the drums. A layer of milk gets adhered on the surface of drum and it starts drying till it reaches the knife. The knife scraps out the thin layer and drops the dried flakes into the conveyor. The dried product is taken out. The vapours generated over drums are sucked out through vapour hood. Milk during drying remains in contact with hot drum for relatively longer, causing denaturation of protein. Hence, powder obtained from this technique usually contains higher sediments. This powder is most suitable for

Fig 3.11 Long Tube (Falling Film Type) Evaporator

indigenous milk product manufacture such as *Gulabjamun*. These dryers are getting obsolete due to high-energy requirement.

Fig. 3.12 Drum Dryer

Spray dryer: They dry partially concentrated milk and are considered energy efficient systems. In this equipment, fine spray of concentrated milk is supplied into a chamber. The spray encounters with hot incoming air. Direct contact with air takes away all moisture from the spray drops. Within seconds the drops turn into a dried powder particle. The particles are heavier than air; hence, they settle down and are collected. The air gets saturated with moisture and is directed towards the exit. While diverting the air, care is taken that milk particles do not get carried away. In this system, the residence time and the rise in temperature of the particle are very less. This reduces the damage to the milk particle. This powder, therefore, gets dissolved in water without much of sediments. Hence, the spray-dried powder is considered excellent for reconstitution purposes. A typical schematic diagram of a spray dryer is shown in figure 3.13. Feed (concentrated milk) is sprayed through atomizer. It falls in the drying chamber. The dried product is discharged from the bottom. Fresh hot air is supplied through steam heaters and directed into the drying chamber. The exhaust fan draws the exit air through a cyclone separator. Fine particles carried away, are arrested in the cyclone separator while the clean, saturated air is delivered into atmosphere.

Check Your Progress 3

1. What is importance of vacuum during evaporation of milk?

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Fig. 3.13 Spray Dryer

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2. What are the main components of a vacuum pan?

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3. Explain the working of spray dryer used for milk.

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3.5 *GHEE* MAKING EQUIPMENT

Ghee from *Makhan* (desi butter) is made in a small batch in *Karahi*. After the water is evaporated and ghee is ready, it is cooled and residue is separated. With the help of a stirrer called *Khunti*, scraping is done for better heat transfer. This method is not hygienic though common in villages.

i. *Ghee* Boiler

At an industrial scale of manufacturing *Ghee*, Kettle as shown in figure 3.14 is used. It is a double walled, hemi-spherical or cylindrical shape jacketed vessel. It has provision for steam heating at a steam pressure of 3.5 kg/cm^2 and condensate outlet, safety valve pressure gauge, agitator cum scraper etc. Since there will be deposit formation on heating surface regular scraping at slow speed is required. There is also a product outlet valve for unloading the finished product. The capacity of this kettle ranges from 50 kg to 1000 kg. There is also one dial type thermometer to indicate the temperature of the jacket. The temperature is varied during preparation of ghee. Same vat or a separate vat may be required for settling the residue and cooling the ghee. For this, agitator is stopped and the product is held overnight and the residue, which settles in, the bottom is filtered out. Ghee is then packed in the polyethylene or plastic pouches or tin-coated cans. Filling and sealing is done manually. For large production, this operation is also mechanized. Suitable filters and cappers are available.

Continuous ghee-making machine has been developed at National Dairy Research Institute, (NDRI), Karnal based on the principle of scraped surface heat exchanger to manufacture *ghee* from butter. It has capacity of 500 kg/hour and above.

3.6 *KHOA* MAKING EQUIPMENT

Khoa is a heat desiccated product and made by concentrating whole milk at atmospheric pressure, unlike concentration under vacuum in the milk evaporators. Milk is boiled and evaporated by stirring. The stirring and scraping is done to avoid milk deposits sticking on the heating surface. Initially the scraping is slow as the water content is high and the surface deposition is slow. At final stage, the intensity of scraping increases. The product is taken out in a high viscous and yet flowable form, as it is hot. The cooled mass gets solidified and is called '*Khoa*'.

i. Karahi

Traditionally khoa is made in the open vats, "*Karahi*" referred earlier. The *Karahi* offers advantages such as its availability, cost, extent of repair and maintenance, and versatility in use. This can use any heating source like coal, wood or Liquefied Petroleum Gas (LPG). Initially milk has large water content hence agitation/scraping is slow and intermittent. As the concentration increases the fouling of heating surface increases. Hence, vigorous scraping is required. Also the heat intensity is reduced progressively as the water availability for evaporation reduces. All these operations are performed manually and depended on the skill of the operator.

ii. Jacketed Kettle

Hemi-spherical jacketed kettle is shown in figure 3.14. Small entrepreneurs and dairies prefer this equipment. However, this unit has disadvantage of low capacity and the curvilinear profile which causes surface fouling. The scraping of surface, loading of raw milk and unloading of finished product is manual. This unit differs from ghee kettle primarily on the design of scraping mechanism, as the degree of scraping required is more for *Khoa* during its manufacture.

iii. Conical Process Vat

It is an improved version of Jacketed vessel developed at NDRI Karnal, for its scraping ability and product handling (Fig.3.15). This equipment has straight-line profile of the heating surface, hence, easy to scrap. The scrapers are motorized with speed regulation; hence, scraping speed can be varied in relation to the requirement of the product. Product is loaded from the top while it can be unloaded through an axial discharge mechanism. A batch type Scraped Surface Heat Exchanger (SSHE) is also placed in figure 3.16. This makes about 10-12 kg khoa per hour.

iv. Continuous khoa-making Machine

This machine is developed and perfected to manufacture 50-60 kg of *Khoa* per hour. An inclined scraper surface heat exchanger has been developed at National Dairy Development Board, Anand. Both of these units prepare *khoa* @ 45-50 kg per hour from raw milk and 300-350 kg per hour from condense milk. These units are required for large-scale manufacturing of *khoa* and are used mostly by established dairy plants.

Fig. 3.14 Ghee Kettle

Fig. 3.15 Conical Process Vat

Fig. 3.16 Batch Type SSHE Unit

Check Your Progress 4

1. Explain the working of Jacketed kettle used for making *ghee* and *khoa.*

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2. List the other equipment developed for making *khoa.*

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3.7 *DAHI* AND *LASSI* MAKING EQUIPMENT

Dahi is an indigenous dairy product and well known fermented milk product of India. *Dahi* is produced by following two processes: (i) Traditional method and (ii) Standardized method.

i. Traditional Method

This is a household method of production of *dahi*, which is also used in *Halwai*'s shop. The fresh milk is first boiled, cooled to body temperature and then bacterial culture (also called starter culture) is added to it @ 0.5%. The last step is known as inoculation. Previous day's *Dahi* or buttermilk can also be used as starter. After inoculation, it is allowed undisturbed overnight. In case of *Misti doi* (payodhi), cane sugar is added just after boiling milk. Equipment for production of Dahi, are, Karahi, *Khunti* (ladle), circular earthenware mould, etc. as required and discussed earlier. For curd setting, other containers of choice can be used.

ii. The Standardized Method

It is practiced at organized sector of Indian dairy industry. Fresh, sweet, good quality pasteurized milk is heated to 35-40^{o}C. Then its fat and SNF percentage are standardized. Milk is cooled, then, to 22^{o}C and inoculated with 1-3% of specific starter culture. The mix is filled in glass bottles or plastic cups and is kept for 16-18 hours at about 30^{o}C temperature. This is called incubation. After the definite period of incubation, firm curd is formed and acidity reaches to a satisfactory level.

Then, the curd is cooled to below 10°C and stored at about 5°C temperature. In case of "*Misti doi*", cane sugar is added to milk in heated condition. Artificial colour (brown) or sugar-caramel and *gur* are added.

Equipment required to adopt standardized method of Dahi production are as follows:

Double-jacketed multipurpose vat: As discussed earlier, is necessary for heating milk and addition of milk powder and cane sugar for standardization purpose. Heating or cooling medium flows inside the jacket. Pipeline is attached with it and a drain cock attached to drain the content, whenever necessary. Ladle is used to stir the milk during addition of culture to milk. It is of stainless steel and kept clean.

Incubator: It is needed for setting the curd. It is a closed room or cabinet where temperature 30+5°Ctemperature is maintained by mechanical means. And the mix (milk+culture) is kept undisturbed for 16-18 hours at that particular temperature to bring about fermentative changes. After the curd is set, the cups are placed in the cold storage.

iii. *Lassi* Making Equipment

A process vat for preparation of curd is needed. This is a large jacketed vessel, usually vertical tanks having provision for heating, cooling and agitation. These are similar to ghee kettle as shown earlier. In these surface scraping is not required. Hence, the scraper performs as agitator only. Also there is provision for supply of chilled water to cool the product as per the process need. After addition of sugar, the mass is gently stirred to make it in slurry form. This product is, then, filled through an appropriate filling machine.

3.8 *PANEER*, *CHHANA* AND CASEIN MAKING EQUIPMENT

These products are acidic coagulated milk products unlike cheese discussed earlier. *Paneer* is prepared by coagulating standardized heated milk. Curdled mass is pressed to get *paneer* and the whey is allowed to be drained-off, while *Chhana* is unpressed mass usually prepared from cow's milk. Following equipment are used:

i. Vat

The heating and coagulation of milk is done in a stainless steel double walled vat as shown in figure 3.3 The stirring is usually done with a ladle. In case of a large kettle, a mechanical agitator is fitted with a motor (Fig.3.4). At the bottom of one of the side of the vat, a drain-valve is provided to drain whey after coagulation. Steam line is equipped with a safety valve, pressure gauge kettle and a water line is provided at the junction of steam line to ensure hot water into the jacket of the vat. To obtain uniform temperature, H-shaped diffuser is provided at the bottom of vat. The vat is provided with over flow line open to atmosphere. This enables release of pressure in the jacket, if any.

ii. Press

After draining the primary whey, the curdled mass is collected in hoops lined with a muslin cloth and weight is applied. In the traditional method, about 45 kg weight is applied for 15-20 minutes to allow secondary whey to drain-off. The matted block is then cut into pieces and dipped in the chilled water. Thus, the paneer is obtained manually in a batch.

Continuous *paneer/chhana* making system is being developed based on the twin-apron conveyor design. In this system operations involved have been mechanized.

iii. Casein Production

Commercial casein is prepared from sour milk. About 2 to 5% milk turns sour during summer due to delay in receiving or processing. To recover some money casein is made. Coagulation vat is used and curdled mass is dried in a dryer. The dried particles are milled in a grinder to make it in powder form.

Check Your Progress 5

1. Explain the working of multipurpose process vat used for *dahi* making.

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2. Explain process difference in *dahi* and *lassi* making.

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3. List the equipment needed for the manufacture of paneer.

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3.9 LET US SUM UP

In this unit, we have learnt equipment required for the manufacture of various milk products. We have started with butter making equipment. For butter making, one needs cream, which is obtained from a cream separator discussed in Unit 2.This cream is stored in a cream-ageing vat where it is also pasteurized. A good quality pasteurized cream is pumped into a churn. The churns are partially loaded and enough space is provided for cream to have concussion during rotation of churn. Proper temperature helps clumping of fat. During rotation guard is provided to protect the operators. After churning, buttermilk is drained and clumped butter is unloaded in a trolly, and sent for packaging. If the quantity of cream availability is still more, one can, then think of a continuous butter making machine.

For cheese making a cheese vat with agitator is required. After the desired heating of standardized milk, curdling is done with rennet, an enzyme. Cooking, cutting of curd is done with special knife and then, the whey is drained. The curdled mass is put into hoops for further removal of secondary whey under pressure. The curdled mass becomes a solid matted block, which is waxed and stored for ripening in the cheese cold storage. The fermented block is dewaxed and milled to prepare cheese with desired flavour. Thus, milling machine, and suitable packaging equipment are also needed to prepared finished product.

For ice cream making, the equipment line depends on the quantity and rate of production. In fact, this is true for all products. We need ingredient mixing and aging tank. Normally two tanks are needed, this will help in carrying out simultaneous operations like blending, pasteurization and homogenization. Batch type freezer is used for small scale while continuous type is used for large-scale production. The scraper blade should be sharp and straight to avoid damage to the inner surface of the freezer. In continuous type unit, the pumps are kept in good condition. Their discharge capacity should be measured from time to time. Refrigeration jacket should be clean and free from oil.

Milk condensing is done to prepare milk powder. Evaporator does the job of removing water from milk under vacuum. A dryer needs lot of heat energy to remove water, therefore, pre-concentrated milk is used into the dryer. The evaporator is relatively efficient equipment. A vacuum pan is used to concentrate milk either to prepare sweetened condensed milk or supply partially concentrated milk to drum dryer. Long-tube, multi effect evaporators are used for large milk handling and also to produce concentrated milk in continuous manner. Proper vacuum in the evaporators is the main maintenance issue. The components like vapour condenser, vacuum pump and steam ejector need attention. This section also gives lot of noise, which should be kept under control. Check for air leakage from joints. Also the vibrations from various pumps, etc. be checked and removed.

Drum dryers are obsolete now. These are not very common in the dairy plants any more. It is difficult to maintain the surface of drums and the sharpness of blades. Spray dryers are energy efficient and much improved with their multi-stage operation and instantization process to improve the quality of powder. Care and upkeep of drying chambers and atomizers/ nozzle is the most important area for our attention. If atomizer is clean, the particle size will be under control. The fire hazards will also be minimized. The chamber, if kept clean, will have bearing on the quality. Cyclone separator should be effective and no dents be seen near powder exit. If this is faulty, the powder loss in the exhaust air will be above permissible limit.

Ghee kettle/ boilers are usually trouble free equipment. Ghee residue gets deposited on the inner surface, hence, the scrapers should be effective. At the end of the operation, surface needs proper cleaning. The scraper motors run under hot and humid condition, the lubrication level should be checked regularly. Steam pressure of 3.5 kg is must; the steam valve and traps should be in good condition. This section has lot of spilled fat around. This is hazardous; hence, floor and the operating platform should be kept clean. To avoid accidents, proper railings and guard be ensured around kettle.

For *Khoa* making, hemi-spherical jacketed kettle, conical vat, batch type Scraped Surface Heat Exchanger (SSHE) and the continuous type machines are discussed. *Khoa* is the most difficult product amongst indigenous products to prepare and handle. Main reason is the quality attributes in relation with the equipment employed for manufacturing. Batch type units have ability to maintain quality attribute but are not efficient systems. Hemi-spherical unit offers advantage of its cost but difficult in scraping the product from the heated surface, hence, fouling/burning are the issues. Conical process vat is better but with added cost. The batch SSHE gives difficulty in handling the product especially during unloading. Continuous units have advantage of higher capacity but are expensive. The sharpness of blades and cleanliness of surface are the points, which need greater attention.

Lassi making requires very simple and less expensive equipment. We need a process vat to pasteurize the standardized milk, keep it warm during growth of culture, and preserve it at low temperature. It has provisions for heating, cooling, and mixing, so that the set curd is converted into slurry form. All precautions are taken to avoid external contamination. This slurry is filled liked pasteurized fluid milk. The standardized and pasteurized milk is filled in cups after inoculation of culture. The curd setting is done in an incubator to keep milk warm. After the curd is formed, these cups are moved in cold room.

Paneer, chhana and casein are made in coagulation vat. After curdling primary whey is drained from the vat through strainer. Left over co-agulated product is chhana, if made from cow's milk. For paneer, buffalo milk is the best. The curdled mass is pressed for mating and secondary whey is removed through a press or under dead weight. The matted mass is cut into desired size and pieces are cooled in chilled water. Industrial casein is obtained by drying the curdled mass in a dryer. A dryer and grinder are the additional equipment needed for casein manufacture.

3.10 KEY WORDS

Concussion	:	Successive shock to the cream for clumping of fat.
Dasher	:	Scraper cum beater part revolves inside freezer chamber.
Freezer	:	It is a jacketed drum that carries refrigerant between two shells and mix in the central drum.
Overrun	:	Swelling of frozen mix by absorbing air
Vacuum	:	A negative pressure
Multi-state	:	More than one shell and tube exchanger
Calendria	:	Unit facilitates concentration of product
Cyclone	:	Induces centrifugal action on dried particle and separate them
Reconstitution	:	Remixing of dried product with water.
Denaturation	:	Permanently alteration of physical state of Protein
Double-jacket	:	Double walled construction for indirect heat transfer

3.12 SOME USEFUL BOOKS

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3.13 ANSWERS TO CHECK YOUR PROGRESS

Your answers should include the following points:

Check Your Progress 1

1) i. Used as holding/storage tank
   ii. Does the pasteurization of cream
   iii. For flavour development
2) i. Rotates cream for concussion/clumping of fat particle
   ii. Partial filling allows free fall of cream within the churn
   iii. Rotation at different speeds and directions

3) i. Vat for storage and curdling of milk

   ii. Provision for heating & drainage of whey

   iii. Equipment for expulsion of whey i.e. some pressing system

Check Your Progress 2

1) i. Provision for freezing the mix.

   ii. Provision for mixing & incorporation of air

   iii. Dismantling ability for quick cleaning of freezer

2) i. Shape of freezer

   ii. Manner of incorporating the air through rotor

   iii. Working of positive pumps for cream mix and ice-cream

3) i. Method of making softy i.e. without hardening

   ii. Difference between softy and ice cream

   iii. Description of hardening room, a deep freeze storage

Check Your Progress 3

1) i. Importance of low boiling temperature due to vacuum

   ii. Methods to create vacuum inside the pan

2) i. Container to hold product during concentration

   ii. Method of heating of the milk

   iii. Provision for removing vapours

3) i. Hoe drop-let are created through the atomizer

   ii. Drying chamber shape and size

   iii. Role of hot air in drying the atomized spray of concentrated milk

Check Your Progress 4

1) i. Role of double walled vessel to heat the product

   ii. Importance of scraper during heating

   iii. Heat control system to maintain temperature

2) i. Locally made equipments such as *Karahi*

   ii. Newly developed equipment at various R & D centres

Check Your Progress 5

1) i. purpose of heating, holding and cooling

   ii. To mix *Dahi* culture uniformly

2) i. Setting of curd in the vessel and cups

   ii. Purpose of agitator during *Lassi* making

   iii. Filling process for curd in cups and lassi in pouches

3) i. Equipment for holding and co-agulation such as vat

   ii. Provision for curd matting and pressing

UNIT 4 PREVENTIVE MAINTENANCE OF DAIRY PLANTS AND MACHINERIES

Structure

4.0 OBJECTIVES

After reading this unit, we should be able to specify:

- importance of preventive maintenance over break-down maintenance
- how an effective maintenance programme is prepared
- how to develop a lubrication schedule for a dairy plant
- to keep S.S.equipment and its surface in good condition.
- proper upkeep of all service pipe lines
- proper upkeep of gaskets used in the dairy equipment
- to keep dairy plant surrounding attractive and clean.

4.1 INTRODUCTION

In the Unit 3, we have learned various equipment required for the manufacture of milk products. An attempt was made to enrich with the operation of different equipment involved in the processing of most common milk products. Yet some special milk products could not be covered. However, the exposure given will give enough background knowledge to understand other equipment.

In this Unit, we will learn as to how to prolong life of equipment with proper planning. As we know the milk processing equipment are expensive, hence, need greater care to give best results. One way to maintain the equipment is to run as long as it works and repair it when it stops working. It is called “Breakdown Maintenance”. A scientific way of maintenance would be to do “Preventive Maintenance”(PM). As a thumb rule 6-12% of machine cost will be required for proper maintenance of machine every year.

In order to carry out PM programme, planning is done. We will learn different records and forms used to follow up schedules. These will act as guidelines for plant operators. These records also indicate the preparations for future planning. What are the needs of spares, oils and greases, etc., can be easily decided. Oiling and greasing is lifeline for individual machine. Every equipment has been recommended a lubrication schedule. For every dairy plant, daily, weekly, monthly and quarterly planning can be done. A lubrication route for the technician can be suggested and appropriate checks planned.

Dairy equipment are required to work under unfavorable conditions of high moisture, chemical environment, and temperature and pressure stresses. These conditions do affect the life of material with which the equipment is fabricated. Also the aesthetic look of equipment is need of such industry. It gives psychological impression to workers and the public for the conditions prevailing within the plant.

All the processing equipment need water, steam, refrigeration, air and electricity. These are supplied through appropriate pipelines and cables. Well-maintained service lines not only reduce the losses but also offer good look. Injuries and accidents can also be prevented with little care.

Most of equipment are provided with components made of rubbers. These are unavoidable, yet designed with utmost care. To maintain quality of product the upkeep of these components are a must. Readers will learn, as to how to take care of these parts and prolong their life.

Finally, even if each and every equipment is in order, the plant surrounding, landscape sanitation needs utmost care. Building maintenance is the first impression given to the visitors and public who pass by this unit. All walls, seepage, odour, well-trimmed grass and shrubs, well parked vehicles, etc. offer reputation of the dairy plant, as a first impression. A summary of civil maintenance will be discussed.

4.2 PRINCIPLES OF PREVENTIVE MAINTENANCE

Dairy equipment are expensive due to their specialized construction. Some of these are sophisticated and imported, hence, needs proper attention. In general, there is less appreciation to the maintenance activity, Preventive Maintenance (PM). Its importance is realized at the time of break down. A PM programme is a “procedure” designed to increase plant productivity, decrease maintenance, reduce operating cost, and to increase life of the equipment. It involves:

i. Routine external inspection

It means external viewing in terms of noise, vibration, heating or any sign of malfunctioning. This is noted and corrected, if any.

ii. Periodic internal check-up

It is done when the equipment is shut down at the end of operation. This is not a major repair action. One has to decide the duration after which this check up is done. In this adjustment of control instruments, replacement of lubricants, surface touch ups, etc. are carried out. During this check up, looking at the condition of equipment can make an idea on the possible major over-haul.

iii. Major repair/over-haul

Major repair is then planned preferably in the season when the equipment is not in use. Most of the major repairs are carried out during summer month when the milk handling capacity is less. For refrigeration section, the repairs are planned in winter months. Prior to shut down selection, procurement and stocking of spares must be ensured.

iv. Evaluation of equipment performance

A good engineering function is to carry out routine evaluation of each and every equipment. Due to normal operation, the efficiency of equipment reduces; this in turn affects the productivity. There are set procedures to calibrate and measure the flow capacities, heat transfer efficiency, product output, utilities consumption, etc. Again the frequency of such evaluation is a matter of experience and planning. The awareness on the part of management is also an important factor.

v. Record keeping is a part of PM procedure

We must maintain the work and breakdown record of the individual equipment. This will also indicate the repairs carried out. These records help in subsequent planning. These records are called “Log books”. Proper proforma is developed to indicate exact duration of running, various inputs utilized, efficiency and check parameters, records of repair and nature of complaint and the person who carried out the operation and repair. Periodic verification is carried out by superiors as a check and feedback.

If above procedures are adopted, the cost of maintenance will be less, equipment efficiency will improve, plant productivity will increase, accident possibilities are avoided, and finally the life of expensive equipment is extended.

Check Your Progress 1

1. What are the advantages of PM programme.

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2. What do you understand by the external inspection?

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3. What is the periodic internal check up?

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4. Distinguish between internal check up and major overhaul.

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4.3 DEVELOPMENT OF PLANT MAINTENANCE PROGRAMME

The very first step for development a PM programme is to record basic equipment data with appropriate classification. Recording should be simple but reliable. Usually card file system known to engineers could be adopted. This information can be required any time, hence, be readily available and preserved.

i. Administrative information

This should include equipment's name, its supplier, sanction order, date of purchase, date of commissioning, its cost, etc. This will be needed at later date.

ii. Technical details

Information such as serial No./model/style, capacity/speed/rating or size, recommendations of manufacturers for installation/operation/lubrication type and quantity/frequency of lubrication replacement and precautions, if any.

iii. Specific details

Mechanical, electrical and utilities required such as regular water, soft water, refrigerant, steam, fuel, electricity, compressed air, and quantity of effluent discharge, etc. It may also record the working pressure and temperatures, voltage, insulation and the inventory number given while entering in record to identify it.

iv. Identification of critical points

Now decide the list of specific points of each equipment to be inspected, and point/area, which should not be inspected. Obviously the point, which wears out fast or gets eroded/damages, needs regular inspection. The parts dangerous to the worker or likely to stop the plant operation should be avoided. Natural question comes in mind is as to what to inspect. The answer will be from the recommendations of equipment manufacturers manual. Then prepare a checklist in the order of priority. The idea is to give a written guideline to the person who will carry out inspection. This checklist helps to recall and assure proper execution instead of leaving on the memory of the individual.

v. Frequency of check-up/inspection

It is decided based on the condition of equipment. Older equipment needs frequent inspection as compared to newer ones. Similarly, there may be safety recommendations; hence, frequency of inspection will be increased. The extent of equipment used and the type of wear will also play role in deciding the frequency.

vi. Equipment performance

Finally, we should keep on evaluating the performance of equipment. Normally equipment performance will decrease with time. It will then increase cost of production. The report/remark of operator in the logbook will act as a feedback. Hence these comments be seen and compared with the manufacturer's recommendations. If it is felt that the performance in term of flow, capacity, quality, utility consumption etc. are above normal then actions are required.

Planning is then made as to when to shut down the equipment, what spare parts are needed and made available. It is also assessed as to whether skill is available within the maintenance group or help from outside will be needed. How much financial burden will be on the dairy and if the money is available. These are some of the crucial pints of judgment of efficient PM programme.

Check Your Progress 2

1. What should be recorded in equipment data sheet?

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2. How to decide the frequency of checkup?

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3. How performance of equipment is measured?

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4.4 GUIDELINES FOR EFFECTIVE LUBRICATION PROGRAMME

A guideline for proper lubrication of the equipment for any dairy plant can be prepared from the recommendations made in manuals of individual equipment. Manufacture of equipment does indicate the type, quantity and lubricant required. From various lubricants recommended, a common list of lubricants could be prepared to minimize diversified needs. Mark the points of lubrication on equipment and in the record book. Then, plan a schedule and route for technician. Evaluate the suitability of lubricant application method and change if required. Normally the cost of lubricants ranges from three to ten per cent of the machine cost.

With the information gathered, a “Route Map” could be prepared. This map covers all machines that can be lubricated in one shift or a day. This way daily, weekly, monthly, quarterly, semi-annual and annual lubrication chart are prepared. A Supervisor or Engineer needs to monitor these charts for effective lubrication programme.

4.5 CARE AND CLEANING OF S.S. SURFACE

Stainless steel (SS) is expensive metal and therefore, needs care. The frequency and the extent of cleaning depend on the extent of usage and the condition.

i. Cleaning of soft deposits

Ordinary deposits like dirt, grease are cleaned with mild detergent (soap) and washed and dried.

ii. Hard deposit

However, hard deposits need different treatments such as rubbing/buffing with polishing powder and SS brushes. Soft cloth or pads are used to shine the surface. Plastic sponge or fibrous brushes are also safe to use. Avoid iron wire brush (steel brush) and should never be used for rubbing. This brush will leave iron particles on S.S.surface, which will cause rust.

iii. Care with sanitizers

If Chlorides/Bromides/Iodides based chemicals used under acidic condition for long; there are greater chances of corrosion, hence should be washed properly.

iv. Care with salt solutions

These leave dirty spots on drying, hence should be washed after use. No paint or any coating is done on SS surface. Sometimes rust like appearance may occur which is due to some iron chip or part adhered on SS surface for cleaning. 5 to 15% caustic soda (hot or cold) is commonly used. Sometime 0.1 to 2.0% hot solutions of Sodium Metasilicate, tri-Sodium Hexa Metaphosphate, and Tetrasodium pyrophosphate, Sodium Tripolyphosphate are used as excellent removers.

Organic solvents are sometimes used to remove oil, grease, paints or hard deposits. These organic solvents are ether, alcohol, kerosene, gasoline, etc. Highly adherent ink, paint, etc. can be removed by butyl acetate. For very heavy water deposits, 15-20% nitric acid can be used with caution. Acid cleaning is followed by proper washing to remove any trace of acid.

Check Your Progress 3

1. What is Lubrication route map?

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2. How soft deposits are removed from S.S.Surface?

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3. How hard deposits are removed from S.S.surface?

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4. What specific preventive measures should be taken for S.S.Surface?

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4.6 CARE OF PIPES AND FITTINGS

You will find that a milk processing plant is full of various types of pipes. Various utilities like milk, water, air, steam, chilled water, hot water, refrigerant, electricity, etc. are transported/conveyed through these pipes. To regulate and control flow, different valves and fittings are provided within this piping network. This network must work without the loss of product, energy, corrosion, noise/vibration, leakage, etc. They should also offer ease in working and accident free operation.

i. Care of pipelines

Pipeline once laid, very little can be done. Only protection from moisture, oxygen and acidic environment should be done. If pipe is imbedded in soil, asphalt covering will protect it. Overhead pipes are kept dry and painted. Inside pipe corrosion can only be minimized if entry of oxygen could be reduced. Even dissolved oxygen in water affects it.

ii. Care during installation of pipes

Water hammering is due to movement of water with jerk. This is caused by sudden closure of opening of fluid and accumulation of residual fluid inside pipe. This obstructs the normal flow. Hence, pipelines are given proper slope and drainage point to avoid any accumulation. Pipe supports are adjusted to give proper slope to the pipes.

iii. Maintenance of pipes joints

Some pipes carry hot and cold fluid like steam and chilled water. The temperature change causes thermal expansion of metallic pipes. These pipes have provision to absorb expansion. Check for roller support and expansion joint/loops of pipes. Similarly, the leakages from pipe joint should never be allowed to continue. As soon as a leak is noticed, it should be plugged by replacing the gasket or correcting the alignment.

iv. Care with pipe insulation

You will note that certain pipes have insulation covered with Aluminum cover (cladding). Pipelines carry hot or cold fluid. Steam line is insulated with glass wool reinforced with chicken wire mesh and cladded for long life. Similarly, chilled and refrigerant lines are covered with thermocole insulation and cladded. We must ensure proper insulation if it is found removed or not in good condition.

v. Care of valves and fittings

These are integral part of pipeline system and of different types and shapes. Valves may develop leakage either from gland of the stem or valve seat may not close the valve fully. If gland is leaky, it is repacked and lightened. The stem threads of the valve should also be lubricated if the gland is dry. The valve seat is also cleaned and grounded if seating is not proper. In most of the cases valves are replaced. Fittings, i.e., the elbow, bends, unions, flanges, sockets, tee, cross, plug, etc. help in change of direction or connection to the equipments. Usually for any defect, these are replaced.

Check your Progress 4

1. How to avoid corrosion in M.S.pipes?

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2. Describe water hammering?

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3. How to prevent leakage from valves?

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4. List various fittings used in a dairy plant?

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4.7 MAINTENANCE OF RUBBER AND GASKETS

Dairy equipment have number of joints and connections requiring leak proof arrangement. Stationary equipment like plate type heat exchanger (chiller or pasteurizer) will have gaskets between individual plates. Moving or revolving equipment such as pump shaft or cream separator will require shaft seals, ‘O’ rings etc.

i. Characteristics of rubber and gaskets

All of these must be chemical resistant, as acid and alkali are used as detergents. These should be resilient to offer leak proof joints. These are of varied shapes and sizes to suit particular location or purpose for which these are used. They are required to work under high temperature and preserves, yet should not got damaged or contaminate the milk and milk products. It is, therefore, important that the rubber and gaskets should be of non-toxic material, should be heat resistant, durable and should not get damaged with the chemicals used for cleaning. The material of rubbers/gaskets is discussed in the unit 1.

ii. Care with gaskets and seals

These have comparatively shorter life, hence require utmost care. Since these are between joints or moving parts, over tightening be avoided. You will notice leakage from pasteurizer at the start. Slowly the leakage will reduce and may stop without tightening the plates. This is due to heat expansion taking place. If you notice leakage even after enough warming up, then plates may be tightened. Over tightening may permanently deform the gaskets. This will result in reduced thickness/gap between the plates. Ultimately, this will affect the capacity of pasteurizer. Similarly packing/’O’ ring in the union or joint should not be over tightened. Usually a good joint should be leak proof. This could be made leak proof by hand tightening and does not require a spanner. Gaskets between pipe joints get damaged while reassembling. This is due to poor alignment of pipelines. As discussed in the previous chapter, the alignment must be corrected before tightening the joint.

iii. Pump seals

These also need good care. Seals are expensive and require correct assembling. The carbon seal face rubs the stationary wall of the pump body, hence, the surface should be well polished and clean. While fixing the new gasket, old gasket and its particles should be removed with either a gasket remover or cleaned with the help of a sand paper.

4.8 DAIRY BUILDING SANITATION

A clean and well maintained dairy building and its surrounding promotes cleanliness habit amongst labour force and quality of its products. It automatically gives positive publicity and awareness to public for quality of products. A clean surrounding gives a sense of pride. A regular inspection by a team of decision makers helps in identifying the areas that need attention. It includes plant surrounding (Land Scape), condition of building, equipment and machinery, storage and warehousing, lighting, services/drains, hygiene of employees, toilets, dressing rooms, canteen, drinking water zone, insects/rodent infestation etc.

There are some indicators for clean and efficient dairy plant. These will reflect how good a plant is:

- Toilets and workers amenity rooms are the first in the list. A neat and clean, well ventilated, odourless toilets indicate the level of sanitary practices in the plant. Workers dressing room be well lighted, and should have enough space. Floors should be clean, shiny and throwing of trash behind doors or under the benches should be discouraged.
- Building premises should not harbour broken or discarded equipment/furniture. Trash and rubbish should not be thrown around that creates breeding ground for insects and rodents.
- Wall, floor and ceiling should remain clean, dry and well painted. In the dairy, light colour paints are used for walls and ceiling to reflect dirt or deposit for immediate attention. There should be proper lighting and water or dirt should not be accumulated at any point on the floor. Insects and flies should be adequately prevented entering in the milk-processing zone. Doors and window should have wire mesh covers and even air curtains should be provided. These air curtains produce thin layer of high-speed air to prevent entry of flies.
- Mould control is also important since the dairy plant uses lot of water, hence, more humidity causing moist environment. This is conducive to mould growth. To prevent this, all exposed surfaces should be kept dry. These are brushed, cleaned with soft detergent and a spray of 5000 ppm of sodium hypochloride is done. This destroys the mould spores. Further spray of quarternary ammonium compound is done to inhibit mould growth. This should be repeated every week.
- Insect and rodent control in general should be practiced. There should be no accumulation of dirt/ filth inside as well as outside. The garbage and wastes act as breeding place of insects. Good insecticide spray can be performed around the drains of dairy plant. For outdoor spray, Methoxychlor, Malathion or permitted insecticide with recommended strength could be used. All equipment is covered to avoid entry of these insects and pest. Rat proof building designs are made. Building openings are plugged. Height of the floor and steps are made such that rats cannot jump or climb. If at all, the rats find entry, they should be eliminated.

Check your Progress 5

1. What is external surveillance of Dairy Building?

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2. What specific points should be observed in dairy walls, floors & ceiling?

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3. How mould is controlled?

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4. How to prevent insects in a dairy plant?

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4.9 LET US SUM UP

The preventive maintenance programme is normally not well understood by the Plant Management. The simple reason is that people are tuned to manage the show after the breakdown. The advance planning necessitates preparations for enough spare parts and systematic maintenance. In the long run, the preventive maintenance programme improves the quality, as there are less number of breakdowns. It also reduces the manufacturing cost, hence, improves the productivity.

Often the management is interested to know how much will a dairy plant cost and then followed by how long will it take to pay for itself? The professionals engaged in maintenance programme may find these questions embarrassing but the advance planning pays subsequently. The main objective of preventive maintenance is to make timely repair and prevent unscheduled interruptions. This also helps in eliminating personnel hazards and extends the useful life of equipment. In this unit, procedures as to how preventive maintenance are done have been described in detail. The intelligent maintenance group will prepare a basic equipment data, which gives complete history of the newly acquired equipment, which will subsequently be useful at the time of disposal/ replacement of the equipment. Each manufacturer also gives the recommendations of critical points on each machine, which may form a proper schedule for maintenance. With regard to procedure, the external inspection, which is conducted almost daily gives, the first hand knowledge of the condition of equipment, dairy plant and its surroundings. Sometimes, a group of supervisory/

managerial staff takes a round and note down general aspects of the equipment, such as noise of equipment, rise in temperature, smoke or other emissions, operating parameters indicated through various gauges provided on equipment, lubricants level through indicators, general upkeep, moisture condensation, filth, etc. Any abnormality is immediately corrected and this will give way for internal inspection. For internal inspection, equipment has to be shut down, sometimes dismantle and, therefore, this aspect is done with appropriate planning. Internal inspection depends as to whether we have a standby arrangement or there is need to shut down the plant. Often a total shut down is planned for lean period.

A periodic re-evaluation of maintenance programme is done through assessment of plant performance. This assessment also helps in taking decision as to whether the equipment involves high maintenance cost or requires excessive down time. The repetitive failure suggests the plan for replacement of the equipment.

It easy to develop a lubrication schedule programme with the help of equipment data sheet. Individual equipment manufacturer describes the type of lubricant and the frequency of its replacement. With the help of equipment inventory, a total lubrication route map with schedule of lubrication – daily, weekly, monthly, quarterly, annually is prepared and a complete lubrication year chart can easily be prepared. Each oiler/lubricator performs his assigned tasks based on the recommendations from this very schedule.

For care and cleaning of stainless steel surfaces following practice should be implemented. Use only soft fibre brush or pads to mop the surface. Iron/ steel brushes should be avoided. Salt and minerals of water gets deposited on the surface, hence, some water conditioner/softener should be used. No metal part or weld spatter should remain adhered on the SS surface. It initiates the corrosion. Whenever acid cleaners are used, these should be neutralized with alkaline solution followed by hot water rinse. Avoid chlorides solution in higher strength. Equipment must be dried after water wash. There should be no stress on the equipment. Thermal/ mechanical stresses enhance corrosion. For any repair such as welding, same grade SS electrode should be used.

Maintenance of pipes and fittings is a big challenge. As soon one enters a dairy plant, the quality of maintenance can be judged by the upkeep of pipes, valves, insulation, supports, etc. All moving parts of valves such as stem threads, sleeve, lever, should be regularly lubricated. Dry stems lead leakage. Similarly stuffing boxes develop leak, hence, the packing should be replaced. Valve seat does not close the valve due to deposit. The seat is cleaned and reset. Most of the pipe joint get leakage, the gaskets should be replaced and pipe alignment is also corrected. Pipe insulation and aluminum cladding also gets damaged in due course. Regular repair/ renovation be carried out to avoid heat loss and ugly appearance. Steam traps of steam lines often indicate leakage. To avoid wastage of steam, the trap nozzle/ seat should be reset or cleaned.

Rubber packing and gaskets are the most vulnerable parts of the equipments. Every equipment uses them in one form or the others. Pasteurizer plates, manhole gaskets, special parts such as pump seals, separators, homogenizers, fillers, ‘O’ rings in flanges, unions are made from non-toxic rubbers. These get damaged due to wrong assembling of the equipment. Due care must be given to the alignment, proper tightening pressures, recommended temperatures and pressures.

The maintenance issues pertaining to individual equipment have been discussed along with their descriptions; hence, no separate discussion is required. The general upkeep and maintenance of dairy building and its surroundings is equally important. The first impression of any visitor is formed only by outside appearance. A routine surveillance / visit by decision makers should be made regularly to see for general cleaning. There should not be waste scattered around, general filth, water accumulation, dampness patches on walls, ceiling or floors and all lights and electrical gadgets be in order. There should be no water seepage or leakage from pipes or taps. Landscape around dairy is well maintained. Hedges, shrubs, lawns, pots etc. be well trimmed, sized, painted. All connection roads, streets or subways are made clean, properly marked. Doors, windows and other entry points should be provided with fly proof mesh, window pans/ glasses in good condition. Rodents and insects control through building design and subsequent provisions be ensured. Regular spray of pesticide and fungicide is carried out.

4.10 KEY WORDS

Preventive	:	Systematic planning prior to any breakdown
Installation	:	To erect or place equipment in position along with other necessary connections.
Water hammering	:	Vibration and noise due to water accumulation inside Pipeline
Land scape	:	Plantation and shaping of land
Rodent	:	Rats
Infestation	:	Contamination
Emission	:	Exhaust from machine
Dismantle	:	To open the equipment components
Stuffing box	:	Box between a rotating shaft and stationary body to prevent leakage
Alignment	:	Straightness of pipe or its components
Fittings	:	Various components of pipe such as socket, union, tee, elbow, bends, valves, etc.
Surveillance	:	External examination/visit
Dampness	:	Moist condition
Gadgets	:	Small equipment
Pesticide	:	Chemical to kill insects
Fungicide	:	Chemical to destroy mold

4.11 SOME USEFUL BOOKS

Ahmad Tufail. (1990). *Dairy Plant Engineering and Management*. Kitab Mahal Publisher

Anantakrishnan C.P. and Simha N.N. (1987). *Dairy Engineering, Technology and engineering of Dairy Plant operation* Laxmi Publications, Delhi

Newcomer, J.L. (1981). *Preventive Maintenance Manual for Dairy Industry*. Venus Trading Co., P.O.Box 17. ANAND 388 001. India.

4.12 ANSWERS TO CHECK YOUR PROGRESS EXERCISE

Your answer should include the following points:

Check Your Progress 1

1) i. Effect on productivity due to poor maintenance
   ii. Effect on increase in maintenance cost
   iii. Effect on life of machine

iv. Psychological effect on workers

2) i. What critical points should be observed during visit?

ii. How to judge the problem of any equipment

3) i. What critical points of the machine should be checked?

ii. When and at what interval inspection should be done?

4) i. The season of the year when major repair is done.

ii. State of equipment operation or in use

iii. Advance preparation needed before shut down of equipment

Check Your Progress 2

1) i. Type of information to be collected

ii. Technical specification details of equipment

iii. Operation details of equipment to be recorded

iv. Type and quantity of lubricant required and list of spares

2) i. Condition and functioning of equipment.

ii. Importance and duration of operation

3) i. Production efficiency of equipment

ii. The change in consumption of services/utilities

iii. Level of pollution being created by the equipment, if any

iv. Methods of determining various efficiency parameters.

Check Your Progress 3

1) i. Different points on equipment require lubrication.

ii. List of equipments and types of lubricants needed in a plant

iii. Schedule of lubrication to be carried out

2) i. Types of deposits on S.S.surface

ii. Name the detergents used for cleaning

iii. Discuss methods of cleaning

3) i. Types of hard deposits on surface of equipment.

ii. Name the detergents used for cleaning

iii. Discuss methods of cleaning

4) i. How to avoid rust like development?

ii. How to keep surface shining?

iii. Name special cleaning agents for removal of special deposits.

Check Your Progress 4

1) i. Causes of corrosion occurring in pipes

ii. Care and maintenance methods taken

iii. Installation care to be taken

2) i. How to keep walls/floor/ceiling clean

ii. What provisions should be made on doors/windows

3) i. How mold grows on equipment surface.

ii. Name various chemicals used to prevent mold

4) i. Provisions made to prevent entry of insects.

ii. Name various insecticides used from time to time to control insects.

UNIT 5 BASIC PRINCIPLES AND COMPONENTS OF REFRIGERATION SYSTEM

Structure

5.0 OBJECTIVES

After reading this unit, we should be able to:

- state the meaning of refrigeration and explain the basic principles and working of a vapour compression refrigerating machine
- describe the working function of different components of a refrigerating machine.
- enumerate the properties of refrigerants and specify the importance of selection of these in a refrigerating machine

5.1 INTRODUCTION

Refrigeration means production of cold, i.e., to bring and maintain the temperature of an enclosed space below that of its surroundings. This enclosed space can be a refrigerator cabin or deep freeze cabin or cold storage, etc. that is being used to store food/ dairy products at low temperature. It can also be an air-conditioned room or building where low temperature of air is required for human comfort. In this way, refrigeration has very wide applications such as food preservation in domestic as well as in food/dairy industries, ice-manufacturing, ice cream manufacturing, textile industries, air conditioning of buildings, transport air conditioning, liquidification of gases, research and medical applications, etc. We are familiar to these different uses of refrigeration. But we don't know about how the refrigeration/ cold is produced, how a refrigeration system works, what are the various components of refrigeration etc. We will learn about how and why of refrigeration in this unit.

The temperature of an enclosed space can be lowered down and maintained if we are able to extract heat energy by some means from the space. On extraction of heat energy, the temperature of the space lowers downs. Due to the temperature difference, heat will again flow itself from high temperature surrounding to low temperature space and tend to increase its temperature. To maintain the space cold, this heat inflow is also continuously required to be extracted by the refrigerating machine. However, providing insulation around the space can reduce this heat inflow. Thus the refrigeration load reduces by insulation.

In this way refrigeration means producing and maintaining cold in an enclosed space by extraction of heat energy and retarding the natural flow of heat from surroundings to the space by insulating it. Now the question is that how this heat energy can be extracted or what are the possible methods of production of refrigeration?

There are many methods as ice-refrigeration, air refrigeration, steam-jet refrigeration, vapour compression refrigeration, vapour absorption refrigeration, by using liquid gases, thermo-electric cooling, adiabatic demagnetization, etc. The most common and widely used method of refrigeration is Vapour-Compression Refrigeration System. In most of the dairy and food industries, this system is used. Here we will discuss it in detail.

5.2 BASIC PRINCIPLES OF VAPOUR COMPRESSION REFRIGERATION SYSTEM

In this system, we select any suitable gas/liquid matter (known as refrigerant) whose saturation point at atmospheric pressure is very low, i.e., less than the required low temperature of refrigeration. (Saturation point of a liquid is such value of temperature at which if heat energy is given to liquid at constant pressure, its temperature will not change but it will evaporate from liquid phase to vapour phase in the same way as water changes into steam at 100^{o}C at the atmospheric pressure). During evaporation, it will absorb its latent heat. If this latent heat is again taken back, it will again convert to liquid at same temperature as steam if cooled at 100^{0} C, changes into water. (Saturation point or temperature is different for different substances and directly proportional to pressure). Thus when such type of liquid is allowed to flow inside the bundle of tubes going through refrigerated space, it will start evaporating, absorbing its latent heat from the space around tubes and produce cooling. After absorbing latent heat the liquid will convert into vapours. For continuous cooling, these low pressure and low temperature vapours are again required to be converted to low-pressure low temperature liquid and made to flow through refrigerated space. For that these vapours are first compressed in a mechanical compressor to such a high pressure where the saturation point becomes more than the atmospheric temperature. Being at higher pressure and temperature, these vapours will reject their latent heat to the atmosphere and condense i.e. convert to liquid at the same high pressure in a condenser.

After condensation this high-pressure liquid is allowed to pass through an expansion valve and expand to low pressure. As soon as the pressure of refrigerant liquid is reduced, the saturation point also reduces to a very low value. So, some of the liquid evaporates, i.e., converts into vapour taking latent heat from the rest of the liquid and thus cooing it. Now this low pressure, low temperature partially vapourized liquid is again ready to flow through the refrigerated space to extract heat energy and produce cooling by fully evaporating in tubes.

In this way, the refrigerant is made to flow continuously through the closed system from one component to the other connected through pipes with the help of compressor as shown in flow diagram (fig.5.1). It absorbs heat while flowing through the evaporator coil in refrigerated space and rejects it to the atmosphere while flowing through the condenser. The condition of refrigerant keeps on changing while flowing through different components of the system and it continuously produces cooling in refrigerated space.

Fig. 5.1 Arrangement of Components of a Vapour Compression Refrigeration System

i. Tons of Refrigeration

The capacity of any refrigerating machine is given in terms of its capacity of cooling. And one ton refrigeration capacity of a machine means, it can convert one ton of water at 0^0C into ice at 0^0C in 24 hours. Mathematically, it means 50 Kcal/min, i.e., a refrigerating machine of 1 ton can extract 50 Kcal of heat from the refrigerated space in one minute.

ii. Co-efficient of Performance (C.O.P.)

C.O.P. of a refrigerating machine is the ratio of heat extraction rate to the power consumption. Higher C.O.P. means better is the performance of refrigerating machine.

In the coming pages we will study the construction of different components. How they work, how they perform different processes on refrigerant and in what sequence they are arranged.

Check Your Progress 1

1. How the refrigerant absorbs heat and produce cooling while flowing through an evaporator?

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2. How the pressure and temperature of refrigerant increases in a compressor?

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3. How the refrigerant rejects the heat absorbed in an evaporator?

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4. How the temperature of refrigerant reduces after passing through an expansion valve?

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5.3 MAJOR COMPONENTS OF VAPOUR COMPRESSION REFRIGERATION MACHINE

A vapour compression-refrigerating machine is comprised of the following components connected to each other through 'refrigerant flowing pipes'. Each component is performing different operation or process on the refrigerant. After undergoing these processes in different components, the refrigerant returns to its original state. Thus the refrigerant undergoes a cycle of processes and this cycle is called vapour compression cycle. The arrangement of components is also shown in Fig.5.2.

Fig. 5.2 Vapour Compression Refrigerant System

i. Refrigerant Compressor

It is mechanical equipment run by electric motor or petrol/diesel engine. Its main function is to suck the low pressure and low temperature vapours of refrigerant coming from evaporator and compresses it to high pressure, high temperature vapours. In this way, it also pumps the refrigerant through the system.

ii. Condenser

It is fitted after the compressor in the 'refrigerant flowing line'. It is a type of heat exchanger. It is simply a bundle of pipes surrounded by any cooling medium, i.e., air or water. High pressure high temperature vapours coming from compressor flows inside the pipes of condenser and loose their latent heat to surrounding air or water through the large area of wall of pipes. On loosing heat, the high-pressure refrigerant vapours convert to high-pressure liquid.

iii. Receiver

It is simply a metallic tank fitted after the condenser. It is generally used only in large refrigeration plants where quantity of refrigerant is large. Its purpose is only to store the high-pressure refrigerant liquid coming from condenser.

iv. Expansion Device

It is fitted after the receiver and before the evaporator or evaporating coil. Its construction is such that it allows the high pressure refrigerant to flow through a narrow opening which offers resistance to flow and maintains pressure differential. Thus its function is to decrease the pressure of refrigerant liquid while flowing from receiver to evaporator and allows it to expand. Sometimes it also controls the flow. As soon as the pressure is reduced, saturation point also lowers down than the refrigeration temperature required and liquid is partially vapourized cooling the rest of liquid from condenser temperature to evaporator temperature. This low temperature liquid then enters the evaporator.

v. Evaporator/Evaporating Coil

It is again a type of heat exchanger in the shape of a bundle of pipes. It is situated in the refrigerated space. The low pressure liquid from expansion valve flows through the bundle of pipes called evaporating coil and while evaporating absorbs its latent heat from the surrounding air of refrigerated space through the wall of pipes. As the evaporating coil produce cold it is also called cooling coil.

Check Your Progress 2

1. Which component forces the refrigerant to flow through the refrigeration system?

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2. Which component of the refrigeration system is fixed inside the cooling space?

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3. Name the component, which differentiates the high-pressure side and low pressure side of a refrigeration system.

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5.4 REFRIGERANT COMPRESSOR

As the name indicates, it is a machine used for compressing the refrigerant. It sucks the low-pressure vapours coming from evaporator, decrease their volume and thus increase the pressure. When pressure increases, the temperature will also increase naturally. So the compressor discharges the high pressure and high temperature refrigerant to the condenser.

There are different types of compressors depending on their shape and methods of compression used in vapour compression refrigeration system and are classified in many ways as follows:

(i) According to the method of compression

- Reciprocating compressors (piston reciprocating in the cylinder).
- Rotary compressor (cylindrical housing and eccentric roller arrangement)
- Centrifugal compressor (valve casing and impeller arrangement)

(ii) According to the number of stages

- Single stage compressor.
- Multi-stage compressor

(iii) According to the location of the Prime Mover

- Open-type compressor
- Hermetic compressor

The most commonly used compressors in the cold storage of a dairy plant are reciprocating type.

i. Reciprocating Compressor

Construction: Figure 5.3 shows the single stage, single acting reciprocating compressor. The main body of compressor is a metallic cylinder, on one end of which is attached to the cylinder head and the other end is attached with the crank casing. In the crank casing, crankshaft is fitted on bearings. On the crank bearing surface, the big end of connecting rod is fitted. The other end of connecting rod is joined with the piston through a pin called gudgeon pin. The piston is of round shape and of the diameter matching with inner diameter of cylinder. When the crankshaft is rotated by the electric motor, crank rotates and pushes and pulls the piston in the cylinder with the help of connecting rod. In this way, the piston moves back and forth i.e. reciprocate in the cylinder

The cylinder head on the other side consists of two hollow sections as suction and discharge manifolds. The suction and discharge manifold are connected to the cylinder head separately through suction and discharge valves. On the other side, these are connected to suction and discharge lines. Thus the main parts of a reciprocating compressor are as follows:

(a) Cylinder Block; (b) Cylinder Head; (c) Suction and Discharge Manifolds; (d) Suction and Discharge Valves; (e) Piston; (f) Connecting Rod; (g) Crank Shaft; (h) Crank Case; and (i) Main Bearings.

All the moving parts, i.e., piston in cylinder, connecting rod, gudgeon pin, crank, crank shaft, bearings, etc. are lubricated by some pressure lubrication system. The lubricating oil is filled in the crank casing up to the required level. While running and compressing the refrigerant, heat is also produced due to compression and friction in moving parts. Thus the compressor becomes hot and needs to be cooled.

Fig. 5.3 Reciprocating Compressor

Small capacity compressors are air-cooled and large capacity compressors are water-cooled. In air-cooled compressor, fins are provided on the outside of cylinder to increase the area of heat transfer and hence to increase the cooling of hot compressor. And in water-cooled compressor, water jackets are provided over the outer surface of cylinder. The crankshaft is connected to the electric motor shaft via a coupling. In this way, electric motor rotates the crankshaft and runs the compressor.

Working: When the compressor is run by an electrical motor or a diesel engine, its crank shaft rotates. With the rotation of crankshaft, piston continuously reciprocates in the cylinder. When the piston reaches to top end position in the cylinder, there is already some refrigerant vapour present at higher discharge pressure. As the piston moves downward, volume in the cylinder increases and pressure of refrigerant gas starts decreasing. On decrease of pressure, discharge valve is automatically closed. As the pressure further decreases below the level of suction pressure of vapours, suction valve opens and the refrigerant vapours from the evaporator starts flowing in the cylinder until the piston reaches to bottom end position. This stroke of piston is called suction stroke. After the suction stroke, piston moves upward, suction valve closes due to spring action and the volume of vapours sucked in suction stroke decreases and thus pressure increases. When pressure becomes greater than the discharge pressure on the other side of discharge valve, it opens automatically and the vapour refrigerant is discharged into the condenser through discharge line until the piston again comes to the top end position. This stroke is called discharge stroke. In this way the cycle of suction and discharge strokes is repeated continuously at high speed and compressor continuously sucks the low pressure vapours from evaporator and discharge it at high pressure in the condenser. In single stage compressor, the refrigerant vapours are directly compressed from evaporator pressure to condenser pressure in one stage.

In multi-stage compressors, there is more than one cylinder. The first stage cylinder discharge is given to the suction of next stage cylinder and so on. The pressure is raised from evaporator pressure to condenser pressure in two or more stages. Multistage compressor is generally used when the difference between the suction and discharge pressure is large.

ii. Centrifugal Compressor

The type of compressor as discussed before is positive displacement type compressor because it sucks and compresses the refrigerant vapours in the same way as a simple cycle pump does. But the centrifugal compressor does not act on this principle. What it does, it simply gives a rotary motion to the refrigerant vapour. Due to rotary motion, centrifugal force develops which push the refrigerant vapours outward and compresses. The detailed construction and working is given below. Its working is same as that of a water tullu pump used in our houses for lifting the water.

Construction: As shown in figure 5.4, there is a volute casing made of iron/steel. In the casing an impeller is fixed on the shaft rotating in casing. The shaft comes out at the center of casing and coupled to the shaft of electric motor via a coupling. The construction of impeller is a circular plate on which vanes are fixed. On the other side, the center part of casing is connected to suction line from where suction vapours come to casing.

Working: When the impeller is rotated at high speed by the motor, the vapours entrapped between vanes of impeller also rotates and directed outwards due to development of centrifugal force. In this way, refrigerant vapour rotates in the volute casing and also being pulled outwards with high velocity. As they get the discharge opening in the casing, move out of the casing and the high velocity converts into high pressure. Thus with continuous running of impeller, the vapour continuously enters the center part of impeller and move out from casing with high pressure.

Fig. 5.4 Centrifugal Compressor

ii. Hermetically Sealed Compressors

The reciprocating and centrifugal compressors as discussed above are also called as open type compressors because the compressor and motor are separate and joined by the rotating shaft. In open type compressor, there are always chances of leakage of refrigerant through any annual space between the shaft and stuffing box of compressor. To avoid this leakage and also to get some more benefit, the hermetically sealed compressors are designed. In this compressor, both the motor and compressor are closely fitted in an outer casing called hermetically sealed casing. It has cylindrical shaped compact body and only inlet and outlet pipes of refrigerant are welded to it. In this way, chances of leakage of refrigerant become nil. This type of compressor is also very less noisy and requires less space. The lubrication of moving parts of compressor is also very simple and effective because there are no chances of loss of lubricating oil due to leakage, fuming, etc. Due to all these advantages, hermetically sealed compressors are preferred and used in domestic refrigerator, room air conditioners (ACs), water coolers and other small capacity refrigerating units. The maintenance of this compressor is very less but once any maintenance is required, it cannot be done at the site itself and the system is first evacuated from refrigerant and then compressor is removed and sent to the company repair shop.

Check Your Progress 3

1. What is the principle of increasing pressure of refrigerant in a reciprocating compressor?

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2. What is the principle of increasing pressure of refrigerant in a centrifugal compressor?

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3. In which type of compressor the pressure increase is more?

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4. What is the main advantage of a hermetic compressor?

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5.5 CONDENSERS

As the name suggests, condensers are used for condensing of refrigerant vapours. In the refrigerant line it is fitted after the compressor. That means after compression in compressor, refrigerant vapours, which are at high pressure and high temperature, are passed through condenser. Condenser is actually a nest/bundle of tubes/pipes. Hot refrigerant vapours pass through this bundle of pipes and transfer their latent heat to the pipes. So, the pipes become hot and are simultaneously cooled from outside either by air or water. In this way, the heat energy of refrigerant vapours is ultimately transferred to cooling air or water through the wall of pipes. As the refrigerant vapours release their latent heat, the condensing commences i.e. vapours converts to liquid. It is exactly same as when steam is cooled and converted to water. Thus condenser converts high pressure and high temperature vapours into high-pressure liquid continuously. The refrigerant flow through condenser pipes due to pumping force of compressor. After coming out of the condenser the high pressure liquid refrigerant is either stored in the receiver or made to flow through pipe to reach to the expansion valve. Thus the working of condenser is very simple. It can be easily understood by looking at this example. We know that hot milk put in a glass will cool slowly as compared to if it is put in an open pan. The reason is that in case of pan the area of contact with air increases thus rate of heat released is more. In condenser also we do the same thing i.e. we increase area by flowing the vapours through large bundle of pipes.

Depending on the construction and cooling medium used, condensers are mainly classified in three types as mentioned below.

- Air-cooled condenser
- Water-cooled condenser
- Evaporative condenser

i. Air Cooled Condenser

In an air-cooled condenser atmospheric air takes away the latent heat of refrigerant flowing through bundle of condenser tubes and condenses the refrigerant. The tubes made of copper or steel are bend in the shape of 2 to 8 rows as shown in the figure 5.5. From one side refrigerant enters and on the other side it exits. Some fins of aluminum in the shape of wire or plate are also welded to the bundle of pipes to increase the heat transfer area. These fins help in cooling of refrigerant and tubes. The heat of refrigerant spreads in the tube and fins and easily transferred to surrounding air because of more area of contact with air. Sometimes a fan is also used which blows air over the condenser tube and fins. It increases the heat transfer rate in the same way as we try to cool the hot tea by blowing air by mouth over tea. When no fan is used, the condensers are called natural convection condenser and when fan is used these are called forced convection condensers. A natural convection air cooled condenser with wire shape fins is generally used in a domestic refrigerator. And a forced convection air-cooled condenser with plate shaped/ flat fins is generally used in a room air conditioner. Generally air-cooled condensers are not used in large plants due to their less heat transferring capacity.

Fig. 5.5 Air Cooled Condenser

ii. Water Cooled Condenser

In a water-cooled condenser water acts as a cooling medium i.e. it absorbs the latent heat of refrigerant passing through bundle of condenser tubes. The heat carrying capacity of water is more than that of air. So, water-cooled condensers are more effective. But these are costly because of additional water flowing systems. So, their use is restricted to large plants only. These condensers are commonly used in commercial and industrial refrigerating units.

In this type of condenser, the tube rows are arranged in an enclosed shell/cylinder as shown in figure 5.6. These are also called shell and tube condensers. Here the cooling water enters from one end of tube and flow inside the tube bundle/rows arranged in shell and exit from the other end. In the enclosed shell, there is one entrance for refrigerant vapours and exit for refrigerant liquid. So, when refrigerant enters the shell and flow outside the cooling water tubes in the shell, the latent heat of refrigerant vapours is transferred to the cooling water through the wall of tubes and it condenses i.e. convert into liquid and exit from the shell. The cooling water also becomes hot after taking heat of refrigerant and exit from the other end of tube bundle. For continuous working of condenser, the hot water coming out of condenser is required to be cooled again for reuse in condenser. Spraying or flowing through showers in the cooling tower or a spray pond separately cools this hot water. While spraying some of the water evaporates by absorbing latent heat from the rest of water and thus cooling it. That cooled water is again re-circulated to the condenser.

Fig. 5.6 Water Cooled Condenser

iii. Evaporative Condenser

In an evaporative condenser the bundle of condenser tubes is wetted from outside by water spray figure 5.7. This water when evaporates in the flow of atmospheric air, absorbs heat from the refrigerated vapor inside the tubes and condense it. You already know that in case of water-cooled condenser, water takes away the heat of refrigerant and becomes hot. Then spraying in air in a cooling tower cools this hot water. In cooling tower, water is cooled by evaporation. Now here in case of an evaporative condenser, the water is pumped from the sump to a spray header and sprayed through nozzles over the condenser tubes in which refrigerant vapours are flowing. The heat of refrigerant crosses the wall of tubes and transfers to the water that is wetting the outside surface of tubes. At the same time, a fan draws air from the bottom side of the condenser and discharge out of the top of condenser. Due to flow of air the water over the surface of tubes evaporates and cools the rest of water. The cooling by evaporation in air can be easily understood by an example. If you dip your hands in a bucket of water and shake in air, you will feel cooling effect on your hands. That is only because the water in your hands evaporate in air and absorb its latent heat from your hand thus making you feel coolness. When shaking of hand is more, more is the air flow over hands, more is evaporation and more is cooling effect.

Fig. 5.7 Evaporative Condenser

Check Your Progress 4

1. How the heat transfer from refrigerant to atmosphere is increased in a condenser?

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2. Which one is more effective amongst the air cooled and water cooled condensers and why?

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5.6 EXPANSION VALVES AND CONTROL DEVICES

Expansion Valve is a very important component in the refrigeration system. Its function is just opposite/reverse to the compressor. Compressor increases the pressure of refrigerant vapour by decreasing its volume while the expansion device decreases the pressure of refrigerant liquid by increasing its volume i.e. allowing it to expand. Actually compressor maintains high pressure of refrigerant liquid in the condenser and receiver. But the expansion valve prevents this high-pressure liquid refrigerant to go to the evaporator as it is. It allows the high pressure refrigerant liquid to flow through a very narrow section which offers resistance to flow and decrease its pressure. As pressure reduces after passing through narrow opening the saturation temperature also decrease to a lower temperature than that required in evaporator. Thus some of the low-pressure liquid evaporates at once cooling the rest of liquid up to that saturation temperature. Then this partially vaporized low-pressure liquid enters the evaporator. In some expansion device that narrow section is automatically adjustable according to the amount of cooling required around the evaporator in refrigerated space. In this way, the expansion device also acts as a control device. The commonly used types of expansion/control devices are as follows:-

- Capillary Tube
- Thermostatic Expansion Valve
- Low Pressure Side Float Valve

i. Capillary Tube

It is only an expansion device and not a control device. So, its function is only to reduce the high-pressure liquid refrigerant from condenser to low pressure liquid refrigerant before being fed to the evaporator. It is generally used in domestic refrigerator, drinking water cooler, room AC, etc. because of its simplicity and low cost. As shown in fig.5.8. It is simply a copper tube of very small internal diameter and of varying length depending on its application. The inside diameter is generally about 0.6mm to 2mm and length varies from 0.5m to 5m. Due to frictional resistance offered by small diameter tube, the pressure of refrigerant drops when it flows through it. Pressure drop is greater when length of tube is larger and diameter is smaller. Conversely if length is reduced or diameter is increased, pressure drop will be less. The diameter and length of the capillary tube are decided as per the system requirement

Fig 5.8 Capillary Tube

ii. Thermostatic Expansion Valve

It is an expansion device and control device both. It maintains constant temperature of refrigerant vapour going out of evaporator automatically. It consists of a needle valve and a seat, a metallic diaphragm or bellow, spring and an adjusting screw as shown in Fig. 5.9. Between the valve and valve seat a small passage/ orifice forms through which refrigerant flows. When valve rests on seat, the passage is closed and the flow is stopped. When valve moves away from seat, passage opens and refrigerant starts flowing. When valve further moves away, it create more wide passage allowing more refrigerant to flow through it. In addition to that, there is a feeler bulb, as shown in Fig. 5.9 attached to the outgoing tube of evaporator. The feeler bulb is connected to a capillary tube, which is further connected to the valve chamber over the diaphragm. In the feeler bulb the same liquid refrigerant is filled partially. Since feeler bulb is installed on the outgoing tube of evaporator, therefore, it will be at the same temperature as the temperature of refrigerant vapour going out of evaporator. When the cooling requirement increases in the refrigeration space or putting more items to cool in the refrigerator, temperature of outgoing refrigerant vapour will increase by absorbing more heat from more items thus increasing the temperature in feeler bulb. Due to increase in the temperature in feeler bulb, pressure will also increase which will push the diaphragm through capillary tube. The diaphragm will move the valve away from valve seat and allow more refrigerant to flow in evaporator to meet the increased cooling requirement. On the other hand, when cooling requirement is less, less will be the heat absorbed by refrigerant in evaporator and less will be temperature of outgoing refrigerant vapour. Due to that temperature of refrigerant in the feeler bulb will also decrease thus decreasing the pressure on diaphragm. On decrease in pressure, diaphragm will move by spring action and tend to set the value near to valve seat. In this way less refrigerant liquid will enter the evaporator according to less cooling requirement.

The thermostatic expansion valve keeps the superheating of refrigerant vapour, coming out of evaporator, at a constant level and controls the quantity of refrigerant liquid going to evaporator coil according to the cooling requirement in refrigerated space.

Fig. 5.9 Thermostatic Expansion Valve

iii. Low side Float Valve

It is also both an expansion and control device. As its name suggests, it is a type of float valve and as the float is situated on the low-pressure side, it is called low-side float valve. The working of this float valve is exactly same as that of a ball valve fitted in water tank at our homes for maintaining a fix level of water in tank. Like floating ball, there is a float, which floats on the liquid refrigerant level in the valve body. The high pressure liquid refrigerant from the receiver and high pressure pipe enters the float valve body through a needle valve and on passing through this valve becomes low pressure liquid. This low pressure liquid refrigerant fill the space in valve body and then evaporating coils connected to valve body. The float is connected to needle through an arm. When the low pressure liquid refrigerant level falls down due to more evaporation in evaporating coil, the float also comes down and moves the needle away from valve thus allowing more refrigerant to meet the requirement. On the other hand when cooling requirement lowers, the evaporation also lowers and so liquid refrigerant level increases in the evaporator. Due to that the liquid level also increases in the connected valve body, thus lifting the float. The float in turn pushes the needle in the valve seat and reduces the inflow of refrigerant. The major advantage of the low-side float valve is that it maintains a constant liquid level in the evaporator under all loading conditions regardless of the evaporator pressure and temperature.

Fig. 5.10 Low Side Float Valve

Check Your Progress 5

1. Which parameter is tried to keep constant in:
   i) Thermostatic expansion valve?
   ii) Low side float valve?

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2. What is the difference between an expansion device and expansion cum control device?

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5.7 EVAPORATORS

It is the only component of refrigeration system, which is fitted inside the refrigerated space. You must have seen the evaporator coil wrapped around the freezer box/ icebox in a domestic refrigerator or fitted inside a cold room. All other components i.e. compressor, condenser and capillary etc. are fitted outside the refrigerator cabinet on the backside. An evaporator or evaporator coil is a bundle of copper/ steel tubes fitted in the refrigerated space. One end of the coil is connected to expansion valve and the other is connected to suction side of compressor. The refrigerant liquid after expanding in the expansion valve/control valve situated just outside the refrigerated space enters the evaporator coil. After expansion the temperature of refrigerant liquid is very low. As it flows through the evaporator coil, it absorbs heat from the surrounded refrigerated space outside the coil through the wall of tubes and get evaporated i.e. convert into vapours. Absorbing more heat in the evaporator may further superheat these vapours. These vapours are at very low pressure and temperature and are continuously sucked/pulled by the compressor on the other end. With continuous flow of refrigerant through evaporator the air or water, whatever is surrounding the evaporator tubes gets cooled and it further cools all the items placed there. In this way the working of an evaporator is just opposite to that of the condenser i.e. here the refrigerant vapours absorb heat from the air/ water surrounding the evaporator coil in place of releasing heat as in the condenser. Therefore, being a heat exchanger, the construction of evaporators is also same as that of condensers. The evaporators may be of natural convection type or forced convection type depending on the airflow naturally over evaporating coil or flows forcefully by a blower. However, depending on the manner the refrigerant liquid is fed to the evaporator coil, evaporators are of two types (i) Dry Expansion Evaporator (ii) Flooded Evaporator.

i. Dry Expansion Evaporator

Actually these types of evaporators are not completely dry. But the dry word is said because these are usually partially filled with liquid refrigerant and other part of evaporator coil is exposed to vapour only. It is because the amount of refrigerant liquid fed to coil is less as compared to the space available in the coil. Due to less amount of refrigerant, the temperature of outgoing refrigerant vapours is more than the saturation temperature at evaporator pressure i.e. vapours gets superheated. Dry expansion evaporators Fig. 5.11 are generally used in small units with less cooling requirements. The advantage of these evaporators is that the quantity of refrigerant filled is less and so these are cheap. But the heat transfer is poor because only vapours are in touch with most of the inside surface of evaporator tubes.

Fig. 5.11 Dry Expansion Evaporator

ii. Flooded Evaporators

Flooded evaporators are those in which evaporator coil is fully filled with liquid refrigerant. There is an accumulator to which the evaporation coil is joined as shown in Figure 5.12. The accumulator is joined with the low side float valve chamber. A fixed level of liquid refrigerant is automatically maintained in the accumulator and flood chamber by the low side control valve. At this level of liquid refrigerant in the accumulator, the evaporator coil is almost filled with liquid refrigerant. As only liquid is in touch with almost all the inside surface of evaporator tubes, heat transfer from the surrounding of evaporator to the refrigerant liquid through wall of tubes is more. So, the cooling produced by flooded evaporator is more as compared to dry expansion evaporator but the quantity of refrigerant used is more so these are costly. On absorbing heat some liquid convert to vapours. These vapours lift up in the form of bubbles and accumulate at the top of accumulator above the level of liquid. Simultaneously more liquid comes in the evaporator coil from accumulator. As level of liquid falls down in accumulator more liquid comes from low side float control valve. The top of accumulator is connected to suction line of compressor through which vapours are sucked by compressor.

Fig. 5.12 Flooded Evaporator

Check Your Progress 6

1. What is the difference between dry expansion evaporator and flooded evaporator?

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2. What is the main advantage and disadvantage of a flooded evaporator?

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5.8 SELECTION OF REFRIGERANT

There are various desirable properties of refrigerants, which decide their suitability for use in a vapour compression-refrigerating machine. Depending on the requirement and looking at the properties of various refrigerants available, the most suitable refrigerant is selected for a particular purpose. The prime consideration is of the boiling temperature of refrigerant at atmospheric pressure. It should be below the required low temperature in a particular application. But also it should not be too low. Some other thermodynamic and physical properties are also important which decide the efficient working of refrigerant in refrigerating machine. For example, freezing temperature of refrigerant should be far below than the operating temperatures. Latent heat should be high (Latent heat is the amount of heat absorbed by one kg of refrigerant liquid during evaporation or amount of heat given away by 1 kg of refrigerant vapour during condensation). At atmospheric temperature, condensation pressure should not be too high. The volume per unit mass of refrigerant should be low to reduce the power consumption of compressor. Thermal conductivity should be high i.e. it should easily transfer heat.

All the properties mentioned above decide only the working efficiency of a refrigerant. However, there are certain other properties also which sometimes effect the selection of a refrigerant. A refrigerant should be safe in use. It should be chemically inert, non-flammable, non-explosive, and non-toxic. It should not have bad effect on food items in case of leakage. It should be non-corrosive. It should not have depleting effect on the ozone layer in atmosphere i.e. it should be environmentally safe. It should be cheap and easily available.

The most suitable refrigerant in a dairy plant is generally 'ammonia' due to its favorable thermodynamic and physical properties. Its boiling point is -77.8^{o}C. Due to large latent heat, it has a high heat carrying capacity. Moreover, it is cheap and easily available. It is also environmentally safe. But major disadvantage is that it is toxic, irritating, food destroying, sometimes flammable. But in a large industrial dairy plant, the necessary safety measures are taken to deal with ammonia refrigerant. In small units, Freon and hydrocarbon are used.

Check Your Progress 7

1. What is the first main consideration in the selection of a refrigerant for a particular refrigeration plant?

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2. Why ammonia is most suitable refrigerant in a dairy plant ?

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5.9 LET US SUM UP

Refrigeration means production of low temperature. Low temperature may be required in various types of applications such as food preservation, air conditioning, process industries, liquidification of gases, etc. Low temperature is commonly produced with the help of a vapour compression refrigeration machine. The machine has four major components as compressor, condenser, expansion valve and evaporator connected to each other through pipes. Some refrigerant gas is filled/ charged in the refrigerating machine. All the four components carry out four different processes on the refrigerant, which continuously flow through the closed refrigeration system. Compressor compresses the refrigerant gas to high pressure and high temperature. Condenser cools and condenses the high-pressure gas to high-pressure refrigerant liquid. Expansion valve expands the high-pressure liquid to low pressure low temperature liquid. And finally in the evaporator this low temperature liquid evaporates and absorbs heat from surrounding and thus produce cooling. After evaporation in evaporator, compressor again sucks the low-pressure refrigerant vapours and the refrigeration cycle continues.

There are different types of each component of a refrigerating machine and different types of refrigerant gases available. Selection of a particular type of each is made depending on the requirement.

5.10 KEY WORDS

Refrigerant : Any gas which takes part in the refrigeration i.e. which works as a working medium in a Refrigeration Plant.

Saturation Point : It is that condition of pressure and temperature of a substance at which if heat is given to its liquid state, it changes into vapour state or if heat is taken away from vapour, it changes to liquid without any change in its temperature and pressure.

Sensible Heat : If there is change in temperature of a substance by absorbing or releasing heat energy that heat is called sensible heat.

Latent Heat : If there is no change in temperature rather there is change in state of a substance by absorbing or releasing heat energy, it is called latent heat. For example, a liquid at saturation point absorbs latent heat and evaporates into vapours at same temperature and vapours at saturation point, if release the latent heat, condense to liquid.

Super-heating : On absorbing latent heat, saturated liquid changes to saturated vapours. When further heat is given to these saturated vapours, the temperature starts increasing and the process is called superheating.

Evaporation : It is the process of changing of saturated liquid (Liquid at saturation point) to saturated vapour by absorbing latent heat.

Condensation : It is the process of changing of saturated vapours (vapours at saturation point) to saturated liquid by giving away latent heat.

Compression : It is a process of increase in pressure of a gas or vapours by decrease in their volume.

Expansion : It is the process of decrease in pressure of a gas or vapours by increase in their volume.

5.11 SOME USEFUL BOOKS

Arrora S.C. and Domkundwar S. (1993). *Refrigeration and Air Conditioning*, Dhanapat Rai & Sons, Nai sarak, Delhi 110 006.

Arrora C.P. (1981). *Refrigeration and Air Conditioning*, Tata McGaw Hill Publishing Company, New Delhi

Ballaney P.L., (1976). *Refrigeration and Air Conditioning*, Khanna Publishers, New Delhi.

Khurmi R.S. and Gupta J.K. (1987). *Refrigeration and Air Conditioning*, Eurasia Publishing House (P) limited Ram Nagar, New Delhi 110 055

5.12 ANSWERS TO CHECK YOUR PROGRESS

Your answers should include the following points:

Check Your Progress 1

1) i. Condition of refrigerant in the evaporator is partially vapourized liquid at low temperature than that of surroundings of tubes.

   ii. Heat always flows from high temperature to low temperature i.e. from surrounding air to the refrigerant.

   iii. On loosing heat, the surrounding air or water becomes cold and on absorbing heat, the partially vapourized refrigerant becomes fully vapourized and superheated.

2) i. Compressor reduces the volume of refrigerant.

   ii. On decrease of volume, pressure and temperature of refrigerant increases.

3) i. On absorbing heat in evaporator, refrigerant liquid converts into vapours.

   ii. In compressor, temperature of vapours increases with pressure and becomes higher than the atmospheric temperature.

   iii. Being at higher temperature than atmospheric, these vapours reject heat and again convert to liquid state in the condenser.

4) i. On passing through expansion valve, pressure of refrigerant reduces.

   ii. Due to reduction in pressure, saturation temperature also reduces.

   iii. As the actual temperature of refrigerant liquid is higher than its saturation point, some of the refrigerant liquid starts evaporating by absorbing latent heat from rest of liquid until the actual temperature of refrigerant becomes equal to its saturation temperature.

Check Your Progress 2

1. i. Compressor
2. ii. Evaporator
3. iii. Compressor and Expansion valve

Check Your Progress 3

1) i. With the rotation of motor, a piston reciprocates in the cylinder, alternately undergoing suction and discharge stroke.

   ii. During suction stroke of piston, refrigerant vapours enter the cylinder through suction valve. Discharge valve remains closed.

   iii. During discharge stroke, refrigerant vapours are pushed against the higher pressure in the condenser through discharge valve. Suction valve remains closed.

2) i. Refrigerant vapours are rotated at high velocity by the impeller.

ii. Due to centrifugal force developed in rotating vapours, these are pushed outwards.

iii. Vapours come out of discharge opening with high velocity. This high velocity then converts into pressure in the condenser.

3) i. Reciprocating compressor.

4) i. Chances of leakage of refrigerant to atmosphere become nil.

Check Your Progress 4

1) i. By increasing heat transferring area either by increasing the length of tubes or by providing fins.

ii. By using forced flow of air or water over the condensing tubes.

2) i. Water-cooled condenser because of higher heats carrying capacity of water.

Check Your Progress 5

1) i. Superheating of vapours in evaporator

ii. Liquid refrigerant level in the evaporator.

2) i. Expansion valve only decreases the pressure of refrigerant.

ii. Expansion/control valve decreases the pressure and also controls the quantity of refrigerant flowing to evaporator.

Check Your Progress 6

1) i. Dry expansion evaporator is filled partially with liquid refrigerant and partially with vapour refrigerant.

ii. Flooded evaporator is filled almost completely with the liquid refrigerant.

2) i. Advantage is that heat transfer is better.

ii. Disadvantage is that, quantity of refrigerant is more and so these are costly.

Check Your Progress 7

1) i. Boiling point or saturation point should be lower than the required low temperature.

2) i. Heat carrying capacity is more due to large latent heat.

ii. Environmentally safe.

iii. Cheap and easily available.

UNIT 6 COOLING SYSTEMS FOR MILK AND MILK PRODUCTS

Structure

6.0 OBJECTIVES

After reading this unit, we should be able to:

- apply the use of refrigeration in dairy industry
- specify the various purposes of refrigeration of milk & milk products
- know about different types of refrigeration equipment used in dairy industry.

6.1 INTRODUCTION

In the last unit we have acquired the basic knowledge about producing refrigeration and the general construction and working of a refrigerating machine and various types of its components. In this unit, we will concentrate on the use of refrigeration in dairy industry. Now the possible question which may arise in our mind is that why the refrigeration or cooling is required for milk or milk products? When and where the refrigeration is applied on dairy products? How much and how long the cooling is required? And finally how the required refrigeration is achieved efficiently or what are the actual methods and actual design of equipment used in the refrigeration of dairy products? We will try to find answers to all such type of questions, so that we may become familiar with type of cooling methods used for milk and milk products at various stages of production, processing and consumption.

First question is that why refrigeration/ cooling is required for milk and milk products. We know that cooling of milk is done to retard the bacterial growth and prevent it from spoiling. Because as soon as the milk is produced bacterial growth starts in it. If it is allowed to remain at normal temperature as 15^{o}C to 35^{o}C for a long time, bacterial growth will continue. Now all the milk produced at dairy farms cannot be used at once and it needs to be distributed to different places, needs to be transported to small or large dairy industries for processing and making of milk products. Thus after production milk is required to be chilled upto 4^{o}C or less until, it is distributed and consumed or processed to check the bacterial growth, avoid the spoilage and preserve the quality as it is produced. Even after processing and packaging, the milk and milk products are required to be chilled, i.e. to be kept at a low temperature until these are consumed.

Now we know that refrigeration is very much essential for preservation of milk and milk products by storing at a low temperature between the production and consumption stages. So, one application or use of refrigeration is to increase the storage life of milk and milk products. The other application is that refrigeration may also be required in carrying out some operations on milk like milk pasteurization, butter making, ice-cream manufacturing, freezing/ hardening, etc. Milk cannot be pasteurized without cooling after keeping at a higher temperature, butter cannot be formed without churning the cream at lower temperature and ice cream cannot be manufactured without cooling and freezing and hardening it. So, in the nutshell we can say that refrigeration is an integral part of dairy industry and is needed mainly for:

- Milk chilling at production farm
- Storage of milk and milk products before consumption
- Processing and manufacturing of milk and milk products like ice-cream

One more aspect to the use of a refrigeration unit in dairy industry is that it can be used either directly or indirectly. In the direct cooling we install the evaporating coil of refrigeration unit at the place where cooling is required for milk and milk products. But in the indirect cooling, an ice bank i.e. a chilled water tank/ice bank is installed separately. In this ice-bank tank the evaporating coils of the refrigeration unit are fitted and around it water is filled. When refrigeration unit operates, the evaporating coil absorbs heat of water and make it chilled water. Then this chilled water is supplied to the cooling equipment and it cools the milk or milk products.

6.2 FARM MILK COOLERS

Milk chilling means cooling the milk below 4°C at production and collection centers so that to preserve the quality as produced until it is transported and distributed. The equipment used for initial chilling/ cooling of milk depends on variety of variable factors such as quantity of milk, availability of chilling facilities etc. In general the milk chilling at production farm or collection centre can be done in two ways i.e.

1. Can cooling
2. Bulk milk cooling

These methods are described in detail as follows:

i. Can Cooling

In this method, the milk is stored in cans after milking at production centre. The milk remains in cans until it is used or processed. These cans are cooled by any of the cooling methods as described below:

a) Use of ice-chambered non-insulated cans

The cans are of special type in which the milk is filled in the inside chamber and ice cubes are filled in the outside chamber. The temperature of ice is 0°C, less than that of milk. So, it absorbs heat of milk through the wall of inside chamber and cools it. While cooling the milk the ice melts and changes into water. As the cans are non-insulated to the atmosphere, the cooling loss to the atmosphere is high. The method requires supply of ice and large space for storage of cans. This method is not so commonly used because wastage of ice is more.

b) Immersion of milk cans in chilled water insulated tank

In this method, there is an insulated metallic tank as shown in fig.6.1. Insulated means, any type of insulating material is applied on the outside surface of tank. The insulated material reduces to a large extent the transfer of heat from surrounding to the cold tank and thus reduces considerable cooling loss to the atmosphere.

The tank is filled with chilled water and the cans are placed in water such that the water level remains at the neck of cans. The chilled water will chill the milk by absorbing heat of milk in cans through the wall of can. The chilled water can be available naturally in cold regions or the chilled water may be formed by putting ice blocks in water. Ice blocks can be purchased from market. Here the rate of cooling is slow. But the method avoids the use of separate refrigeration machine/equipment.

Fig. 6.1 Immersion of Cans in Chilled Water Insulated Tank

c) Immersion of milk cans in a chilled water insulated tank with separate refrigeration unit

This method is generally used in large dairy farms where quantity of milk produced is large. In this method, there is an insulated tank, which is filled with water as shown in fig.6.2. At the top of tank a small refrigeration unit is placed consisting of a hermetic compressor and an air-cooled condenser. The evaporator coil connected to the condenser via a capillary tube is dipped in water in the tank. The milk cans are placed in the water within tank.

When refrigeration unit runs, the evaporating coil cools the water. An agitator fitted in the tank circulates the chilled water around the cans. The agitator increases the heat transfer and decreases the chilling time. In this way, the milk placed in the cans is chilled. This is a very efficient method. But it is also costly due to power consumption by the refrigeration unit.

Fig 6.2 Immersion of Cans in Chilled Water Tank with Separate Condensing Unit

d) Immersion cooler with a refrigerating unit

It is the most compact, fast and effective method of milk can cooling. In this method, there is a small capacity hermetic compressor and air-cooled condensing unit (figure 6.3). The condenser is connected to a specially designed evaporator through a capillary tube. The evaporator is a double wall hollow cylinder, which can be directly dipped in the milk can. Inside the cylindrical jacket between the two walls, the refrigerant expands and evaporates and absorbs heat from the milk through walls of evaporator. An agitator fixed in the hollow space of cylindrical evaporator increases the speed of cooling. A thermostatic control switch automatically switches off the compressor when milk is chilled up to required temperature. In this way, immersion cooler is easy to operate and works automatically. It is generally preferred where the power is easily available. This type of cooler is very convenient for use in small farms having power supply facility as it does not need water for cooling, easy to operate and maintain and is automatic in operation.

Fig 6.3 Immersion Cooler

e) Surface Coolers

These are generally used when production of milk is high in individual farms or when collection center is established to collect the milk produced by small farmers. In this system, as shown in fig.6.4 a tubular type of cooler is mounted on a stand at a sufficient height such that below it a milk-can can be placed. Above the tubular cooler there is a milk distribution trough and below is the collection trough. The tubular cooler is cooled up by flowing chilled water through the tubes or by directly using it as evaporator coil of a refrigeration unit. When milk falls from distribution trough over the surface of tubes it gets chilled and collected in the collection trough. From the collection trough, it is directly taken in a milk can placed below. In this way, it is a continuous process and as the unit runs, milk is continuously chilled.

ii. Bulk Milk Cooling

When the production of milk at one time of milking in a dairy farm is in thousands of litres, the bulk milk coolers can be used. These are easy to clean and wash and remain hygienic in use. The construction of bulk milk chiller is shown in fig.6.5. There is a huge size bulk milk tank fabricated of alloy steel. This tank is permanently

Fig. 6.4 Surface Cooler

fixed in an outer metallic tank insulated from outside. In the bottom space left between inner milk tank and outer metallic tank, the evaporator coils made of copper are placed. A thermostatic expansion valve is generally used with the evaporating coils. The compressor and condensing unit is placed nearby at a suitable place. Water is filled in all the space left between milk tank and outer tank. When the compressor runs, the refrigerant flowing through evaporating coil evaporates and absorbs heat from the surrounding water. Thus the water gets chilled and even some ice formation takes place around the coil. This chilled water is spread over the outer surface of milk tank top by chilled water pump for better heat transfer. In this way, the chilled water circulates around the inner milk tank and cools the milk filled in. At the top of milk tank, an agitator motor is fixed which rotates the agitator in milk through an elongated steel shaft. The agitator is also made of steel. When agitator rotates, it circulates the milk along the inner surface of tank and increase heat transfer. The refrigeration unit works automatically and stops when there is sufficient quantity of ice and chilled water outside the milk tank. Due to ice, cooling of milk continues even when refrigeration unit i.e. compressor is not running.

Fig. 6.5 Bulk Milk Cooler

Check Your Progress 1

1. What is the main difference between in-can coolers & surface coolers?
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2. What is the benefit of using bulk-milk coolers in place of in-can cooling?
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3. For what purpose the cooling can or tank is insulated?
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4. For what purpose the agitator is used in bulk milk cooler?
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5. Why water is used as a cooling medium in farm milk coolers?
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6.3 CHILLED WATER SUPPLY SYSTEM IN DAIRY PLANT

As already discussed, the cooling of milk by using chilled water is an indirect method of cooling. In this method first the supply water is stored in a large tank where it is cooled/ chilled by a separate refrigerating unit. Then this chilled water is supplied through pipes to the various milk cooling equipment in the plant. This method is very commonly used in most of the dairy plants due to its various advantages over direct cooling system. In a dairy plant, large quantity of milk is handled/processed. The milk is collected from the milk supply tankers at a particular time. All this milk cannot be processed at a time and needs to be kept in chilled condition to preserve its quality. Moreover, the cooling of milk/milk-products may be required in some other processes also. Thus, the cooling requirement is not continuous or steady. And any time any amount of cooling may be required. For this type of requirement, it is generally not feasible to install refrigeration unit at each cooling point. On the other hand, the indirect cooling suits very much due to its various advantages as given below:

1. As the volume of chilled water being less than the volume of refrigerant vapours, the piping cost is very less in case of indirect cooling.
2. Simply controlling the flow of chilled water can easily control the amount of cooling.
3. A small size refrigeration plant is needed for indirect cooling. This small unit may run continuously and keep the water in chilled condition in the insulated tank. On continuous running, there may be partially freezing of water in the tank resulting in the formation of ice. In the peak hour of cooling load and also in case of power failure, the required amount of chilled water can be made available from the ice/chilled water tank to meet the cooling load.
4. In case of any leakage in cooling pipes, only chilled water will come in contact with milk and the toxic refrigerant if any will remain away from milk/milk-products. Thus it is also safe to use indirect cooling.

i. Chilled Water Tank/ Ice-Bank Unit

The chilled water tank is also called ice-bank unit because when there is no supply of chilled water to dairy plant and refrigeration unit is continuously cooling the water, ice-formation will take place. This ice works as a bank of chilled water, which can be supplied during the peak of cooling requirement. As shown in figure 6.6 it is a metallic tank whose outside surfaces are insulated with glass wool and brick wall. The tank contains a network of cooling coils through which the refrigerant flows. The cooling coil/evaporator coil is of flooded type and remain filled with refrigerant liquid generally ammonia. The liquid ammonia from the receiver of refrigeration plant enters the coil through a low side float valve. The low side float valve reduces the pressure and temperature of liquid ammonia and maintains a constant level of it in the cooling coil. The liquid ammonia absorbs heat and cools the water outside the pipe in the tank. On absorbing heat the liquid ammonia evaporates and its vapours lift up and accumulates in the accumulator above the coils. From the accumulator, these vapours are sucked by compressor through an insulated pipe and again compressed and sent to condenser. A float valve keeps the water level constant in the tank. An agitator installed on one end of tank keeps the

Fig. 6.6 Chilled Water Supply System/Ice-Bank Unit

water flowing over cooling coil for better heat transfer. Outside the tank on one side, the cooling water pumps are installed which take water from the bottom of tank through their suction pipes and supply it to the dairy plant through the network of chilled water pipes. After fulfilling the cooling requirement, the chilled water becomes normal water and is again supplied to the chilled water tank from the top near the agitator.

Check Your Progress 2

1. Why the chilled water tank is also called ice-bank unit?

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2. Which type of evaporating coil is used in chilled water tank?

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3. What are the benefits of using chilled water plant/ice-bank unit in a dairy plant?

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6.4 REFRIGERATED STORAGE FOR MILK AND MILK PRODUCTS

In every household, milk is used and stored in a cold place for a day or two. In the same way, the other milk products, *i.e. ghee,* butter, *lassi*, *paneer*, etc. are also needed to store at a lower temperature. The milk and all other dairy products processed or manufactured in a dairy industry needs to be stored at a lower temperature until these are distributed and consumed. Therefore, different types of storage equipment for dairy products are in use depending on the quantity of dairy products to be stored, storage time, storage temperature required, ease in handling the dairy products and any other typical requirements for dairy products. All these are being described as follows:

i. Household Refrigerator

It is very common equipment used in the houses/shops for storage of milk, vegetables, fruits, drinks and other eatables, etc. It is available in various capacities starting from 90 L to 360 L. It is an insulated cabinet in the shape of an almirah. Within this cabinet, a freezer or commonly called icebox is situated at the top. Below this there are 3-4 perforated or grilled shelves. At the bottom, there is a vegetable basket. The door of this refrigerated cabinet is also insulated. Around the icebox generally made of aluminum, the evaporating coils are wrapped. In the backside of cabinet, a hermetic compressor and an air-cooled condenser is fitted. The outlet of condensing coil is joined to the inlet of evaporating coil through a capillary tube crossing the back wall of cabinet. The evaporating coil is dry expansion type. When compressor is started, the refrigerant liquid within the evaporating coil flows and evaporates. While evaporating it absorbs heat and cools the icebox and surrounding air. The cold air around the coil is heavier than the warm air at the bottom. So, by natural convection, the cold air settles down and warm air lifts up. The circulating cold air current cools all the items placed on shelves. The temperature of cooling coil is low enough such that within the icebox temperature is less than $0^{o}C$. So, the water placed in ice trays convert to ice, which can be used for various purpose in the house. The temperature in the cabinet outside the icebox is generally from $0^{o}C$ to $4^{o}C$. Within the cabinet wall a thermostatic control is given which can be adjusted for slow or fast cooling. Due to thermostatic control when the required temperature inside the refrigerator cabinet is achieved, the compressor automatically stops. When this temperature again rises above a certain level, the thermostatic control again starts the compressor. In this way, once the thermostatic control knob is adjusted, the required low temperature is maintained in the refrigerator cabinet.

Fig. 6.7 Refrigerator

ii. Deep Freezer

For some type of dairy products or other eatables, e.g., ice-cream, the temperature of the storage space should be very low i.e. below the freezers point, such that, the ice- cream remains in frozen condition. Hence, for storage of ice cream, the generally used household refrigerator will not serve the purpose. For that deep freezers are used. It has a box shape insulated cabinet with an insulated door at the top. The inside wall is made of thin plastic sheet behind which the evaporating coils are fixed all round. As on the outer side of evaporating coil there is an insulating layer, all the cooling effect of coils comes inside the cabinet through the thin sheet. Outside the refrigerated cabinet, there is a hermetic compressor with air fan cooled condensing unit. The length of capillary used is more in case of deep freezer due to which the temperature of evaporating coil is very low generally -20^{o}C. Deep freezers are generally used at ice-cream shops and parlours.

Fig. 6.8 Deep Freezer

iii. Walk-in-Cooler

These are big size refrigerating cabinets such that the operator can go inside the cabinet through a door. These are usually installed in large dairies where the quantity of milk products to be stored is large.

Walk-in-cooler is generally installed on a platform at a slightly upper level than the floor level. The wall and roof of the cabinet is made of an inner and outer steel sheet. Between these sheets the polyurethane foam is filled. First it is in liquid form and pumped under pressure between the inner and outer wall of sheet metal. As the foam expands it bonds with steel sheets and hardens in place. In this way the wall of cabinet becomes very strong and solid and also light in weight. The wall is fire resistance and waterproof. The foam acts as an insulating material and prevents the heat flow from outside to inside of cabinet. By insulating, the cooling requirement and hence the compressor capacity reduces to a large extent. There is a locking arrangement on the door and it can be opened from both sides. Inside the cabinet, the lights are also provided. The compressor and air-cooled condensing unit are installed in a separate cabinet outside the refrigerated cabinet. The dry expansion type and finned evaporating coil is situated in an enclosed box fitted at one of the wall inside the cooler. In front of the coil a cooling fan is provided. When compressor runs the temperature of evaporating unit falls down. Simultaneously the cooling fan/blower runs which sucks the air flowing over the evaporating coil and circulate this cold are in the whole space of cabinet. In this way inside air gets cooled which further cools the dairy products stored in the cabinet. The open racks may be used for keeping the products in cabinet. At some appropriate point inside the cabinet the probe of a temperature controller is fixed. As the desired temperature reach in the cabinet, temperature controller senses it, and switch off the compressor automatically. The walk in cooler is very easy to use and repair. It may be available in various sizes depending on requirement.

iv. Display Case

It is a highly useful item from business point of view. Most of the food shops, restaurants, ice-cream parlours, sweet shops or any other such type of business place have one or more refrigerated display cases which are made in various sizes and shapes. A display case serves two purposes, one it preserves the foodstuffs until these are sold and other it displays the foodstuffs in an appealing way. A cold air blanket preserves the foods displayed in this type of cases. The compressor and air-cooled condensing unit are generally installed in the bottom of case at a hidden place. The evaporating coil may pass through the shelf or surrounding wall or in the roof depending on various designs. A blower type-evaporating coil may also be used. The food items stored in these cases are usually wrapped in clear and transparent material such as cellophane, which protect them from dust/germ in air. But by wrapping the food the refrigeration load increases considerably than that in case of unwrapped food.

v. Cold Storage

These are actually the small or big size cold rooms made of general construction material i.e. bricks/ cement etc. like any room of a building. Difference is that there is only one entrance door and no window/ ventilation etc. All the inside surface of cold room i.e. walls, roofs, floor, door, etc. are insulated properly. The thickness and amount of kind of insulation depend upon the local conditions. The insulated door is air tight with proper sealing. Inside the cold storage, generally the blower type finned evaporator coil is fixed on any one of the walls. Only the inlet and outlet of evaporator coil crosses the thickness of wall. The evaporator is generally flooded type i.e. full of the refrigerant liquid. A blower sucks the cold air over the coil surface and forces it to flow through the space in cold store. The other components of refrigeration plant, i.e., compressor, condenser, receiver, expansion and control valves are situated outside the cold room and as near as possible to minimize the cost of pipes. The compressors used in a cold storage are generally of reciprocating type and refrigerant used is ammonia. Ammonia is used in cold storage because it is cheap and efficient and also a very good quality refrigerant. The compressed ammonia gas is either condensed in a water-cooled condenser or an evaporative condenser. The condensed ammonia is stored in the receiver from where it is supplied to evaporator through the control valves/ expansion valves. The height of cold room is generally kept low. Cold storage rooms can be made of varying capacity and operating at varying temperature. The storage period is considerably shorter in case the items are stored at a temperature above their freezing point, i.e., not more than 15 days. However, for items stored at a temperature below their freezing point, storage period can be very large and the cold storage in this case is named as frozen storage. Frozen storage is generally of small size than the cold storage.

Check Your Progress 3

1. What is the difference between a household refrigerator and deep freeze?

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2. In which type of application a walk-in-cooler is used?

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3. What is the purpose of using blower type evaporating coil in a cold storage?

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6.5 ICE-CREAM FREEZERS

Ice cream is a well-liked dairy product. It is always consumed in frozen condition. The freezing temperature of an ice-cream mix is very low due to the ingredients like milk sugar, salts and cane sugar, etc. Therefore it is required to be cooled to a very low temperature for freezing. Thus, manufacturing of ice cream is not possible without the refrigeration/ cooling application. An ice-cream freezer has the following functions during manufacturing of ice cream.

1. First, It must cool the mixture of ice-cream ingredients to the proper low temperature for handling in packages/containers. Thereafter, it must cool the packaged ice cream to a low enough (such a low) temperature so that the ice cream hardens properly with smooth consistency and uniform ice-crystals.
2. Alongwith cooling, it must mix a predetermined amount of air uniformly into this ice cream in such a manner that it gives the ice cream the proper swell or overrun.
3. If required, It must perform the mixing of fruits and flavour into ice cream while it is being frozen.

Here we will discuss only the first major function of ice-cream freezing equipment, i.e., cooling and freezing of ice-cream mix. The extraction of heat from ice-cream mix takes place in three different steps. First is the extraction of sensible heat of liquid mix so that its temperature lowers down to the freezing temperature. Second step is extraction of latent heat of liquid mix at freezing point so that it becomes semi-frozen slush. And third is the extraction of sensible heat of this slush so that its temperature further lowers down below the freezing temperature and it become hard ice cream. Depending on the amount of ice cream to be manufactured and so the amount of heat extraction, the freezing equipment is designed. Freezers of the commercial type may be classified as batch or continuous, depending upon whether the ice cream is made in batches or is ejected in a continuous stream. Depending on the type of cooling/ method of refrigeration, these are also classified as brine type or direct expansion type. In the brine type, the brine is cooled to a required low temperature by a conventional refrigeration plant and is supplied to the ice-cream freezer for extracting heat of ice-cream mix. This is the indirect method of cooling. Brine is simply a solution of salt in water and can be cooled to quite low temperature less than 0^oC without freezing. So, brine is used in place of water in case of ice-cream manufacturing application. In the direct type, the refrigerant is directly expanded in the suitably designed ice-cream freezer where it evaporates and extracts heat from ice-cream mix. The various types of ice-cream freezer/ equipment are explained here.

i. Batch Freezer

It consists of a double wall cylindrical drum of varying capacity. The inside wall of freezing cylinder is made of steel or copper with a stainless steel liner. The outer wall is insulated with cork and covered with airtight metal housing. The narrow space between the inside and outside wall is called jacket through which either chilled brine or refrigerant flows. Due to narrow passage in jacket, the brine will flow with high speed and provide good heat transfer. At a time one batch of ice-cream mix is put in the drum and cooled by the flow of brine or expansion of refrigerant in the jacket. Inside the cylinder a dasher is fitted which rotates by a direct motor drive. The dasher has scrappers, which scrap the frozen ice cream from the refrigerated inside surface of cylinder. A beater is also provided for whipping/ mixing of air into the ice cream so that it becomes fluffy.

Alongwith the freezing cylinder, certain other accessories are also used in batch freezers. The batch-measuring device measures the charge of mix. The draw-rate indicates the stiffness of the ice cream by means of load on the dasher motor.

The ice-cream mix is required to be cooled to a certain temperature depending on the level of stiffness required. Therefore, some means of controlling the cooling and stopping during the whipping and unloading period must be provided.

ii. Refrigeration Control

In case of brine cooling, control is very much easy by simply controlling the flow rate of brine through the cylinder with the help of a valve. But in case of direct expansion of refrigerant usually ammonia, two principal types of controls are used as shown in figure 6.9. These are York-type refrigerating system and the creamery - package type refrigeration system. Both the systems control the flow of ammonia vapors from accumulator to the suction of compressor.

a) In the York-type system, the accumulator with low side float control valve is situated at a higher level than the freezing cylinder. Due to float valve, a fix level of liquid ammonia is maintained in the accumulator. The bottom of accumulator is connected to the bottom of freezing cylinder with a pipe. In the same way, top of freezing cylinder is also connected to the top of accumulator through a pipe and control valve. When this valve is open, the liquid ammonia filling in the freezing cylinder being at a lower level takes heat from the ice-cream mix and produce cooling. On absorbing heat liquid ammonia converts into vapours, which lift through control valve, and accumulates in the evaporator. From the accumulator, compressor sucks these vapors. When the control valve is closed, the ammonia vapours formed in the jacket of freezing cylinder cannot lift up to the accumulator and also cannot pass through the bottom because of lighter weight. In this way, the ammonia gas collects in the jacket and push back the liquid ammonia from jacket thus stops the cooling very quickly. Thus control valve is open when freezing is to start and closed when freezing is to be stopped during whipping.

b) In the creamery package type refrigeration system, The liquid ammonia is filled in the freezing jacket and accumulator in the same way as in York type system. But here in this case, the control valve is provided in the passage between accumulator and compressor. When the valve is opened, it allows the compressor to reduce pressure in the accumulator and hence in the freezing jacket. By reduction in pressure more and more liquid ammonia will evaporate to a low temperature and produce more cooling. When the valve is closed, it does not allow the compressor to suck ammonia vapors and thus builds up the pressure in the refrigerator jacket. Due to higher pressure, the saturation point increases and the rate of evaporation and hence cooling lowers irrespective of that the refrigeration jacket is still filled with liquid ammonia. This control method does not stop the freezing so quickly as the first method described. Hence the control valve is shut off in advance so that

Fig. 6.9 The York-type Refrigerating System for Batch Freezer

Fig. 6.10 The Creamery Package Type Refrigeration System for Batch Freezer

the cooling reduces at proper time. The cooling goes on reducing but does not stop. However it may be beneficial sometimes in the ice cream processing.

iii. Continuous Freezer

In the continuous freezer, the ice-cream mix is continuously fed or pumped under pressure from one end and we get ready ice-cream from other end continuously. In this way here ice cream flows under pressure. During flowing through the freezer, it undergoes all the processes, i.e., freezing, whipping of air, mixing of various fruits, etc. The continuous freezer is desired due to its various benefits like it saves space, labour and cost of operation. Moreover in continuous freezer, more uniform results are obtained. Due to continuous flow of ice-cream mix, heat transfer is also improved and we get positive control on the percentage of air and mix. The system of refrigeration is almost of the same type. Generally ammonia is used as the refrigerant, which is directly expanded in the jacket of freezing cylinder.

Depending on the feeding arrangement of ammonia, two types of continuous freezers are as described below:

a) Vogt Freezer using Jet type Ammonia System

The freezing cylinder alongwith ammonia refrigeration system is as shown in Fig 6.11. A jacketed tube type-freezing cylinder is situated above the accumulator. In the accumulator, the level of liquid ammonia is maintained with the help of float control valve. From the liquid ammonia feed line, liquid ammonia is fed to the jacket of freezing cylinder by the jet action through a nozzle. It expands in the jacket of freezing cylinder tube and freezes the ice cream mix flowing inside the freezing tube. The metered quantity of air mix enters from one end by the action of pump and frozen ice cream comes out from the other end continuously. After producing cooling the ammonia vapours drops back in the accumulator. From the vapour zone of accumulator, the compressor again sucks these vapours. Below the jet a spring-loaded quick shut-off valve is provided which when operated quickly stops the ammonia supply and hence cooling in freezing cylinder.

b) Creamery Package Continuous Freezer

The freezing cylinder of this freezer is like that of a batch freezer as shown in Fig 6.12. The size of freezing cylinder is large and it is connected to an accumulator fixed at a higher level, which maintain the liquid ammonia always filled in the freezing cylinder. The accumulator is connected to the compressor through a backpressure valve. However, the system of feeding the ice-cream mix is made continuous i.e. it enters from one end and exit from the other end by the force of a metering type pump. The metering type pump can also control the flow rate of mix. Air is also fed continuously along with mix through a control valve. The working of this type of freezer is automatic i.e. the ammonia is controlled automatically depending on the quantity and quality of mix and cooling required.

Fig 6.11 Jet Type Ammonia Circulating System in the VOGT Freezer

Fig 6.12 Creamery Package Continuous Freezer

Check Your Progress 4

1. What are the different steps of extraction of heat from ice-cream mix in a ice-cream freezer?

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2. What is the main difference between a batch freezer and continuous freezer?

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3. What is the difference between york/vogt type refrigeration system and creamery package type refrigeration system of an ice-cream freezer?

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6.6 LET US SUM UP

Different types of cooling systems for milk and milk products are designed on the basis of temperature requirement, amount and type of milk/ milk products to be cooled/ processed, place of application, availability of resources, etc. The cooling can be direct or indirect. Direct cooling means when the refrigerant itself is expanded in the cooling or freezing apparatus. These are also called direct expansion system. Indirect cooling means when a vapor compression refrigeration unit chills water first and this chilled water is then supplied to cooling/ freezing apparatus. The basic components of the refrigeration systems i.e. compressor, condenser, expansion valve, evaporator coil, etc. are same. Only their types and type of refrigerant vary as per different cooling requirement.

6.7 KEY WORDS

Direct cooling	:	In direct cooling, the refrigerant liquid is directly expanded in the evaporating coil/jacket of cooling apparatus.
Indirect cooling	:	In indirect cooling, first the water is cooled by evaporating coil of refrigeration system in a separate chilled water tank. Then the chilled water is circulated through cooling apparatus for cooling of milk/ milk products.
Chilled water	:	Water at a temperature of 0^oC to 4^oC.
Condensing Unit	:	It is a box in which the compressor, air cooled condenser and filter/drier of a refrigeration system are separately fitted. The condensing unit can be installed at a suitable place and connected to the cooling coil and expansion valve through pipes.
Stiffness	:	It is the property of a material by which it resists any external force to change its shape.
Accumulator	:	It is simply a small tank connected to the inlet and outlet of evaporating coil/jacket. It is situated at a level above the evaporating coil. It maintains a constant level of liquid refrigerant in the coil. The refrigerant liquid absorbs heat in the cooling coil and converts to vapours which lift up and accumulate in the accumulator.
Freezing point	:	It is that value of temperature at which a substance changes from liquid/semi-liquid state to the frozen state.
Deep Freezing	:	When the temperature of a frozen substance is further lowered down from freezing point, the process is called deep freezing. In deep freezer, the frozen product becomes harder.
Whipping	:	It is the process of mixing of air into ice-cream mix so that its volume increases and it becomes fluffy.

6.8 SOME USEFUL BOOKS:

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6.9 ANSWERS TO CHECK YOUR PROGRESS

Your answer should include the following points:

Check Your Progress 1

1) i. In-can coolers are used when production of milk is less and surface coolers are used when milk production is high.

   ii. In-can cooling is a batch process where surface cooling is a continuous process.

2) i. In bulk milk coolers, handling of milk is easy, as it is through pumps where milk cans are heavy to handle.

   ii. Washing and cleaning is easier in bulk milk coolers.

   iii. Cooling of milk is more efficient and effective in bulk milk coolers.

3) i. To retard the natural heat flow from surrounding to cooling equipment.

   ii. To reduce the cost of cooling.

4) i. Heat is conducted very slowly from the cold surface to the milk and then within the milk.

   ii. Agitator moves the milk in such a way that cold milk near the surface moves to the center and warm milk from the center moves near to cold surface.

   iii. Increase the heat transfer rate from milk to the cooling surface and so reduce the cooling time.

5) i. Water is easily available.

   ii. Good carrier of heat energy

   iii. More effective than air.

Check Your Progress 2

1) i. When water is not taken continuously from the chilled water tank, it stays there and starts freezing at the surface of cooling coil.

   ii. Ice-formation at the surface of coil works as a bank of chilled water when more water is required in the plant.

2) i. Flooded type

3) i. Control on amount of cooling is easy.

   ii. To meet the peak of cooling load is easy by simply increasing the supply of chilled water from chilled cooler tank/ice-bank unit.

   iii. No risk of spoilage of foodstuffs on leakage of refrigerant.

   iv. Small size of cooling pipes is required.

Check Your Progress 3

1) i. Temperature maintained in deep freeze is lower than that maintained in household refrigeration.

   ii. Temperature in deep freeze is well below the freezing temperature of food/ dairy products stored.

2) i. Walk-in-cooler can store large quantity of milk/milk products and also compact and easy to install at any available place. It is also easy to use and repair.

3) i. The blower pulls the air over cooling coil with high speed and spread it in the whole cooling space effectively.

   ii. With high speed of circulation of air, heat transfer from products to cooling coil increases.

Check Your Progress 4

1) i. Sensible heat from initial temperature to freezing temperature.

   ii. Latent heat at freezing point.

   iii. Sensible heat from freezing temperature to deep low temperature.

2) i. In batch freezer, ice cream is prepared in batches. Batch freezer has a fixed capacity of preparing ice cream at one time.

   ii. In continuous freezer, ice cream is prepared in a continuous stream. Ice-cream mix is continuously fed on one end and final product is taken on the other end of continuous freezer.

3) i. In York type, control on cooling is made by controlling the flow of ammonia vapours from freezing cylinder to accumulator through a control valve. Cooling can be completely stopped immediately in this case.

4) i. In creamery-package type, control on cooling is made by controlling the flow of ammonia vapours to the suction of compressor. Cooling cannot be immediately stopped but however reduced in this case by closing the control valve. This slow cooling is sometime desirable in whipping process.

UNIT 7 COLD STORAGE AND INSULATION

Structure

7.0 OBJECTIVES

After reading this unit, we should be able to:

- define the principles and components of a cold storage
- enlist various types of cooling loads in a cold storage
- explain the importance of insulation, types of insulating materials and their method of application in cold storage.

7.1 INTRODUCTION

Refrigeration plays an important role in preservation of perishable commodities, i.e. to safeguard these against spoilage, particularly the food items including milk and other dairy products. The milk and dairy products although produced continually must be preserved against the time of distribution and kept until required by the consumers. This time may be weeks or even months after processing. For this reason, the principles governing the deterioration of food substances are an integral part of study of refrigeration as a whole. The deterioration or spoilage of milk and other dairy products is mainly due to bacteria growth. Bacteria are minute organisms and many species of these are found in milk and dairy products. Certain types of bacteria act upon the milk sugar or lactose to produce lactic acid, which bring about decomposition or souring of milk. The souring of milk is apparent by its disagreeable odour and bitterness of taste and it will not be suitable for human consumption. In the same way, spoilage of fatty dairy products like butter and cheese take place resulting from chemical changes of fat and oils and they emit a rancid or sour odour. All these physical and chemical changes and bacterial growth causing spoilage of dairy products can be considerably retarded in their activities by their exposure to low temperature conditions and proper level of humidity and purity of surrounding air. These favourable conditions are generated in cold storage to retard spoilage and preserve the stored products for a longer period. Thus the cold storages are designed according to favourable conditions of temperature, humidity and purity of air required for the type of dairy product to be stored. The basic principle of producing cold or low temperature in cold storage is same by using a vapour compression refrigeration system.

Insulation of cold storage is also given importance because it retards the flow of heat from surrounding to the cold room and is an integral part of cold storage. Just as in PVC electric wire used in homes, the PVC insulation covering the copper wire prevents electric current to flow from copper wire to our hand, the thermal insulation around a cold store-storage prevents inflow of outside heat. In actual all the materials offer resistance to the flow of heat but which have high resistance are called insulators. The surrounding temperature is always higher than the cold storage temperature and heat will continuously flow inside in the absence of insulation. It will make the refrigeration plant ineffective. Thus the design of proper insulation i.e. type of insulating material, its thickness, its method of fixing etc. is equally important in the design of a cold storage.

7.2 PRINCIPLES OF COLD STORAGE

Cold storage is the method of preserving perishable commodities including dairy products in their fresh and wholesome state for extended periods by providing and controlling proper temperature and humidity conditions within the storage compartments. Because normal atmospheric conditions of temperature and humidity are seldom at a level conducive to the safe and prolonged storage of perishable foods, it is necessary that artificial methods be provided to produce such an environment. This safe environment is formed of various favorable conditions of air inside the cold storage given below:

i. Types of Conditions inside a Cold Storage

a) **Temperature:** The first main condition of air required in a cold storage is 'Low temperature'. The low temperature retards or arrests most of the spoiling activities like bacterial growth in dairy products.

b) **Humidity:** It is the moisture content of air in cold room. It is also an important parameter and required to be kept in a certain range. Very low humidity means the product will loose its moisture due to increased evaporation in dry air. Very high humidity means the growth of moulds/ bacteria will take place. However, effect of humidity is lowered down either by packaging the products or by wrapping these with moisture resistant paper.

c) **Motion of Air:** It means that the cold air should not be stationary but should flow continuously over the products for better heat transfer. It is ensured by suitably designing the cooling coil and blower

d) **Purity of Air:** It is also an important parameter because impure air may badly affect the quality of food products stored in. Suitable measures are taken to ensure purity of inside air.

In this way the major consideration is made for temperature, humidity, motion and purity of air in a cold storage. But in what range the temperature and humidity should be? That is decided and designed based on some prior considerations as mentioned below:

ii. Prior Considerations in Deciding inside Conditions of a Cold Storage

In actual, cold storage conditions are determined first by the type of food to be stored and second by the length of time such foods are to be stored.

a) Type of Food: In general, types of foods are divided into two groups:

1. Foods in which living process continues, i.e. these absorb oxygen and produce respiration heat. Fruits and vegetables come in this category. The low temperature exposure has only a retarding effect on these foods.

2. Non-living foods such as meat, fish and dairy products that are highly susceptible to the activity of spoilage agents. These products deteriorate rapidly unless the drastic preventive measures of preserving these are taken.

b) **Storage Time:** Second consideration is the length of time for which dairy products are required to be stored/ preserved. It decides chiefly that the products are to be stored in frozen or unfrozen state. The storage period is less for unfrozen products and longer for frozen products. However, this rule is not so simple because the storage period, even in frozen state, varies considerably from product to product. Freezing temperature also vary for different dairy products.

Thus there is a wide variation of data for storage temperature, relative humidity, freezing point, maximum storage period at different temperature etc. for various types of dairy products. A sampled data is given in Table 7.1.

Table 7.1 Storage of Dairy Products

Commodity	Storage Temperature	Relative Humidity	Approx. storage time	Average freezing point
Cheese	1.5°C	65 to 70%	-	-2.25°C
Butter	7°C	80 to 85%	2 months	-
Butter	-23° to -20°C	80 to 85%	1 year	-
Cream (Sweetened)	-26°C	-	Several months	-
Skim Milk (Dried)	4°C	-	Several months	-

Some dairy products like ice-cream is always stored in frozen condition i.e. at a deep low temperature. Depending upon the available data, the main parameter, i.e., *temperature* to be maintained in the cold storage is decided on the basis of type of dairy product and duration of storage.

Depending on the temperature range, the principal refrigeration system employed with cold storage is divided in two groups as ‘chillers’ and ‘freezers’. Chillers maintain a temperature above 0°C i.e. above the freezing points of products and freezers maintain the temperature below 0°C, i.e., below the freezing point of products.

Check Your Progress 1

1. How the foodstuffs/ dairy products can be stored for a longer period without spoilage?

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2. What are the different types of conditions, which are maintained inside a cold storage for preservation of food products?

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3. What are the factors, which decide the temperature to be maintained in a cold room?

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7.3 COMPONENTS OF A COLD STORAGE

i. Cold Room

It is an insulated room, cabin or compartment with an insulated door for loading and unloading the products to be stored. Size of the cold room varies considerably depending on the variety and amount of products to be stored. There may be more than one cold room in a dairy plant operating at different temperatures. Generally separate cold rooms are designed for different dairy products of varying temperature requirements.

ii. Cooling Coil/Diffuser

Cooling coil. also called as evaporator/ evaporator coil, is the only component of refrigeration machine which is fixed inside the cold room. As the name suggests, it cools the products kept inside the cold room. Depending on the size of cold room/ store, one or more cooling coil (evaporator coil) with air diffusing system is fixed inside the cold store. In air diffusing system a fan or blower pulls the air over the cooling coil and diffuses this cold air in whole space as shown in fig.7.1. It is fixed at heat height on the suitable wall of cold store. However, height may vary as per the requirement. Maximum distance is maintained between the cooling coil and cold store door. Sometimes air ducts hanging from roof may also be used for proper distribution of cold air in the whole space. The cooling coils may be of two types as ‘direct expansion evaporator coils’ or ‘chilled water coils’.

a) Direct Expansion Cooling Coil

In this type of cooling coil, the refrigerant is directly expanded and evaporated. That’s why it is also called as evaporator. During evaporation, the refrigerant absorbs heat of the surrounding air and produce cooling effect. It is more efficient and cheap method of refrigeration. But the drawback is that any leakage of refrigerant like ammonia can spoil the food products stored.

b) Chilled Water Coil

In this system chilled water from Ice bank is circulated through the cooling coil. It is preferred where the purity of air is highly important i.e. where there is a risk of spoilage of all the foodstuffs because of the presence of traces of refrigerant in cold air due to any leakage.

iii. Compressor Room

In a large sized cold storage of a dairy plant, a separate room for compressors is provided. This room is situated as near to cold room as possible to minimize the piping and insulation cost and also to enhance the overall performance of the plant. Generally there are more than one reciprocating type compressor. Separate compressors are there for cold rooms working at different temperatures because of difference in suction pressure. However, the discharge pressure and temperature of all the compressors is same. So the discharge line of all the compressors is merged into a single line and connected to condenser.

Fig.7.1 (a) Blower Type Cooling Unit

Fig. 7.1 (b) Blower Type Cooling Coil

iv. Condenser and Receiver

As the discharge temperature of the all the compressors is same, a single condensing unit is employed. Either a water- cooled condenser with cooling tower or an evaporative condenser is used. The condenser is situated in an open space nearest to condenser room/cold room to minimize the piping cost. The receiver is also situated near to condenser to collect the compressed and condensed refrigerant gas and then to supply it to cooling coil through control/ expansion valves.

v. Expansion/Control Valves

Separate expansion valves and control valves are fixed for different cold rooms. These are fixed on the outside of that wall of cold room on which the cooling coil is fixed. In this way these are connected to cooling coil across the wall. With dry expansion evaporator, thermostatic expansion valve is used and with flooded evaporator, float control valve is used.

vi. Refrigeration Piping and Refrigerant

All the major components of refrigeration system are connected to each other through pipes. Steel pipes are used with ammonia as a refrigerant and copper pipes are used with freon refrigerants. The pipe connecting the cooling coil with compressor, also called as suction pipe, carry the low temperature refrigerant gas. So insulation is provided on it. All other pipes are bare. As generally the compressor, condenser

Fig. 7.2: Typical Layout of a Cold Storage

and receiver are situated at some distance away from the cold room, the length of connecting pipes carrying refrigerant is also very large. Because of this, the quantity of refrigerant is large. So, the cost of refrigerant is important, as costly refrigerant cannot be used in large quantity. Generally ammonia gas is most accepted refrigerant in the cold storage of a dairy plant. Ammonia is cheap, easily available and also very good refrigerant in performance. The typical layout of cold storage of a dairy plant is as shown in figure 7.2

vii. Safety Devices

In addition to the major components, many safety devices are also installed in a cold storage plant. Some of the safety devices and their function are as discussed below:

1. Low pressure cut-out
2. High pressure cut-out
3. Temperature Indicator/Controller

(a) Low Pressure Cut-out

In a refrigeration plant, when sometime the cooling load decreases or evaporator becomes ineffective due to some other reason, the evaporation of refrigerant liquid in the evaporator coil decreases. Due to decrease in evaporation of refrigerant, the pressure of refrigerant vapours also decrease in the suction side of compressor. This low pressure also called high vacuum may cause damage to the equipment, i.e., any pipe or joint can burst. It also puts heavy load on compressor. This high vacuum is avoided by the use of low-pressure cut-out, which switch off the compressor automatically as soon as the pressure in evaporator decreases below a certain value.

As shown in fig.7.3, it consists of an electric switch, which is operated by the combined force of a spring and pressure force in the suction line. At normal suction pressure, it remains in OFF position. But when suction pressure decreases below a certain limit, it comes in ON position and activates a relay, which switch off the compressor. It is a mandatory fitting with compressor of a refrigeration plant.

Fig. 7.3 Low Pressure Control

(b) High Pressure Cut-out

In a refrigeration plant, the condenser effectiveness may decrease sometimes due to failure of cooling water supply to condenser or by deposit of dust or sludge etc. on its surface or by the presence of air with refrigerant vapour in the condenser.

When condenser effectiveness decreases, the vapours are less able to condense and due to more vapours continuously coming from compressor, their pressure may increase than the normal value. This high pressure is dangerous to the equipment i.e. compressor and condenser. Hence to avoid high pressure, a high-pressure cutout is connected to discharge line, which switch off the compressor automatically in case the pressure in condenser exceeds to an upper limit.

As shown in fig.7.4, it consists of an electric switch, which is operated by the combined force of a spring and pressure force in the discharge line. At normal discharge pressure, it remains in OFF position. But when discharge pressure increases above a certain limit, it comes in ON position and activates a relay, which switch off the compressor. It is a mandatory fitting with compressor of a refrigeration plant.

Fig. 7.4 High Pressure Control

(c) Temperature Controller

In a cold storage, once the food/dairy products stored come at a low storage temperature, there is no more heat to be extracted from the foodstuffs kept in cold storage. However, some heat may come inside from the hot surrounding but its rate is very less due to effective insulation all around the cold room. It is also very less as compared to heat extraction rate of the refrigeration plant. Thus, there is no further need to keep on running the refrigeration plant until the inside temperature again increases above a certain limit. So, for that purpose some automatic method is required which switch on and switch off the compressor depending on the temperature inside the cold room. An electronic temperature controller is generally used for this purpose. When the refrigeration plant is operated, it senses the temperature of cold room continuously through a probe hanged inside. As soon as the required low temperature is reached inside the cold room, it automatically activates a relay switch, which switches off the compressor. This temperature, at which the compressor is switched off, is called cut-out temperature. Now again, when inside temperature starts increasing due to inflow of some heat from surrounding and also through operating the door of cold room, and when it crosses an upper limit, temperature controller starts the compressor. This upper limit temperature is called cut-in temperature. In this way, temperature controller is the most important control device in a refrigeration plant.

Fig 7.5 Temperature Controller

Check Your Progress 2

1. What is the difference between direct expansion cooling coil and chilled water-cooling coil?

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2. Why a blower is used with cooling coil in an air diffuser of cold storage?

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3. What is the difference between a chiller type and freezer type cold storage?

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4. What is the need of low pressure and high pressure cut-out?

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5. What is the need of a temperature controller in a cold storage?

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7.4 DESIGN CONSIDERATIONS

Until now we have discussed that cold storage is required to store the food/dairy products at low temperature so as to preserve these for a set period of time. The cooling coil of refrigeration system installed inside the cold storage extract the heat of the product and lower down their temperature. After lowering down the temperature to a set range, this temperature should be maintained so as to preserve the products. To maintain that temperature it is necessary to extract all that heat energy which enters the cold storage by some means. Thus to know the capacity of refrigeration plant required, we must know the amount of heat to be extracted in a given period of time i.e. the cooling load on refrigeration plant. There are various types of cooling loads that are taken into consideration in a cold storage. All these are explained as follows:

i. Heat of Products

This is the main part of heat, which is required to be extracted and is known as major cooling load. When the products are stored in a cold storage, these are initially at higher temperature. To lower down their temperature, their heat is required to be extracted. It is divided in three groups:

(a) Chilling load above freezing

Chilling load is calculated by the following formula: -

Chilling load on refrigeration System of cold store = Amount of heat extracted per unit time in kilo-Joules/min

$$= \frac{m.\ Cp.\ (T_1 - T_f)}{\text{Chilling Time in Minutes}}$$

Where, m = Mass of product stored in Kg

Cp = Specific heat in kJ/ kg ^oK

(Heat required to be extracted from 1 kg of product for lowering its temp. by 1^oC)

T_1 = Initial Temperature of product at loading time in ^oC

T_f = Freezing temp. in ^oC in case of freezing or the final temperature above freezing point in case of chilling only.

(b) Freezing load

If the product is required to be freezed, this load is also added in the chilling load given above. It is given as:

Freezing load = Amount of heat extracted per unit time for freezing

$$= \frac{m.\ h_{fg}}{\text{Freezing time in min}}$$

Where, m = mass of product in Kg

h_{fg} = Latent heat of fusion
(Amount of heat in KJ/kg required to be extracted from 1 kg of product at freezing temp. to convert it from unfrozen to frozen state)

(c) Deep freezing load

If the product is required to be deep freezed i.e. it is required to be stored at a temperature lower than its freezing temperature, the load is calculated as follows and added in the above mentioned load.

Deep Freeze Load = Amount of heat extracted per unit time for deep Freezing

$$= \frac{m.\ Cp.\ (T_f - T_2)}{\text{Deep Freezing Time}}$$

Where, C_p = Sp. Heat of frozen product
(heat required to be extracted from 1 kg of Frozen product to lower its temperature by 1^oC).

T_f = Freezing temperature

T_2 = Final temperature required for storage

Thus in case of chilling only, first type of load is considered. In case of freezing, first and second type of load are added and taken into consideration. In case of deep freezing, all three types of loads are taken into consideration.

ii. Heat Conducted in through Walls, Roof and Floor of Cold Storage

A cold storage is generally situated at such a place in a dairy, which is not exposed to direct sun. All the walls, roof, floor are insulated i.e. insulating material is fixed around which prevent the heat flow from surroundings. But, in spite of that there may be some cooling loss to the surroundings, however, it may be negligible, depending on the difference in temperature inside and outside of cold storage and type of material of wall and insulation. This continuous heat flow through walls, roofs etc. is added in the cooling load of refrigeration plant.

iii. Heat Gain from Product Handling Labourers

The products are stored and arranged in cold storage by labourers. They also loose some heat in cold store due to its low temperature. This heat also puts some cooling load on refrigeration system.

iv. Heat Gain from Lighting and Power equipment

There may be a variety of appliances like fan or blower motor, any safety device, lights etc., which continuously loose heat in cold storage and put some cooling load on the refrigeration plant.

v. Heat Gain due to Infiltered Air

While loading or unloading the product in cold storage, the door is opened. During this period, the cold air of cold storage escapes out and hot air from surrounding come in, putting extra cooling load on the system, which depends on the time for which door is kept opened.

vi. Heat Gain through Ducts

After evaporation in the evaporating coil, the refrigerant gas, which is at lower temperature, flows to compressor through pipes. These pipes are exposed to higher temperature of surrounding and some heat gain to refrigerant gas takes place. However, it can be generally reduced by properly insulating the suction line of compressors outside the cold store.

All the above-mentioned heat gains are required to be removed by refrigeration plant of cold storage. Thus all these contribute to the cooling load which is considered before designing or finding out the capacity of refrigeration plant required.

Check Your Progress 3

1. What do you mean by cooling load in a cold storage?

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2. What is the deep freezing load in a freezer type cold storage?

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7.5 RATING OF INSULATION

In general all materials offer some resistance to the flow of heat. But those materials, which offer heavy resistance to the flow of heat through them, come in the category of insulating materials. And the heat-conducting behavior of a material is indicated by the property named as thermal conductivity. The letter 'k' denotes it. Thermal conductivity of a material is equal to the amount of heat in kcal transmitted per hour per square meter area per degree Celsius difference in temperature for one-meter thickness. So, if we know the thermal conductivity of an insulating material, k and all other conditions i.e. area of heat flow, A, thickness of insulation material t and temperature inside and outside the cold room in T_i and T_o, we can calculate the amount of heat passed in kcal/hour through the insulating material as per the given formula:

$$\text{Heat passed in kcal/hour} = \frac{(T_o - T_i).\ k.\ A}{t}$$

We can judge from this formula that heat flow will decrease if the value of k is less, heat flow area is less and thickness of insulating material is more. The factor t/ k is called heat resistance of a material and it should be higher for an insulating material. However, in actual the wall of a cold storage or any refrigerated cabin is not made of insulating material only. It is made up of more than one material. For example in the wall of a domestic refrigerator outside layer is of sheet metal and inside layer is of plastic and in between the insulating material such as glass wool is fixed as shown in figure.

Fig. 7.6 Refrigerator Wall

The calculation for overall thermal conductivity of this type of wall is made like:-

$$Ko = \frac{1}{\dfrac{t_1}{k_1} + \dfrac{t_2}{k_2} + \dfrac{t_3}{k_3}}$$

Where, k_1, k_2, k_3 are the conductivity of different material used and t_1, t_2, t_3 are the thickness of layers of those materials.

In this way, rating of insulation is done and the calculation for heat entering to cold space through all the walls, roof, floor, etc. is made.

7.6 PROPERTIES OF INSULATING MATERIALS

In the previous topic, we came to know that how insulation is important in cold storage and how the rating of insulation is done. Depending on that, we can decide the type of insulating material and its thickness in a particular application. But the heat resisting property of insulating material is not the sole requirement in refrigeration. There are some other properties also which play an important role in the selection of an insulating material. One of these properties is mechanical strength. It comes in picture when some insulating materials are also to be used as load bearing floors and to form self-supporting partitions. Another important property required in an insulating property is that it should be moisture resistant. It should not deteriorate or loose its heat resistive property in the event of moisture collection on it. Thus some other properties, which are considered while applying an insulating material, are as mentioned below:

a) Mechanical strength

b) Moisture resistance

c) Low odour level

d) Safety to health

e) Inflammability

f) Repellence to insects

7.7 TYPES OF INSULATING MATERIALS

There are several types of insulating materials either available in natural form or manufactured in the convenient size and shape from natural materials. So these are broadly classified into two groups as follows:

(i) Natural insulating materials

(ii) Insulating materials manufactured from natural materials.

i. Natural Insulating Materials

Some materials which are already available in nature and posses good insulating property are cotton, animal hair, wool, asbestos, silica, rock or slag, saw dust, wooden shavings, cork etc. Many times these can be used directly by filling in the space between double walls of refrigerated space. But, sometimes a binder is mixed in some of the natural materials to apply them in the shape of plaster coverings.

ii. Manufactured Insulating Materials

These are manufactured from naturally available insulating materials. Some of these materials are as discussed below:

a) Cork Board: These are manufactured by drying the cork and then pressing to shape by baking at moderate temperatures. On baking, the natural gum binds the mass together leaving the air cells in it. These may be available in varying thickness. These are commonly used in cold storage of dairy plant.

b) Thermocole: It is an outstanding insulating material used in cooling application. Its closed cell structure gives it excellent resistance to moisture. It also has good mechanical strength.

c) Kopak: It is a silky fiber taken from Caba tree. It is manufactured in the form of slabs which are light in weight. It can also be used in its loose form.

d) Celotex: It is produced from sugarcane.

e) Insulating Wool: - Some insulating materials are melted and blown by air into fibrous form so as to give insulating material in the form of wool. This wool contains too much air space, which increases its insulating property.

Check Your Progress 4

1. Lets there are two different materials A and B. If thermal conductivity of A

is more than B but its thickness is less than B, then which one is better insulating material?

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2. Name some of the properties other than thermal resistance, which are considered important in the selection of an insulating material.

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7.8 INSULATION APPLICATION AND MANAGEMENT

After discussing various types of insulating materials and their properties, it is now the turn of knowing about their application at the site and proper care and maintenance thereafter. One major threat to the insulating material is moisture. So, it should be applied and maintained in the way that it should always remain waterproof and air-proof. Other major consideration is for mechanical strength required at the place of application. It is more important in case of floor insulation when it has to bear load also. Now we will discuss one by one the insulation of different parts of a cold storage.

i. Insulation of Refrigeration Pipes

In a cold storage, the compressor sucks 'low-pressure and low-temperature vapours' from evaporator coil through the suction line. This suction line generally passes through normal temperature area outside the cold room. If it is not insulated, heat from surrounding area will pass naturally to low-temperature vapours and increase their temperature. The bad effect of this increase in suction temperature is the increase in compressor load. Hence, the suction line of compressor including pipe fitting must be insulated to retard the increase in suction temperature.

Before applying the insulating material pipes, & fittings must be cleaned and then painted with a heavy coat of waterproof asphalt paint. Then the pipes are covered with ready made cork or thermocole lengths which come in half hollow sections, matching with diameter of pipe as shown in Fig.7.7. The insulation covering should be securely wired with copper wire. The seams and any hollow space between the insulation packing should be filled with cork-dust. Then again the whole surface is coated with waterproof asphalt paint.

Fig. 7.7 Insulation of Refrigeration Pipe

ii. Insulation of Cold Room

This is the main part of application of insulation. You already know the importance of effective insulation of a cold room. If properly applied and maintained, the insulation reduces the compressor running time to a great extent and saves the running cost of plant. No area of a cold room should be left without insulation. We will discuss here the insulation of different areas of a cold room.

a) Insulation of walls

Walls of a cold room are generally made of brick and cement. As shown in Fig.7.8 the inside surface of wall is first finished by applying water proof cement plaster or mastic. Then the corkboard or sheets of any other insulating material are fitted on the whole surface with nails. Care should be given on making of good tight joints. Thereafter a second layer of water proof cement plaster is applied by first fitting wire mash on the surface of corkboard. The wire mesh helps in applying and staying in place the layer of cement plaster.

Fig 7.8 Wall Insulation

b) Insulation of ceiling

It is based on the same general principle as that of wall insulation. If possible, the insulation is applied on the top of ceiling slab. In case if it is applied at the bottom of slab from inside the cold room, it is necessary to use more fastening nails or it may be hanged by a strong iron bar structure.

c) Insulation of floors

It is also based on same principle as in case of wall and ceiling but the difference is that the floors should be mechanically strong to bear the weight of storage material. Generally a thick concrete floor serves our purpose. However, when insulating material is applied, it should be mechanically strong and also it should be applied as air tight and water tight.

d) Insulation of doors

The double wall galvanized-sheet insulated doors are available as ready made and fitted on the site with strong hinges and other fittings. All the door fittings also must be galvanized i.e. of corrosion resistant material. The gasket or door seal is fitted on the circumference of door and it fills the annular space between door and doorframe. The door-seal forms the airtight joint between door and door frames and hence serves as an effective insulation against heat and moisture.

Check Your Progress 5

1. What is the general principle of application of insulation?

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2. Which property of an insulating material is considered mainly for floor insulation of cold storage?

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7.9 LET US SUM UP

At average atmospheric conditions, the milk and dairy products spoil in taste and odour mainly because of bacterial growth and chemical changes taking place. Once the products are spoiled these cannot be used for human consumption and are a total loss. All the physical and chemical changes and the bacterial growth retard considerably if we keep the milk and dairy products at low temperature and proper level of humidity in surrounding air. On storing at these favorable conditions of temperature and humidity, products can be preserved for a longer time. The preservation time depends on the type of dairy products and temperature at which it is stored. Dairy products can be stored either in frozen state or unfrozen state depending on required preservation time. Once these conditions of temperature and humidity are decided, cold storages are accordingly designed. Mainly the calculations are made for heat required to be extracted from the products. Some more heat, which enters in the cold storage through various unavoidable sources, is also added. Total heat required to be extracted and sometimes moisture also decides the cooling load of refrigeration plant.

Insulation is very important which cuts the undesirable heat flowing to cold storage from surrounding and hence reduces cooling load of plant. Effectiveness of insulation mainly depends on its heat retarding capability and thickness applied at insulated place. Some other properties of insulation are also important e.g. mechanical strength and moisture resistance, etc. These properties come in picture when the ease in application of insulation and its reliability is looked at. Insulation is applied on a surface so that it must resist the heat, it must bear the load of place, i.e., its strength should be proper and it should be waterproof. Insulation should be carefully watched at regular intervals.

7.10 KEY WORDS

Perishable : The foodstuffs which spoil themselves under normal atmospheric conditions due to any physical or chemical change in their structure. For example all the dairy products are perishable.

Preservation : To protect the perishable commodity from spoilage.

Spoilage : The occurring of those physical and chemical changes in a foodstuff which leave it unfit for human consumption.

Air Diffusion : To spread cold air all around in a cold room.

Chiller	:	The cold store which keep the stored products in chilled condition.
Freezer	:	The cold store which keeps the stored product in frozen condition.
Storage Period	:	The time period upto which a food product can be stored at a particular temperature without spoilage i.e. in preserved condition.
Infiltered Air	:	The hot surrounding air which can enter or infiltrate in the cold room either by operating its door or by some other means.
Insulation	:	The material applied around a cold room to prevent any heat entering from surrounding to cold room due to temperature difference.
Vacuum	:	When pressure of refrigerant vapour becomes lower than atmospheric pressure, it is called vacuum or negative pressure.

7.11 SOME USEFUL BOOKS

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7.12 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Your answer should include the following points:

Check Your Progress 1

1) i. By storing these at low temperature either in chilled condition or in frozen condition.

2) i. Low storage temperature

   ii. Proper level of humidity in the inside air.

   iii. Effective distribution of cold air to each corner of cold storage.

   iv. Purity of Air

3) i. Type of Product

   ii. Storage Period

Check Your Progress 2

1) i. In the ‘direct expansion-cooling coil’, refrigerant liquid itself expands and absorbs its latent heat from the surrounding of coil.

ii. In the 'chilled water cooling coil', water cooled by refrigeration plant is passed through coil where it absorbs sensible heat from surrounding of coil.

iii. To increase the heat transfer rate i.e. to increase the transfer of cooling effect from cooling coil to cold room air.

iv. To diffuse the cold air in whole space so as to increase the transfer of cooling effect from cold air to stored products.

2) i. In chiller type cold storage, temperature maintained is above the freezing point of food/ dairy products.

ii. In freezer type cold storage, temperature maintained is less than the freezing temperature of food/ dairy products.

iii. L.P. cutout is used to safeguard the compressor and other equipment against high vacuum.

iv. H.P. cutout is used to safeguard the compressor and other equipment against high pressure.

v. To control automatically the running and stopping of compressor depending on the temperature inside the cold room.

vi. To maintain the temperature inside the cold room in a fixed range.

Check Your Progress 3

1) i. Cooling load in a cold storage means the amount of heat and moisture to be removed from cold room to maintain it at the desired conditions of temperature and humidity.

2) i. Amount of heat extracted from food/ dairy product after it comes at freezing temperature is known as deep freezing load.

Check Your Progress 4

1) i. Material B

2) ii. Moisture resistance, permanence, Mechanical strength, repellence to insects.

Check Your Progress 5

1) i. Insulation should fully cover the insulating surface i.e. there should be no minor space left uncovered.

ii. Some watertight and airtight material should cover insulation.

iii. It should be given full strength and fitted firmly on the insulating surface.

2) i. Mechanical strength (capacity to bear the load).

UNIT 8 MAINTENANCE AND REPAIR OF COMMERCIAL REFRIGERATION SYSTEM

Structure

8.0 OBJECTIVES

After reading this unit, we should be able to:

- enumerate the general check up of a refrigeration plant while operating it.
- enlist various types of routine check up and maintenance required for safe and efficient operation of the plant
- specify common problems and remedies in a refrigeration plant

8.1 INTRODUCTION

In the previous units, we learnt about the principles of refrigeration, components of refrigeration systems and various types of refrigeration equipment used in the dairy industry. Until now we know only that how these refrigeration equipment are constructed, what is the function of each component, what are different refrigeration processes, etc. But we don't know what steps are to be taken and what are the steps involved in initial inspection, efficient operation and control in running of a commercial dairy plant. What type of periodic check up and periodic maintenance is required for efficient running of the plant? What trouble may come during running of the plant and what can be its solution? Or in the nutshell what should be done, what should not be done during operation, control and maintenance of refrigeration equipment of a dairy plant. All this will be discussed in this chapter. One should go through this unit, very carefully as it is of most practical utility. The knowledge gained in previous chapters will serve as a base to understand all the basic principles of operation and maintenance.

To ensure safe and efficient running of plant, a routine checkup and maintenance schedule is followed. By following this schedule, various parts/components are either readjusted or repaired or replaced. In spite of routine check up and keeping maintenance of the refrigeration plant, some problem may further come during its operation. To each problem there are some causes and remedies which a plant operator should know about. If the causes and remedies are minor sometime he can himself rectify these. However, if these are major, must be attended by expert maintenance staff.

The routine check up and periodic maintenance including servicing, cleaning, setting etc. is given the name as 'preventive maintenance'. Preventive maintenance is done even if the refrigeration plant is working properly. It minimizes the sudden breakdown of plant at the peak load, so prevents failure and saves maintenance cost. On the other hand, any repair, which is done at breakdown of plant, is given the name breakdown maintenance. Breakdown maintenance need to be immediately attended and is generally very costly. So it is usually minimized by properly following the preventive maintenance schedule.

8.2 GENERAL CHECK UP OF A REFRIGERATION PLANT

Some general check-up must be followed before and after running of the refrigeration plant. Some of the important steps are given below:

1. Check all the electrical wires and connections and make sure that all these are in order and well tight.
2. Any wiring diagram and instruction manual should be carefully read and followed.
3. Check the HP, LP cutouts, water flow control valves, pressure regulating valves and all other safety controls and adjust these, if required.
4. Check the temperature controller for its normal functioning.
5. Observe oil level in the compressor crankcase. It should be slightly above the center of the sight glass. Use only proper grade of oil as recommended by the manufacturer for the particular type of compressor.
6. Switch on the condenser fan motor or water pumps in case of water-cooled condenser.
7. After ensuring the proper working of condenser, compressor is switched on. Also check the drive belt tension before starting the compressor. In case the compressor does not start, either there may be some electric problem or some problem in setting or working of LP and HP cutouts or temperature controller. Check all these satisfactorily. If the compressor starts then do not leave system unattended till it has reached its normal operational conditions and again check the following points.
8. The line voltage and load drawn by each phase should be recorded by using proper instruments. The load drawn by each phase should be equal.
9. Check the suction and discharge pressures in the pressure gauges. If these are not within designed limits, determine, why it is so and take the corrective action.
10. Check the flow rate of refrigerant in sight glass or in 'rotameter' and if there is an indication of less quantity of refrigerant, check for any leakage. Then switch off the plant and thoroughly repair the leaky points before adding refrigerant.
11. Again observe oil level in the compressor crankcase through the sight glass and add oil if necessary.
12. If there is a thermostatic expansion valve, feeler bulb must be in positive contact with the suction line and it should be filled with the right amount of gas. It should also be ensured that there is no liquid refrigerant feedback to the compressor crankcase.
13. Recheck all the control valves and safety devices for proper operation and adjust these if necessary.

8.3 PREVENTIVE MAINTENANCE OF COMPRESSOR AND CHECKING ITS GENERAL EFFICIENCY

The compressor is the most important component of a refrigeration system. As it has many moving parts, wear and tear is more. So it requires more care and maintenance. The routine maintenance of compressor has been divided into three different phases as mentioned below:

i. Daily Check-up

Some daily check-ups as given below are made on start of compressor:-

1. Lubricating oil level in the crankcase should be slightly above the middle of sight glass.
2. There should be no oil leakage.
3. The oil pressure and discharge pressure should be in the given range.
4. Driving belt should not be too tight or too loose.
5. No electric wire or connection should be loose or in poor condition.
6. There should not be any abnormal sound or vibration.
7. There should not be any overheating.

ii. Servicing of Compressor

To minimize the wear and tear, the servicing of compressor should be done as per the schedule recommended by manufacturer. Oil should be changed at regular intervals. The oil strainer should be opened and the screen should be removed and cleaned at the time of each oil change. Use only the grade of oil, which is suitable for the type of compressor and also recommended by the manufacturer.

The main shaft of compressor is rested on the stuffing box on the crankcase side of compressor. On rotation of shaft, the bearing surface of stuffing box and shaft undergoes heavy wear and tear and the lubricating oil inside the crankcase start leaking through it. So it needs timely care. Do not simply tighten the bolts and replace the seal to prevent the leakage, but check to see if the crankshaft is scored. If so, replace the shaft rather than putting in a new seal. No kind of seal will stop leakage if the shaft is badly scored and arrangements should be done to repair or replace it.

This is the routine care of compressor against normal wear and tear of moving parts. But this care is not complete. Under the preventive maintenance schedule, check the condition of compressor by opening it up at least once a year. Pay particular attention to cylinder liner, piston rings, valves, valve seats and all bearings. If there is any undue wear and tear of any part, repair or replace it accordingly. On scoring of piston rings, cylinder liner, suction and discharge valves and their seats, the efficiency of compressor to increase the pressure of refrigerant gas will fall down. Also the leakage of refrigerant vapours through the piston rings will increase, which will be a total loss. Mixing of oil traces in the refrigerant gas will also increase. However before dismantling of compressor, a general check on its efficiency can be made. If the efficiency has actually fallen down then the compressor can be repaired accordingly.

iii. General Check on Efficiency of Compressor

A general checking of the efficiency of compressor can be done at any time by adopting the following steps:

1. Close the suction and discharge service valves of compressor.
2. Attach a pressure gauge to the discharge valve gauge port and a compound pressure gauge to the suction valve gauge port. (Compound gauge shows pressure and vacuum of refrigerant simultaneously).
3. Start the compressor and throttle the discharge valve until a head pressure of about 125-psi is maintained.

4. Close the suction valve slowly and when it is completely closed, note the vacuum on compound gauge fitted on suction gauge port.
5. If the compressor produces and also maintain vacuum of 20 inches or more, it may be considered as operating satisfactorily. Otherwise it may be found that wear and tear has occurred in the compressor.

Another simple test in case of a multi cylinder compressor is to place the hand on the discharge line of each cylinder. If there is difference in the temperature it indicates that one of the cylinders is not efficient. If a cylinder is overheating, it may be due to some dirt under compressor valve or undue wear in the valve and valve seat.

After checking the condition of a compressor, make the necessary repairs if the wear seems to be more than normal. Do not wait until the compressor breaks down before replacing worn parts, because the breakdown may come at a time when the compressor is desperately needed. In this way, by properly following the preventive maintenance the compressor remains in a good condition, which not only increases its life but also keeps operating costs and capital expenditure to a minimum.

Check Your Progress 1

1. What are the main parameters in a compressor, which need to be checked daily on each start?

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2. What are the possible causes of overheating of compressor?

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3. What do you mean by general efficiency of a compressor?

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8.4 PREVENTIVE MAINTENANCE OF CONDENSERS AND EVAPORATORS

The main function of condensers and evaporators is to exchange heat between the refrigerant and outside environment. Thus these are maintained so as to exchange the maximum possible heat or to keep the heat transfer resistance at a minimum level. Various types of routine problems that come in operation of condenser and evaporator and their remedies are discussed as below:

i. Cleaning and De-scaling of Condenser

A condenser is either air-cooled or water-cooled or both i.e. evaporative type. Whatever be the type of condenser, its function is to transfer the latent heat of refrigerant vapours flowing inside the bundle of tubes to the surrounding air or water. This heat transfer can be badly affected if the outside surface of tubes is dirty or any scale or sludge is deposited on it. This problem is more serious in case of water-cooled condenser where the naturally available water is used for cooling purpose in condenser. This water may contain many types of salts and minerals, which deposit in the form of scale or sludge on the tube surface and cut the heat transfer. Deposit of dirt also cannot be avoided because the condenser is situated in open. So what we can do is only to follow the proper cleaning and de-scaling schedule to maintain the effectiveness of condenser. A compound named as potassium permanganate is generally added to the water to kill the fungi and keep away the slime deposit from accumulating upon the surfaces.

ii. Purging of Non-condensable Gases and Air

Theoretically, a refrigeration system is closed system. That means only the pure refrigerant flows through the system from one component to the other. But practically it is not completely closed. During the suction stroke in compressor, the pressure of refrigerant vapours above the piston becomes lower than that of atmospheric pressure. Due to low pressure in the compressor, outside air can leak through stuffing box and piston rings into the low-pressure refrigerant vapours. Air can also leak through the repair of compressor and other leaks in the suction line. Some air may also be initially present in ammonia while charging in the system.

Now, you must be thinking that what is the bad effect of presence of this air in ammonia vapours. Actually what happens, when the system runs, the air and other non-condensable gases do not condense in the condenser because their condensing temperature is considerably higher than the condensing temperature of ammonia. And due to their lightweight they collect at the top of the condenser or other high points in the system. The presence of these causes an excess condensing pressure, which increase power consumption. These also put an extra heat transfer resistance and make the condenser ineffective. Thus the air and any other non-condensable gas must be extracted or thrown out of the system for its efficient working. For this, the system is first shut down before allowing the purging of these gases through relief valves.

iii. Oil Traps Draining

In the compressor of a refrigeration plant, the lubricating oil layer between cylinder and moving piston come in contact with refrigerant vapours. Now if the refrigerant is miscible with lubricating oil, it will dissolve in the lubricating oil but the traces of lubricating oil will not mix in refrigerant vapours. It is the case with freon refrigerants and the system is safe against the problem of oil traces going with vapours. However, the choice of lubricant oils in freon compressor need very much care because if lubricant oil is not of right type, its lubricating property can be damaged by dissolved freon refrigerant vapours. On the other hand if refrigerant is immiscible in lubricating oil, it will not dissolve in lubricant oil but the oil traces will mix in refrigerant vapours. It is the case with ammonia, which is most frequently used in large size refrigeration plant of a dairy due to its other favourable properties. These oil traces will go to condenser and evaporator along with the ammonia vapour and form a layer on the inside surface of evaporator tubes and decrease the heat transfer. If some method is not used to prevent this oil to accumulate in evaporator, it will make the evaporator ineffective. For that oil traps are used after compressor which separates out the oil traces from ammonia vapours and prevent these to pass on to the condenser and evaporator tubes. In this way this trapped oil accumulates in the oil trap and must be drained at regular intervals. And whatever amount of oil is added to a crank-case of compressor the same must be drained out from the oil trap.

iv. Purging of Oil out of Evaporators

In spite of that oil trap is installed before condenser in an ammonia refrigeration plant. Some oil traces may pass through it and enter the condenser and evaporator coil along with refrigerant. As the temperature is low in the evaporator, the oil traces accumulate at the inside surface of evaporator coil and cut the heat transfer. In this way lubricating oil layer is more harmful in the evaporator and makes it ineffective. This oil must be purged out at regular intervals by warming up the evaporator coil and then draining the oil after disconnecting the evaporator from rest of the system.

v. Defrosting of Evaporator Coil

This is the another problem with evaporator coil, which cuts the heat transfer, and makes the evaporator ineffective. As the temperature at the surface of evaporator coil is very less, the moisture present in the surrounding air of cold room condenses on the coil surface and then freeze there in the form of frost. This frost puts an extra resistance to exchange of heat from air to refrigerant inside the tubes. This problem is common in case of natural convection evaporator. But in most of the refrigeration plants, a blower type (forced convection) cooling coil is used in which a blower pass the air over the cooling coil with high speed. The speedily passing air does not allow the frost to accumulate on the coil. But sometimes due to very low temperature or failure of blower, frost may come and need to be removed.

There are many types of defrosting methods used in the plant:

- By blowing hot air over the evaporating coil.
- By using electric heater for heating the evaporator and melting the frost.
- By blowing hot discharge gas in the evaporator coil, etc.

Check Your Progress 2

1. What routine maintenance is required in water cooled condenser of refrigeration plant?

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2. What routine maintenance is required in an evaporator of refrigeration plant?

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3. What is the need of fitting of oil trap in the discharge line of ammonia compressor?

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8.5 PREVENTIVE MAINTENANCE OF CONTROLS OF REFRIGERATION SYSTEM

We know that there are different types of indicating and safety devices and also the expansion/control valves in a refrigeration plant. These devices sense the various properties like pressure, temperature, flow, liquid level etc. of refrigerant flowing through the system. The indicating device simply indicates the value of these properties so that the operator and maintenance staff may see these values and have an idea of properly functioning of the plant. The safety devices sense the value of these properties and control accordingly the starting and stopping of the plant to keep these properties in a set range so that to ensure the safe and efficient working of the plant. The expansion/control valves also automatically control the flow and expansion of refrigerant through the system depending on the cooling load and evaporator temperature. In this way we see that the safe and efficient working of the whole plant depend on proper functioning of these control and safety devices just like the functioning of our body depend on functioning of our mind. Thus the 'timely checking, setting or replacement' of all the indicating/control devices is very much important for the safe and efficient operation of the plant. Many times a minor fault in the setting/adjustment of a control device greatly increase the wear and tear and hence the operation and maintenance cost. Controls should be checked at least four times a year, or often, if there is a fine adjustment to make. Making adjustments before hot weather operation is particularly important. The care and maintenance required in each type of these devices is discussed one by one as follows:

i. Thermostatic Expansion Valve

It is the main control valve in a refrigeration plant, which controls the flow of refrigerant depending on amount of superheat in the evaporator. It should be checked frequently at least once a month. Under normal operation, these valves are set for 10^{o}C superheat. But through normal wear in the needle valve and valve seat or also sometimes because of a large particle of dirt or any other foreign material, the valve may open wider even at less superheating. It results the excessive flooding of refrigerant in the evaporator, which will cause liquid traces of refrigerant to pass on to the suction of compressor causing damage to the compressor and loss in efficiency. On the other hand if sometimes the gas leaks out of the feeler bulb, the valve will be closed due to spring action and will not allow liquid refrigerant in the evaporator, thus stopping the cooling. The thermostatic valve should be serviced or replaced as per the manufacturer's recommendations.

ii. Float Control Valve

It keeps the liquid ammonia at proper level in the evaporator. If this valve is sticking closed, the evaporator is starved of liquid, which cuts its cooling capacity. It increases the running time for compressor. On the other hand if due to normal wear and tear or due to any dirt at the valve seat, the valve remains open, even at proper liquid level, it allow too much liquid in the evaporator. It may cause liquid traces of refrigerant to pass on to the suction of compressor. It not only causes damage to the compressor, but also circulates more ammonia than is necessary, which means a loss in efficiency. Thus float control valves should be checked very often, and float and valve kit should be replaced at least once every 6 months or more frequently if they do not respond to adjustment.

iii. Solenoid Valve

It is an electrically operated valve in which the force of a magnetic coil operates valve-stem. Normally, it remains in closed position, but when electric current is supplied to the magnetic coil, magnetic force generates, which open the valve. When current is stopped, it again comes to the closed position. These are used to stop the flow of either liquid or gas at different points in the system to isolate that particular cooling unit or room from the main suction and liquid lines. These valves are usually trouble-free, except for the burning of the magnetic coil, which lifts up the valve stem. On burning of magnetic coil it needs replacement.

iv. Back Pressure-Regulating Valve

In some refrigeration systems 'back pressure regulating valve' is fitted in the suction line of compressor. The function of this valve is to maintain a constant suction pressure and also so the temperature in the evaporator. Any faulty working of this valve may cause the temperature in evaporator too low allowing frost or ice to accumulate between the fins of evaporator and clog the entire unit. Hence regular check-up and setting for accuracy is needed for the back pressure-regulating valve.

v. Relief Valve

At some top point above the condenser, relief valve is given for purging of air and to release excessive pressure in the system. After the excessive pressure has been brought down to normal, it should reseat automatically. However, a particle of dust can hold the valve slightly open and allow ammonia to leak out. If it remains unchecked, a large amount of ammonia can escape through it. So, the valve must be checked and reseated at regular intervals.

vi. Water Flow-regulating Valve

In the shell-and-tube type condenser, a water flow-regulating valve is fitted, which is usually actuated by the condenser pressure. This valve automatically regulates the flow of cooling water so as to keep a constant pressure in the condenser regardless of the variation in flow rate and temperature of refrigerant vapours. If this valve is not checked occasionally, many thousands of liters of water can go waste.

vii. Filter/Strainer

We know that the working of a control/expansion valve is very much sensitive to the presence of any dirt, scale or rust particle in the flowing refrigerant liquid, which may come through fresh charging or rusting in pipes. Any such particle can be filtered from the refrigerant liquid before flowing to the control valve. Thus to install a filter/ strainer before the control valve in the refrigerant line is a usual practice. On running of the plant, this filter/ strainer may get clogged after some period and then needs to be cleaned/ washed or replaced. It should be checked at least once a year.

viii. Pressure Gauge

These are the main indicating devices, which give us the idea that how the refrigeration system is operating. After being in use for some time, the pointing needles of these gauges may either stick or show too high pressure. Any false readings may lead to wrong adjustments, which will affect proper functioning of the refrigeration system. There is an adjusting screw by which the pointing needles can be set to zero. If gauges become rusty and hard to read, replace them, as the cost is very small when compared with the loss due to false readings.

ix. Thermometers

These are installed in the various suction lines, compressor discharge lines, cooling water inlet and outlets, storage rooms, and at other convenient points in a refrigeration plant to indicate the temperature of flowing fluids. These should be frequently checked to see that they are not broken, easily visible and installed properly at the site.

x. Rotameter and Watermeter

These are some other types of indicating devices, which indicate the flow rate of refrigerant and cooling water through the condenser. These should be in working condition and should be replaced if not repairable.

xi. Temperature Controller

It must be kept properly adjusted and set to the required value, as wrong adjustments either will keep higher temperatures than desired in the refrigerated space or lower temperature which will tend to keep the compressors operating longer. The higher temperature than designed may effect the preservation of food products in a cold storage. And lower temperature than that designed will increase the power consumption of the plant. So any wrong adjustment or improper functioning of temperature controller effects the working of refrigeration plant to a large extent and its timely checking and setting must be taken care of.

xii. L.P and H.P. Cut-outs

These should be checked occasionally for their correct operation. Any wrong adjustment will either switch off the compressor unnecessarily or will not work even at dangerous limit of pressure in the suction and discharge line and leave the system unsafe. Thus from safety point of view correct setting of these pressure switches must be ensured.

Check Your Progress 3

1. What is the effect of wear and tear of thermostatic expansion valve or presence of any dirt particle between valve and valve seat on the performance of refrigeration plant?

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2. How the chances of liquid refrigerant going to suction of compressor increases with increase in mass flow rate of refrigerant by a faulty control valve?

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3. What are the effects of any wrong setting of temperature controller on the performance of refrigeration plant?

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4. What is the effect of sticking of float valve in its seat on the performance of plant.

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8.6 COMMON PROBLEMS AND REMEDIES IN A COMMERCIAL REFRIGERATION PLANT

In the previous topics, we have discussed about what care and maintenance should be carried out for each component of a refrigeration plant. All that care/maintenance is given the name as Preventive Maintenance. Because it prevents any problem or fault to appear during the operation of plant and halt its working. But in spite of keeping full preventive maintenance as per the set maintenance schedule, some problem, minor or major, may come at any time during the operation of plant. The minor problems generally have minor causes and remedies, which the operator may himself know and rectify. Hence the operator of refrigeration plant should know about the cause and remedies of some routine problems in plant. However, if the problem is major, such as any tube of evaporator or condenser or refrigeration pipe has punctured or any electric motor or component has burnt or the compressor has gone under heavy wear and tear or any other such miscellaneous problem by which the whole refrigeration plant breakdown, it should be attended by expert maintenance staff.

Here we will discuss some common problems, which appear in day to day working of refrigeration plant, and their possible cause and remedies in brief.

i. Compressor is not starting

1. Fault in electric supply to driving motor
   - Power may not be available. Check with voltmeter or test lamp.
   - Voltage may be very low
   - Any wire or electric connection may be burnt
   - Any defect in motor starter
   - Any one phase in 3-phase supply may be dead
2. Faulty overload cut-out/relay. Check it.
3. Faulty thermostatic switch or temperature controller which may keep the compressor in off position even at higher temperature of cold room due to faulty adjustment or wrong position of its probe. Check and readjust.
4. Faulty H.P./L.P. cutout switch due to faulty adjustment. Readjustment is required.
5. In case the motor is rotating without rotating the compressor, drive belt may be loose or worn out. Replace it.
6. There may be any fault in motor or compressor i.e. either may stuck. Remove the connecting belt and try to rotate both by hand. If any one is stuck, it need repair.

ii. Compressor Runs for too Long or Cooling is Slow

1. There may be excessive cooling load. Check if this is the case.
2. Too much frost may have accumulated on evaporator coil, which is cutting the heat transfer and hence cooling rate. Defrost the evaporator.
3. Thermostatic expansion valve may not work properly and may keep less flow of refrigerant even at full load. It may be either due to wrong placement of feeler bulb or less gas in the bulb. Flow of refrigerant may be judged by looking at sight glass or on the scale of rotameter, if fitted in refrigerant line.

4. The temperature controller or thermostatic switch may be faulty.
   - It may be set for too low temperature. Recheck.
   - The temperature sensing probe is placed at wrong position i.e. in the warmer region. Check it.
   - There may be some inside fault in its circuit. Take suitable corrective measures.
5. Poor condensation due to high discharge pressure in the condenser. There may be many reasons for high discharge pressure. Purge the air and non-condensable gas, if any. See if the condenser needs cleaning or de-scaling.

iii. Frequent Starting and Stopping of Compressor

1. Fault in setting of cut-in and cutout temperature in temperature controller. The difference in cut-in and cut-out temperature may be very less. Reset the temperature controller.
2. The probe or bulb of temperature controller/thermostatic switch is placed directly in cold air stream in front of blower. Due to that the temperature at probe decreases at a fast rate thus switching off the compressor before the whole space in cold room comes at designed low temperature. Check and re-position the probe.
3. Due to less suction pressure or less amount of refrigerant vapours at the suction of compressor LP cutout may switch off the compressor. There may be many reasons for low suction pressure, such as
   - Less quantity of refrigerant in the system.
   - Inefficient heat transfer in evaporator either due to heavy frost or evaporator surface dirty or excessive amount of oil in evaporator or blower is not working, etc.
   - Faulty expansion valve, which does not allow the sufficient flow of refrigerant.
4. Faulty overload relay. Check and repair/replace.
5. High discharge pressure due to ineffective condensation of refrigerant vapours in condenser, which switch off the compressor frequently through H.P. cutout. There may be many reasons for high discharge pressure as follows:
   - Air in the condenser tubes.
   - Too much dirt, scale or sludge has accumulated in the condenser tubes.
   - Inefficient supply of cooling air or cooling water
6. Faulty H.P. and L.P. cut-out. Check and re-adjust.

iv. In-sufficient Cooling/Cold Room is Less Cold

1. Excessive cooling load than that is designed.
2. Too much crowding of food containers which may restrict the diffusion of cold air. Arrange suitably the food containers.
3. Faulty setting of temperature in Temperature Controller. Reset it.
4. Frequent starting and stopping of compressor or less running time of compressor due to various reasons explained in the previous section. Take corrective measures.
5. In-efficient refrigerant flow rate due to less charge in the system. Check the correct pressure of refrigerant in the system.
6. In-efficient compressor, which is not compressing the gas efficiently because of heavy wear and tear or loose driving belt. Take necessary action.
7. Condenser becomes ineffective and need cleaning and servicing.

8. Evaporator coil is less effective due to heavy frost or excessive oil in tubes. So, defrost it and drain the oil, if any.
9. Faulty thermostatic control valve, which does not increase the flow rate of refrigerant liquid to evaporator on increase in superheating in evaporator or increase in cooling load. Check the feeler bulb and capillary. Also check for sticky valve.
10. In case of float valve, the valve may stick in the valve seat thus starving the evaporator from liquid refrigerant. Float valve needs servicing.

v. Heavy Cooling/Cold Room is too Cold

1. Fault in temperature controller setting.
   - Setting of temperature is disturbed and it is set for a lower temperature. Reset it.
   - Temperature controller is not working i.e. is not switching off the compressor when designed temperature is attained. Check and adjust it.
   - Temperature sensing probe is placed at some dead zone, which is warmer than the cold room. Place it correctly.
   - Faulty probe which is not giving correct temperature. Replace the probe.

vi. Excessive Power Consumption of Refrigeration Plant

1. Due to increase in cooling load by
   - Increase in temperature of products at the time of storing.
   - Surrounding temperature is very high due to hot season.
   - Doors of cold room are kept opened for longer times than required.
   - Door sealing/ gasket has worn out
   - Insulation may become less effective by absorbing moisture from any broken layer
2. In-efficient compressor which need overhauling or replacement.
3. Capacity of condenser is either small or it has become less effective due to other reasons.
4. Capacity of evaporator is small than the designed load or it has become less effective due to other reasons.
5. Quantity of refrigerant is either more or less than that required i.e. suction and discharge pressures are not in designed range.

   All the above causes are required to be rectified for reducing the power consumption or running cost of plant.

vii. Noisy Operation

If any part of refrigeration system is producing abnormal noise during running of plant, mostly it itself indicates that what is wrong with it. And so one can judge easily by common sense that what remedial action is required.

As the compressor has many moving parts, it can produce different types of abnormal sounds due to any type of wear and tear, which should be checked by some expert maintenance staff.

Check Your Progress 4

1. How does a fault in setting or working of thermostatic switch or temperature controller may disturb the normal working of compressor?

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2. How do any default setting of a safety device like LP, HP cutout or overload cut-out may disturb the normal working of compressor?

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3. How do a less effective evaporator will deteriorate the working efficiency of refrigeration plant?

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4. How do a less effective condenser will deteriorate the working efficiency of refrigeration plant?

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8.7 LET US SUM UP

There are some general tips, which are to be followed for general check up of a refrigeration plant during operation. A plant operator must know about these tips. In addition to that a plant operator must be aware of the preventive maintenance schedule to be followed for each and every component. Compressor must be checked for any abnormal noise, leakage of oil and overheating etc. Its efficiency can be checked occasionally. The oil level and oil pressures are very important parameters to be checked while running of compressor. Maintenance schedule recommended by manufacture must be followed. The suction and discharge pressures indicated by pressure gauges are good measures of efficient working of whole refrigeration plant. These must be in a set range. In the maintenance of condenser, the routine cleaning, scaling down and purging of air and non-condensable gases are important. The proper working of cooling fan or cooling water pump should be ensured. In the maintenance of evaporator, draining of oil and defrosting are important because the oil layer accumulated inside the tubes and frost accumulated outside the tube cut the heat transfer to a great level and make the cooling coil ineffective. The proper setting and maintenance of controls is also very important as minor adjustment of controls can greatly effect the working of plant and make good energy saving. The common problems in different components and their cause and remedies have also been discussed in the end.

8.8 KEY WORDS

Preventive Maintenance	:	Any repair/servicing, which is done at regular interval as per the fixed schedule irrespective of occurrence of any fault.
Breakdown Maintenance	:	The repair/overhauling which is done when an equipment stop working due to a major fault.
Effectiveness	:	Effectiveness of an equipment means its capacity to perform or its capacity to do the designated work.
Purging	:	Removing or cleaning.
Non-Condensable	:	Any gas which cannot be condensed or changed into liquid at the available conditions of pressure and temperature.
Oil Trap	:	Equipment which is capable of separating out lubricant oil fumes from refrigerant gas.
Oil Strainer	:	A filter which cleans the lubricating oil by removing dirt or carbon particles.
Feeler Bulb	:	Which is attached with outgoing tube of evaporator and the gas filled in it sense the temperature and transmit it in the form of pressure fluctuations to the thermostatic control valve.
Sight Glass	:	A small hole in side wall of crank case and in which an air tight glass is fitted for checking the oil levels.
Rotameter	:	An instrument fitted in refrigerant line which measure the flow of refrigerant.

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8.10 ANSWERS TO CHECK YOUR PROGRESS

Your answer should include the following points:

Check Your Progress 1

1) i. Oil level, oil leakage, oils pressure, drive-belt tension, discharge and suction pressure, cooling water supply.

2) i. Improper working of suction & discharge valves

ii. Inadequate supply of cooling water

iii. High range of suction and discharge pressures

3) i. General efficiency of compressor means the work done by it in increasing the pressure of refrigerant gas per unit of power supplied.

Check Your Progress 2

1) i. Regularly check the working of cooling water pumps

ii. Check for any leakage of water and rectify it

iii. Clean and de-scale all the heat transferring surface by following the proper cleaning schedule

iv. Keep watch on condenser pressure and purge out any air or non-condensable gas through the relief valve

2) i. Keep watch on properly working of air diffusion fan or blower.

ii. Don't allow frost to accumulate on evaporator coil surface

iii. Purge oil out of evaporator if it seems to have become ineffective.

3) i. In case of ammonia compressor the lubricating oil traces mix with ammonia vapours and if these are not trapped, will go to condenser and evaporator coil.

ii. Due to less temperature in evaporator, the oil traces will form a layer on the inside surface of evaporator tubes and cut the heat transfer.

Check Your Progress 3

1) i. On reduction of cooling load, the valve should come close to valve seat automatically and reduce the flow of liquid refrigerant accordingly. But due to wear and tear or dirt particles, valve remains wide open and does not reduce the flow rate of refrigerant thus flooding the evaporator with liquid refrigerant. Due to flooding, the liquid may directly go to suction of compressor without evaporation and badly damage the compressor.

2) ii. When mass flow rate of liquid refrigerant is more than the rate of evaporation in evaporator, liquid fills all the space in evaporator. When liquid level is more than that designed in evaporator, it may slip in the suction line of compressor, thus increasing the chances to be sucked by compressor.

3) i. If cut in and cut-out temperature set in the temperature controller are not in the range of temperature required in cold storage, it may affect the preservation or storage time of food products placed in cold store.

4) i. If the difference between cut-in and cut-out temperature known as differential is too small, the compressor will undergo short cycling i.e. will frequently stop and start, which adversely affects its normal working.

5) i. The evaporator may be starved off liquid refrigerant and so may become ineffective thus badly affecting the cooling in cold storage.

Check Your Progress 4

1) i. In the normal working, there should be sufficient time period between two successive start ups of compressors for equalization of pressure in high side and low side. If, by default, the difference between cut-in and cut-out temperature set on.

2) i. Temperature controller is very small, the compressor will frequently start and stop. Due to this short cycling, the compressor will go undue wear and tear.

3) i. Due to any default setting in a safety device either it may switch off the compressor unnecessarily even under normal conditions or it may allow the compressor to run even in dangerous limits of pressure or load.

4) i. When the resistance to heat transfer from products to refrigerant gas increases in an evaporator, it is called less effective.

ii. Due to ineffectiveness of evaporator, the cooling in cold room will decrease.

iii. On the other hand, due to less heat exchange, the evaporation of refrigerant liquid will reduce thus reducing the suction pressure

iv. If suction pressure decreases than a lower limit, compressor will switch off automatically even when more cooling is required in cold storage. Overall effect of all the above facts is to reduce the working efficiency of the plant.

5) i. A condenser becomes less effective when the heat exchanged between refrigerant vapours and cooling air or water decreases due to increase in heat transfer resistance.

ii. Due to less heat exchange, the condensation of refrigerant vapours will decrease, i.e., the quantity of condensed liquid will decrease but that of vapours will increase.

iii. Due to less quantity of refrigerant liquid coming from condenser, less will be supplied to evaporator and hence less will be the cooling produced.

iv. Due to increase in quantity of vapours, their pressure will increase and if it crosses a certain limit, the compressor will switch off automatically even when the cooling is required and system need to run.

UNIT 9 BASIC PRINCIPLES OF STEAM GENERATION AND DIFFERENT TYPES OF BOILERS

Structure

9.0 OBJECTIVES

After studying this unit, we should be able to:

- define the principles of generating steam in a dairy plant
- describe the process of steam generation
- identify and classify various types of steam boilers
- describe the working of a steam boiler

9.1 INTRODUCTION

Handling of milk and processing it into various milk products requires effective heating arrangement. Amongst the several alternative-heating arrangements, heating of milk in the vessel with the help of steam is the most convenient and appropriate. Steam can be transported through pipelines from its source of generation to all the places of utilization very conveniently. It is the most economical and common source of heat energy, and has been adapted by all the milk processing plants. It is thus of primary importance to have an understanding of generation of steam and its effective utilization in a milk processing plant for safe operation of dairy machinery. The understanding of different types of steam and its heat content is necessary to estimate the amount of steam required for a given processing operation. Knowledge of steam generation appliances and the steam distribution lines helps in effective utilization of steam in a milk processing plant.

9.2 FORMATION OF STEAM

i. Water in Vapour State

If we heat water in a pan placed over a furnace, the temperature of water gradually increases. As the water reaches the boiling stage, vapours will start emanating from its surface. This is water in vapour form and we call it steam. The steam is thus defined as ‘Water in Vapour State’. It is known that, if water is to be boiled in an open pan, it has to be heated up to 100^oC. The pressure above the surface of water in an open pan is that of the atmosphere. Thus the temperature of raising steam at atmospheric pressure is 100^oC. If the pressure above the surface of water is changed, the temperature of raising steam would also change. If this pressure is increased, the temperature of boiling of water also increases. This phenomenon can be very well understood, if we observe the working of pressure cooker in our home.

The weight placed over the lid of pressure cooker helps in increasing the pressure in the vessel. This increases the temperature of boiling of water in it and the vegetables in the cooker get cooked fast in the vessel. Conversely, if we decrease the pressure on the surface of water, its temperature of boiling decreases. It means that water will boil at a lower temperature under reduced pressure or in the vacuum. The above principle is true for all the fluids which could be vaporized.

ii. Saturation Temperature & Pressure

Water, like other volatile materials can thus exist as vapour at different temperatures and pressures. This temperature at which water is converted into vapours at a given pressure is called as 'Saturation Temperature' of raising steam. The saturation temperature of steam at atmospheric pressure is thus 100^oC. The corresponding pressure of raising steam is known as the 'Saturation Pressure' of steam. The saturation pressure of water vapours generated in an open pan would be thus equal to one atmosphere. If the steam is to be raised at a higher saturation pressure, it has to be then generated in a closed vessel. The saturation temperature of steam at the higher pressure would be more and it shall also contain more heat content in it. To make use of steam as a heating medium and also to work out the amount of steam required for a particular milk processing activity, the saturation temperature and the saturation pressure of steam must be known.

9.3 DIFFERENT TYPES OF STEAM

We have learnt about the basic principles of steam generation and its advantages as a heating medium in the context of dairy plants. Now we will go through the different types of steam and how they are different from each other.

i. The Saturated Steam

We know that to generate steam at a given pressure, we have to heat the water in a closed vessel to the saturation temperature of steam generation corresponding to that pressure. Steam thus generated is known as 'the saturated steam'**.** If the steam contain water droplets in it, this will make the steam wet. The steam which remains in contact with water is usually wet. This type of steam is called as **wet saturated steam**. If we separate the water droplets from the steam this will make it dry. This type of steam is known as **dry saturated steam**. A dry steam thus contains no water droplet in it and a wet steam is a mixture of dry steam and water droplets. In milk plants we usually find the wet steam.

ii. Dryness Fraction of Steam

A wet steam means all of the water in it is not in the vapour form. If in 1 kg. of wet steam there are 0.1 kg of water droplets , the rest 0.9 kg will be the dry steam. The ratio of the weight of dry steam in a given wet steam is known as the 'dryness fraction' of the stream. In the above case the dryness fraction of steam would be 0.9. If whole of the steam is dry and there is no water droplet in it, then the dryness fraction of such a steam would be 1.0. In dry steam whole of the water in it will be in the vapour state. The dryness fraction of steam expresses the quality of steam. The more the dryness fraction of the steam, more dry it will be, as more of the water in it will be present in the vapour state. Wet steam could be made dry by passing it through steam separators, in which water droplets are removed from the steam and the steam dries up.

iii. Superheated Steam

Many a times, more heat is provided to the steam, after separating the saturated steam from water, to increase its temperature further. Such a steam is known as superheated steam. Pressure of superheated steam is, however, kept same as that of saturated steam. This is done in a separate device known as Steam Superheater. The super heated steam has higher heat content as compared to saturated steam.

Check Your Progress 1

1. What is Steam

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2. Temperature at which water is converted into vapours at a given pressure is known as:

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3. A wet steam means all of the water in it is not in vapour state, is it correct?

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4. Define dryness fraction of steam.

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9.4 HEAT CONTENT OF STEAM

Let us decide upon the pressure at which the steam is to be generated. After fixing the pressure, we can know the saturation temperature of steam at this pressure from steam tables. This means, water has to be heated to this temperature before the steam will be produced. We can therefore, understand the heat content of formation steam in two stages, the warming stage and the evaporation stage.

i. Warming Stage

During the Warming Stage, heat is added to water so that its temperature is increased to the saturation temperature. At atmospheric pressure the saturation temperature of steam is 100°C. Therefore we will have to heat water up to 100°C for producing steam. For one kg. of water, the addition of heat will raise the temperature of water at the rate of 1^{o}C for every 4.19 kJ of heat added. The heat supplied during the warming stage is known as **Sensible Heat** because it can be detected by sense of touch and produces a rise in temperature to be seen on a thermometer. The amount of sensible heat required to raise the temperature of water from 0 to 100^{o}C would thus be equal to 419 kJ / kg. The sensible heat content increases if the saturation temperature is increased.

ii. Evaporation Stage

In the Evaporation Stage, further heat is applied to 1 kg of water at saturation temperature and pressure. During this stage heat is utilized in changing the state of water from liquid to Vapour state. Temperature remains constant as the evaporation is in progress. Because the heat added during this stage cannot be recorded by a rise in temperature on the thermometer, it is a hidden heat and is called as the **Latent Heat of Vapourization.** The latent heat of vapourization of water is 2257 kJ / kg. Any further addition of heat at 100^{o}C would increase the temperature of vapours approximately at the rate of 1^{o}C for every 1.97 kJ of heat added per kg and will produce superheated steam.

Total heat content of steam would thus depend upon the type of steam. Dry saturated steam is obtained when all traces of liquid in steam is vapourized with just enough of heat to vapourize the liquid. Removal of heat from dry steam causes moisture to condense out and would result in a wet steam. If we measure from 0^{o}C, one kg of dry saturated steam has a total heat content of 419 + 2257 = 2676 kJ. On the other hand, the heat content of one kg. of 95% quality steam (5% moisture) would be 419 + (2257 x 0.95) = 2563 kJ. Addition of 2257 x .05 = 113 kJ of heat would be required to change 95% quality steam to dry saturated steam. Super heated steam contains more heat energy than dry saturated steam. Heat content of dry saturated steam and the superheated steam is usually indicated in a table form along with its saturation pressure and the corresponding temperature. These tables are known as steam tables and are used in estimating the steam requirement for a required milk processing operation.

For example, let us calculate the amount of steam required to pasteurize 500 kg. of milk from 20^{o}C to 72^{o}C. The specific heat of milk is 3.914 and that of water is 4.187 kJ/kg/^{o}C. We shall now require the information on type of steam and the available steam pressure. Let the steam available is of 90% quality, the steam pressure is 3 kg/cm^{2} and the temperature of steam condensate leaving the vessel jacket is 50^{o}C. We shall now make the calculations in the following way:

Milk:

Heat required for heating 1kg.Milk by 1^{o}C	= 3.914 kJ
Heat required for heating 500 kg. Milk from 20 to 72^{o}C	= 3.914 x 500 x (72-20)
	= 101764 kJ

Steam:

Latent Heat of steam (from steam tables) at 3 kg. /cm^{2}	= 2171 kJ
Latent heat of 90% quality steam = 0.9x 2171	= 1954 kJ
Heat of liquid i.e. sensible heat (from steam tables)	= 558.9 kJ
Total heat content of 90% quality steam = 1954+558.9	= 2512.9 kJ
Total heat of 50^{o}C steam condensate = 50 x 4.187	= 209.35 kJ
Net available heat per kg of steam = 2512.9 – 209.35	= 2303.55 kJ
Amount of steam required = 101764 ÷ 2303.55	= 44.18 kg

We now know what steam is and what the basic principles of steam generation are. We have also understood the different types of steam and how to make calculations for the quantity of steam required for accomplishing a given processing operation. Now let us know about the equipment in which steam is generated, that is a steam boiler and understand its construction and functioning.

Check Your Progress 2

1. Heat added to water during warming stage is known as

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2. Heat added to water during evaporation stage is known as

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3. Which steam contains more heat content, Wet Saturated Steam or Dry Saturated Steam?

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9.5 STEAM BOILER

Evaporating the water at appropriate temperature and pressure does the generation of steam. It might look that to perform this function is an easy task. But if large quantities of steam at high pressure are to be produced rapidly and with economy then a considerable amount of skill and specialized equipments are required. The production of steam at high pressure in large quantities would not be possible and economical if the water is heated in ordinary way in a vessel with furnace at its bottom. The heat will go to waste in large quantities by radiation. There will not be an efficient heat transfer to water and evaporation of water may not be controlled. In order to overcome these defects water is evaporated in a closed vessel, in which heat transfer and the evaporation process is controlled. This equipment is known as steam boiler.

Boiler is thus, a vessel in which steam is generated. Heat is produced in the boiler by burning of fuel. This heat is transferred to the water contained in the boiler and the water evaporates to form steam. As has been discussed earlier that steam is generated at a desired saturation pressure, the boiler thus also maintains the required pressure in it. A boiler is therefore also known as a pressure vessel. The construction and appearance of a boiler depends upon the arrangements made for burning the fuel and the mode of transfer of this heat to water.

i. Components of a Steam Boiler

Every boiler consists of three distinct regions, such as, the space for burning of fuel and flue gases, the space for water and the space for steam (figure 9.1).

The Fuel Space: It consists of the furnace chamber and the passage of hot gases as they flow through the boiler. The fuel is burned in the furnace chamber or the fire box. If the fuel is a solid fuel, such as, coal it is burnt by placing it over a grate .The **grate** consists of cast iron bars with spacing between the bars for the flow of air. If the fuel is oil or gas it is burned with help of a specially designed **oil or gas burner**. The combustion of fuel is maintained by a steady supply of air to the furnace. The waste furnace gases escape the boiler through a high **chimney**. A high chimney helps in safe discharge of waste gases in the atmosphere and also creates a necessary pressure differential for flow of air and gases in the boiler.

The Water Space and Steam Space: The water and steam in the boiler is contained in metallic water drums and tubes. The **water space** is the volume of the drum or shell that is occupied by water, and **steam space** is the volume of the entire shell not occupied by water. The level at which the water stands in the boiler shell is known as **water level** and it is indicated by a water level indicator. The level of water fluctuates in the boiler at times but for the best operation the variation should be small. The heating surface is the surface of shell exposed to the fire or the hot gases from the fire.

Fig. 9.1 Constructional Features of a Boiler

The general constructional features of a boiler are illustrated in fig. 9.1. In its simplest form, the boiler shell is kept vertical. It consists of a large cylindrical shell. A firebox is provided in the shell by suitable positioning it with metal plates. The firebox carries a grate at the bottom. The water space in the shell surrounds the firebox from all sides.

The Uptake and Chimney: A tube called **the uptake** starting from the top of firebox passes through the shell and connects the base of the chimney. The chimney is placed at the top of the uptake. One or more cross tubes are is fitted across the firebox to increase the heating surface area and to ensure better circulation of water. A fire-hole is provided in front of the boiler slightly above the grate level. A manhole and a hand hole are provided in the shell to have an access for cleaning. To drain the mud that settles down a mud hole is provided at the bottom. All the openings are closed with suitable covers.

ii. Functioning of a Boiler

The coal burns in the firebox over the grate. Heat produced by burning fuel in the firebox is radiated to the water in the boiler shell. The hot gases while moving upward come in contact with cross tubes and then pass through the uptake tube. During this contact, they give part of their heat to the metal of the tubes and this heat is transferred to water. The water gets heated up and evaporates. The steam produced by evaporation of water gets accumulated in the boiler shell, in the space above the surface of water. The steam generated in the boiler is then tapped off through a suitable valve fitted in the steam portion of the shell.

A boiler also has component units which are primarily intended for the safety of boiler. These components are mounted on the body of the boiler and are known as **Boiler** mountings. Various boiler mountings include: pressure gauge, safety valve, water-level indicator, fusible plug, the safety and satisfactory working of the boiler largely depends upon the reliability of these mountings. We shall discuss various essential boiler mountings in detail in Unit-10.

In the smaller boilers the firebox forms an integral part of the boiler shell. But in large boilers it is separately constructed of brickwork and is known as settings. The brickwork forms the walls of furnace and combustion chamber. It confines the heat to the boiler and makes passage through which the hot gases pass. It also provides support to the boiler shell.

Steam is generated in the boiler under the set of conditions of inlet water and exit steam, while a certain rate of fuel is being consumed. It is neither practical nor expected that whole of the heat produced by the combustion of fuel in a boiler will be transferred to water for generation of steam. Certain amount of heat will go to waste through radiation and through flue gases, etc. Nevertheless, a good boiler is one which gives the economy of steam generation and provides high performance efficiency.

iii. Requisites of a Good Boiler

We would now specify and lay down the necessary requisites of a good boiler. Requisites of a good boiler could be listed as follows;

a) It should be capable of producing maximum amount of steam with minimum cost.

b) It should be capable of quick starting and should be able to meet the variations in steam requirements.

c) All parts and components should be easily accessible for inspection and repair.

d) In order to make the best use of heat supplied, the boiler should have proper arrangement of circulation of water and hot gases.

e) It should be safe in working.

There are many factors for selection of a boiler for a given situation. The most important ones are: the required steam capacity, working pressure in the boiler and the availability of fuel. Based on these the size and the type of boiler are selected. We therefore now need to know about various types of boilers and how these are classified.

9.6 DIFFERENT TYPES OF STEAM BOILERS

In order to have an efficient heat transfer from flue gases to water in the boiler, the heat transfer surface should be made as large as possible. To achieve this two methods could be thought of and based on this the boilers are categorized into two categories.

i. Fire-Tube Boilers

First method could be that the water to be evaporated is contained in a vessel, which is provided with large number of tubes as shown below in figure 9.2.

Fig. 9.2 Principle of a Fire-Tube Boiler

If the hot gases from the furnace are made to flow through the tubes, then a large amount of heating surface of these tubes will be exposed to water to heat the same. Thus considerable amount of water particles will be able to come directly in contact with heating surface. The boilers designed on this principle are known as fire tube boilers. In the fire-tube boilers, the hot flue gases from the furnace are made to pass through the tubes and water surrounds these tubes. The number of tubes varies as per the capacity and design of the boiler. A boiler with large number of tubes is known as multi-tubular boiler. These tubes are placed in the boiler shell. Water in the shell is heated by the conduction of heat from hot gases through the walls of the tubes. Since the shell holds a large amount of water, the evaporation process is slow and it takes more time to raise steam in such boilers. This type of boilers cannot be used to work under very high pressure and are usually made for smaller capacity.

ii. Water-Tube Boilers

In the second case, a chamber consisting of a furnace at the bottom is provided with a number of tubes as shown in fig.9.3.

Fig.9.3 Principle of a Water-Tube Boiler

Here the hot gases travel from the furnace to the chimney through the space outside the tubes in the chamber, while water, which is to be heated, is circulated through the tubes. The boilers designed on this principle are known as water tube boilers. Thus, in the water-tube boilers, the water is contained inside the tubes and hot flue gases from outside surround these tubes. Since the amount of water contained inside the tubes is small the heating is efficient and the evaporation is faster. This helps in increasing the capacity and the working pressure of the boiler. However, these boilers require more attention and the cleaning of tubes is difficult.

Commercial Boilers

Amongst the commercially available fire tube boilers are : Cornish boiler, Lancashire boiler and the Locomotive boilers. Various commercially available water tube boilers are : Babcock & Wilcox boiler, Sterling boilers, etc.

iii. Additional classification of boilers

In addition to the above classification of boilers into fire tube or water tube boilers, further classification of conventional type of boilers may be done in many more different ways according to their construction and service conditions. Boilers are classified according to their use as Stationary, Portable and Locomotive. According to position of furnace inside the shell or outside the shell they are termed as internally fired or externally-fire boilers. Depending upon the circulation of water in the boiler they are classified as Natural Convection Circulation type or Forced Pump Circulation type boilers. A boiler is termed as a High Pressure Boiler if the working pressure is over 80 kg/cm^2 and as a Low Pressure Boiler if the working pressure is less than that.

9.7 OPERATING A STEAM BOILER

In the foregoing sections we have outlined the basic principles of steam generation and the component parts of a steam boiler. Therefore now we may find it convenient and helpful to refer to the earlier portions of this unit to understand the operation of a boiler while reading this section.

i. Feeding Water to the Boiler

For operating a boiler continuous supply of feed water is required. This is to maintain a constant water level in the boiler in relation to generated steam. Water is provided to a boiler by a *feed pump. This* pump is meant to force water into the boiler. Since the inside pressure of the boiler is high, the water needs pumping to a considerable pressure above that of boiler. Both reciprocating and rotary pumps could be used and generally pumps are installed in duplicate for the safety of boiler operation. Feed water is supplied to the boiler through a special one-way valve. This valve does not allow the back flow of water from the boiler due to higher pressure inside the boiler.

The water supply to a boiler is very important. In most localities the natural water contains impurities like suspended solids or the dissolved chemicals. Suspended matter can usually be handled by proper filtration. The dissolved impurities in water are due to compounds of calcium and magnesium. The water containing such impurities is known as hard water. If this hardness of water is not removed, these impurities result in deposition in the form of scale on the heat exchange surfaces in the boiler. The deposition of scale over the tubes in the boiler reduces the transfer of heat from the hot gases to water and decreases the steam raising efficiency of the boiler. It may also lead to corrosion of tubes and damage to the boiler. To avoid this problem, the feed water to the boiler is treated to remove its hardness. Specialized equipment is used for this treatment of water and it is known as *water softening plant*. It is advised to install a water softening unit with every boiler to assure a continuous supply of soft water, otherwise the boiler has to blown down and cleaned frequently and regularly.

ii. Air Circulation & Combustion of Fuel

Fans are used to provide adequate and continuous supply of air for combustion of fuel, circulating the hot gases in the boiler and to discharge burnt flue gases into the atmosphere. A small pressure difference is kept between the point of entry of air at furnace and the exit of burnt gases at the chimney. This pressure difference helps in the flow of air throughout the system. This pressure difference is termed as *boiler draught*. The amount of required draught depends upon the type of fuel and the rate of burning. A high chimney helps in creating the natural draught in the boiler without any fan. A chimney also facilitates the safe discharge of burnt gases to the atmosphere. But the amount of this natural draught is low and is used only in boilers of low capacity. For larger capacity boilers the requirement of combustion air is more and hence a fan is installed at the inlet to the furnace to provide positive pressure. This is called forced drought.

iii. Care and Maintenance

The time that should be taken in raising steam from cold water depends upon the type of boiler and the degree of urgency. In every case steam should be raised as slowly as possible. Similarly rapid cooling of boiler is harmful as it puts excessive strains on the joints. Periodic blow down is necessary with all types of boilers, no matter whether treated or untreated feed water is used. This removes all the solid impurities, if any, present in the boiler. Boiler undoubtedly deteriorates more rapidly when allowed to remain idle than during long periods of normal work. If it is required to remain idle for longer periods most satisfactory method is to remove all doors and covers and thoroughly clean and dry all internal and external surfaces and give a coating of a preservative paint.

Boiler occupies such an important place in dairy plant that much of plant's successful operation depends upon its unfaltering performance. The life of any steam generating plant is dependent upon the amount of care and attention it receives while under steam and during idle periods. Indian Boiler Act-1923 prescribes that only a Certified Boiler Attendant is authorized to operate a boiler. Yet it is worth while for all the dairy workers to become acquainted with general construction of the boiler, for overall safety and precautions.

Check Your Progress 3

1. What is a Steam Boiler?

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2. Differentiate between a Fire-tube boiler and a Water-tube boiler.

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3. What is the purpose of installing a Chimney in the boiler?

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4. Write the disadvantage of using hard water in the boiler?

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9.8 LET US SUM UP

Handling of milk and processing it into various milk products requires effective heating arrangement. Steam is the most economical and convenient source heat energy and has been adapted by all the milk processing plants. The steam is the water in its vapour state. To generate steam at a given pressure, we have to heat the water in a closed vessel to the saturation temperature of steam generation corresponding to that pressure. The wet saturated steam contains water droplets in it, where as, the dry steam has no water droplet in it. Dryness fraction of steam specifies the amount of water present in it. The heat content of steam depends upon the type of steam.

Boiler is a vessel in which steam is generated. Heat is produced in the boiler by burning of fuel. This heat is transferred to the water contained in the boiler and the water evaporates to form steam. A good boiler is the one, which produces maximum amount of steam with minimum cost. Classification of conventional type of boilers may be done in many more different ways according to their construction and service conditions. The major classification is in terms of the fire-tube or the water-tube boilers. The feed water to the boiler is treated to remove its hardness. Boiler occupies such an important place in dairy plant that much of plant's successful operation depends upon its unfaltering performance and therefore it requires due amount of care and attention while under steam and during idle periods.

9.9 KEY WORDS

Chimney : Structure through which smoke from a fire is carried away

Convection : The conveying of heat from one part of a liquid or gas to another by the movement of heated substance.

Evaporation : Change of state from liquid to vapour.

kJ : kilo Joules, unit of heat

Latent Heat : Hidden Heat, heat which cannot be sensed

Soft Water : Water which is free from hardness dissolved impurities, such as, compounds of calcium and magnesium

Steam Tables : Tables presenting the properties of stem in a tabulated form

9.10 SOME USEFUL BOOKS

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Arora C.P. (1998). Thermodynamics. Tata McGraw Hill Pub. Co., New Delhi

Farrall Arthur W. (1979). Food Engineering Systems, Vol.-2 Utilities. AVI Publication, Westport.

Holman J.P. (1978). Experimental Methods for Engineers (International Student Edition). McGraw Hill Book Company, New Delhi.

Eckman D. P. (1976). Industrial Instrumentation, Willey Eastern Ltd., New Delhi.

9.11 ANSWERS TO CHECK YOUR PROGRESS

Your answers should include the following points:

Check Your Progress 1

1) i. Steam is water in vapour state.

2) i. Saturation Temperature

3) i. Yes

4) i. Dryness fraction is the ratio of dry steam in a given wet steam.

Check Your Progress 2

1) i. Sensible Heat

2) i. Latent Heat of Vapourization

3) i. Dry Saturated Steam

Check Your Progress 3

1) i. Boiler is a pressure vessel in which steam is generated.

2) i. In the fire-tube boilers, the hot flue gases from the furnace are made to pass through the tubes and water surrounds these tubes. In the water-tube boilers, the water is contained inside the tubes and these tubes are surrounded by hot flue gases from outside.

3) i. A chimney facilitates the safe discharge of burnt gases from the boiler to the atmosphere. It also helps in creating the natural draught in the boiler for the circulation of air.

4) i. Hardness of water result in deposition in the form of scale on the heat exchange surfaces in the boiler. The deposition of scale over the tubes in the boiler reduces the transfer of heat from the hot gases to water and decreases the steam raising efficiency of the boiler.

UNIT 10 CONTROL AND SAFETY DEVICES FOR STEAM BOILERS

Structure

10.0 OBJECTIVES

After studying this unit, we should be able to:

- identify various boiler mountings essential for safety and control of boiler operation
- classify the boiler mountings
- understand the purpose of their installation
- describe the principle of working and constructional features of various boiler mountings.

10.1 INTRODUCTION

We have learnt in the previous unit that steam is the most economical and convenient source of heat energy and has been adapted by all the milk processing plants. You have also known about the principles of generating steam, different types of steam and their heat contents and how the necessary calculations are made to estimate the amount of steam required for a given milk processing operation. We have understood the general constructional features of a boiler, in which the steam is generated. The Boiler occupies such an important place in dairy plant that much of plant's successful operation depends upon its unfaltering performance

The safety and satisfactory working of a boiler largely depends upon the reliability of several component units, which are mounted on the body of the boiler. These devices are primarily intended for the safety of boiler and control of its operation. In the foregoing Unit-9 no discussion has been made about these devices, so in this unit we shall discuss various essential boiler mountings in detail.

10.2 BOILER MOUNTINGS AND ACCESSORIES

All boilers are fitted with mountings or accessories for the safety of the boiler and for complete control of process of steam generation. These components or elements function with the boiler as a whole and contribute their individual share in the task of steam generation.

i. Boiler Mountings

One category of such component units, primarily intended for safety of boiler, which are installed or mounted on the body of the boiler itself are known as *boiler mountings***.** The safety and satisfactory working of boiler largely depends upon the reliability of various boiler mountings. In accordance with the Indian Boiler Regulations, the following mountings must be fitted to the boilers: two safety valves, a fusible plug, two water level indicators, a pressure gauge, a steam stop valve, a feed check valve, a blow off cock, an attachment for inspector's test gauge, a man hole and a mud hole or sight hole.

ii. Boiler Accessories

Another category of components or elements are the auxiliary units, which are installed with the boilers. These auxiliary units are known as *boiler accessories*. They either help the boilers in their working or increase the efficiency of the boilers. The accessories attached to a modern boiler are: feed pump, feed water heater, air pre-heater, steam super heater and the draught equipment.

10.3 BOILER SAFETY MOUNTINGS

i. Safety Valve

As you know steam is generated in the boiler at a particular pressure. There are possibilities that the steam pressure in the boiler continues to rise and may exceed the value for which the boiler is designed. This may happen due to many reasons, such as, if the water in the boiler shell decreases or the feed water pump fails or the burner continues to supply heat even if the required steam pressure is reached or the steam demand is decreased.

If such thing happens the boiler shell will get overheated and may explode and result in great damage. To avoid this thing to happen, the boiler is provided with a safety device, which is known as the *Safety Valve.*

Function of Safety Valve: The function of a safety valve is to safeguard the boiler from the hazard of pressures higher than the design value. It prevents the steam pressure in a boiler from exceeding a prefixed value. If the inside pressure exceeds the maximum working pressure, this valve opens and automatically discharges the steam from the boiler.

When once the excess steam is vented out and the pressure in the boiler is reduced to the working pressure the safety valve resets to its closed position automatically. The safety valve is located at the highest point in the steam space.

Types of Safety Valves and their construction

The safety valves may be classified into two groups:

a) Weight loaded safety valves

b) Spring loaded safety valves

Dead Weight Safety Valve: The weight loaded safety valve is commonly known as Dead weight safety valve and is illustrated in fig 10.1.

In this valve the weight, in the form of cylindrical cast iron discs, is placed directly on the valve. The valve is made of gunmetal and rests on a gunmetal seat. It is secured on the top of a vertical cast steel pipe. The pipe is bolted to the mounting block which is riveted to the top of the shell. The valve is threaded into a large cast iron casting which is like a vertical pipe like cover. This cover pipe carries the cylindrical disc shaped weights in it. Thus the total load on the valve is the sum total of weight of the valve itself, the weight of cover pipe and the weights placed on the cover pipe. When this load is greater than the force due to steam pressure acting on the valve, the steam will not escape. When the force due to steam pressure exceeds the load on the valve the valve is lifted up from its seat and the steam will escape. The lift of valve is controlled by set screws.

Fig.10.1: Dead Weight Safety Valve

Spring Loaded Safety Valve: If the valve in a safety valve is loaded with a spring instead of dead weights, then it is known as a spring loaded safety valve. A spring loaded safety valve is shown in fig.10.2.

Fig.10.2: Spring Loaded Safety Valve

The spring used in these valves is in the helical form with round or square wires. The wires are made of steel. The load due to steam pressure acts along the axis of the spring. In the tensile load designs the spring of the safety valve is elongated when the excess steam pressure acts on the valve. Whereas, in the compressive load designs the spring of the valve is compressed when the excess steam pressure acts on it. As soon as the excess steam is released, and the pressure reduces below the working pressure, the spring brings back the valve to the valve seat and closes the valve.

The spring-loaded safety valves possess many advantages over the dead weight safety valves. These could be listed as below:

i) A spring safety valve eliminates the need of heavy weights.

ii) A spring safety valve offers easy examination of it and is easy to maintain.

iii) A spring-loaded safety valve is not affected due to jerks or movement.

Installation: Safety valve is mounted on the top of the boiler shell. It is secured to a vertical cast steel pipe and the pipe is bolted to the mounting block which is riveted to the top of the shell.

ii. Fusible Plug

Function of Fusible Plug: Each furnace of the boiler is required to be fitted with a fusible plug. It is used to protect the boiler against the damage due to overheating for the reasons of low water levels. Its function is to extinguish the fire in the furnace of a boiler when the water level in the boiler falls to an unsafe extent and prevent the explosion which may take place due to overheating of the furnace plate. The plug is made of a fusible alloy. It melts away at high temperatures and releases the steam over the grate, thus quenching the fire.

There are many designs of fusible plug. The one which is commonly used is shown in fig 10.3

Fig.10.3: Fusible Plug

Construction: It consists of a gun metal plug body which could be screwed into the crown plate of the furnace of the boiler. The plug body has a gun metal plug screwed into it. This plug has a hole in it and in this hole another hollow gun metal plug placed. Both these plugs are placed together by a fusible metal alloy between them. The fusible metal is protected from the fire by the flange of the second plug.

Working: When the boiler has a normal working level of water the fusible plug is covered with water. When the water level falls too low in the boiler the plug is uncovered out of water. The temperature of the plug which is uncovered by water increases due to heat from the furnace. This melts the fusible metal in the plug and the inner plug falls down, thereby, creating a hole in the plug. Through this hole, water and steam rush in the furnace and the fire is extinguished. After checking and rectifying the cause of fall in water level in the boiler, a new fusible plug is fixed before starting the boiler again.

Installation: Fusible plug is screwed into the crown plate of the furnace of the boiler.

iii. Water level Indicator

Function: The function of water level indicator in a boiler is to show the level of water in the boiler. If the water level in the boiler falls below a minimum level, the operator should make arrangements either to supply more water or to stop firing the fuel. There are two such indicators mounted on the boiler to ascertain the level of water in it. They are also called as water gauges.

Construction: Fig. 10.4 illustrates the commonly used water level indicator of a boiler. It consists of a strong glass tube whose ends pass through stuffing boxes located in the gunmetal castings. The unit is bolted to the front end plate of the boiler. It is so placed that its upper end opens in the steam space while the lower end opens in the water space of the boiler, through the steam cock and the water cock respectively. When the handles of two cocks are in vertical positions the gauge glass is in service. Generally a red mark is made on the glass tube to indicate

Fig. 10.4: Water Level Indicator

normal working level of water in the boiler. The gauge glass tube is provided with a thick guard glass cover to protect against flying glass pieces in case of accidental breakage of tube.

If the glass tube of the indicator is accidentally broken, the water level indicator has an automatic arrangement to shut of water and steam connections to the glass tube. The upper and the lower castings are provided with floating metal balls. When the water gauge glass tube is broken, the water rushes out from the bottom casting and the steam rushes out from the top casting. The flow of water and steam push the metal balls in the casings to the close the holes and stop the flow of steam and water to the glass tube. The operator can then easily shut the cocks and replace a new glass tube. The gauge is sometimes provided with a whistle alarm to attract the attention of operator if the water level in the boiler drops too low or rises too high.

Installation: Water level indicator is usually mounted at that place where it is easily visible to the boiler operator. The unit is bolted to the front end plate of the boiler. It is so placed that its upper end opens in the steam space while the lower end opens in the water space of the boiler.

Check Your Progress 1

1. Name the essential mountings for the safety of the boiler.

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2. Name the essential mountings for the efficient control of boiler operation.

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3. How does a fusible plug works?

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4. What is the purpose of installing a safety valve in the boiler?

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5. What is the location of water level indicator on a boiler plant?

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6. Write the difference between boiler mountings and boiler accessories.

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10.4 BOILER CONTROL MOUNTINGS

In the earlier part of this unit we have concentrated our attention in understanding the devices which are mounted on the boiler for its safety of operation. We have discussed the principle of working of these devices and briefly understood their constructional features. Now we shall try to understand the construction and working of those boiler mountings which are essential in controlling the boiler operation.

i. Pressure Gauge

Function: We know that steam is generated in the boiler at a specified pressure. It is therefore of utmost importance that the boiler operator knows the pressure of steam in the boiler and does appropriate action to control steam pressure in the boiler. There must be a device mounted on the boiler which should provide this information to the boiler operator. This device is known as pressure gauge.

The function of a pressure gauge is to indicate the pressure of steam in the boiler. It is mounted in front of the boiler in such a position that the operator can conveniently read it. The most commonly used pressure gauge is the Bourdon Pressure Gauge. One such pressure gauge is illustrated below in Fig.10.5

Construction: The bourdon pressure gauge consists of curved spring tube of oval cross section. This tube is made up of bronze. One end of the tube is sealed. The other end of the tube is secured to a hollow threaded block. The hollow block forms the passage for steam. The gauge is attached to the siphon tube which is mounted

Fig. 10.5 Pressure Gauge

on the boiler in the steam space. The siphon tube gets filled with the water due to steam condensate and the pressure of steam acts through the water on the inside of the tube. The pressure of steam acting through water causes a movement in the free end of the tube. The link is pulled due this movement and operates the toothed sector. The link movement is magnified and gives a deflection to the pointer which indicates the reading of pressure on the circular graduated disc type dial.

Installation: The arrangement of installing the pressure gauge through a siphon tube mounted on the boiler avoids the steam coming in direct contact with the bourdon tube as the siphon always remain filled with water. This prevents the damage to the bourdon tube due to overheating. The accuracy of an overheated bourdon tube also gets permanently affected and it may give incorrect reading of pressure. Accuracy of the pressure gauge must be checked regularly with the help of a test gauge and the necessary calibration of the gauge must be done if required to get the accurate indication of steam pressure in the boiler.

ii. Steam Stop Valve

Function: Steam generated in the boiler is supplied through pipe lines from boiler to the point of steam utilization in various dairy processing equipments. To control

Fig. 10.6 Steam Stop Valve

the supply of steam from boiler to the main pipe line, a valve is mounted on the top of the boiler. This valve is known as Steam Stop Valve. This valve may be operated automatically or by hand by the boiler operator.

The function of a steam stop valve is to stop or to allow the flow of steam from the boiler to the steam pipe. One such hand operated steam stop valve is shown in the fig.10.6.

Construction: The steam stop valve consists of a valve chest, which has two flanges at right angles to each other. One of the flanges is bolted to the mounting block on the boiler and the other flange is bolted to the steam pipe. The valve chest and the flanges are made up of cast iron. The valve and the valve seat are located in the centre of the valve chest. Both these are made up of gun-metal. The valve is connected to a spindle by a nut. The spindle can rotate free in the valve but at the same time it carries the valve with it when raised or lowered. The spindle has a hand wheel at the top by which it is rotated. The upper portion of the spindle has screw threads, which pass through a nut in the yoke, and two pillars fixed to the body carry the yoke.

Installation: To control the supply of steam from boiler to the main pipe line, Steam Stop Valve is mounted on the top of the boiler and connected to the steam main line.

iii. Boiler Feed Water Check Valve

For operating a boiler, continuous supply of feed water is required. This is to maintain a constant water level in the boiler in relation to generated steam. Water to the boiler is provided by water feed pump installed with the boiler. This pump is meant to force water into the boiler under pressure. Since the inside pressure of the boiler is high, the water needs pumping to a considerable pressure above that of inside the boiler. Thus the feed water pump has to pump the water into the boiler at a higher pressure.

Functions of Feed Check Valve: Feed water from the pump is supplied to the boiler through a special one-way valve installed in the water line. This valve does not allow the back flow of water from the boiler, which may be there due to higher pressure inside the boiler. Also if the feed water pump fails due to some fault, then the pressure in the feed water line would be much lower than that in side the boiler. This could also trigger the back flow of water from boiler to the feed water line and may result in a bigger accident. Thus, the control of back flow of water in a boiler is of utmost importance. The valve, which does this function in a boiler, is known as boiler feed water check valve. One such feed check valve is illustrated in fig.10.7 below:

Fig.10.7 Feed Check Valve

Construction: Boiler feed water check valve consists of two valves combined in one valve. One functions as the feed valve and the other functions as the check valve. The feed valve is operated by hand and its function is to allow or stop the supply of water to the boiler. The other valve which is the check valve is automatic in its function. It prevents the back flow of water from boiler to the feed pump.

The feed check valve consists of a valve chest which has two flanges at right angles to each other. The bottom flange is connected to the water pipe line coming from the water feed pump and the other flange is bolted to the pipe on the boiler side. The valve chest and the flanges are made up of cast iron. The valve and the valve seat are located in the centre of the valve chest. The valve rests on the valve seat. The boiler pressure acts on the top side of the valve while the feed water pressure acts from the bottom side. In normal working conditions the pressure of feed water is greater than the boiler side pressure and valve remains open. If the feed water pressure decreases below the boiler pressure, the force on topside of the valve becomes greater. The valve then closes automatically and shuts the reverse flow of water. This way the valve acts as a check valve.

The lift of the valve is controlled by a spindle. The spindle can be raised or lowered with the help of a hand wheel. The valve is in closed position if the spindle is completely lowered and the valve is pressed against the valve seat. This way the valve carries out the function of a feed valve.

Installation: The feed check valve is fitted to the delivery pipe of the feed water pump and is connected to the boiler slightly below the operating level of water in the boiler.

Check Your Progress 2

1. Write the function of a steam stop valve.

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2. What is the location of steam stop valve on a boiler plant?

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3. What is the purpose of mounting a pressure gauge on the boiler?

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4. List the two functions carried out by the feed check valve.

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5. What is the location of the feed check valve on the boiler plant?

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10.5 LET US SUM UP

The safety and satisfactory working of a boiler largely depends upon the reliability of several component units which are mounted on the body of the boiler. These devices are primarily intended for the safety of boiler and for control of its operation. The category of such component units which are installed or mounted on the body of the boiler itself, are known as boiler mountings.

The essential mountings fitted on the boiler can be grouped in to two categories; the safety mountings, such as, safety valve, fusible plug , water level indicator and the control mountings, such as, pressure gauge, steam stop valve, feed check valve.

The function of a safety valve is to safeguard the boiler from the hazard of pressures reaching higher than the design value. It prevents the steam pressure in a boiler from exceeding a prefixed value. If the inside pressure exceeds the maximum working pressure, this valve opens and automatically discharges the steam from the boiler. A fusible plug is used to protect the boiler against the damage due to overheating for the reasons of low water levels. Its function is to extinguish the fire in the furnace of a boiler when the water level in the boiler falls to an unsafe extent. The water level indicator in a boiler shows the level of water in the boiler, so that if the water level in the boiler falls below a minimum level, the operator should make arrangements either to supply more water or to stop firing the fuel.

Amongst the boiler mountings which are essential in controlling the boiler operation, a pressure gauge is mounted on the front of the boiler in such a position that the operator can conveniently read it. It indicates the pressure of steam in the boiler. To control the supply of steam from boiler to the main pipe line, a valve is mounted on the top of the boiler. This valve is known as Steam Stop Valve. The feed water from the feed - pump is supplied to the boiler through a special one-way valve installed in the water line. This is known as boiler feed water check valve. This valve consists of two valves combined in one valve. One functions as the feed valve and the other functions as the check valve. This valve does not allow the back flow of water from the boiler. If the feed water pressure decreases below the boiler pressure, the valve then closes automatically and shuts the reverse flow of water.

10.6 KEY WORDS

Accessories	:	something extra, helpful, and useful but not an essential part
Compressive	:	pressing together
Flange	:	outside rim or collar to keep something in position
Fusible	:	melting characteristic

Gauge	:	instrument for measuring
Gun-metal	:	alloy of copper and tin
Spindle	:	thin rod for twisting and winding thread.

10.7 SOME USEFUL BOOKS

Gupta C. P. and Prakash Rajendra (1977). Engineering Thermodynamics. Nem Chand & Bros., Roorkee

Rajput R.K. (2003) Thermal Engineering. Laxmi Publication Pvt. Ltd., New Delhi.

Arora C.P. (1998). Thermodynamics. Tata McGraw Hill Pub. Co., New Delhi

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Eckman D. P. (1976). Industrial Instrumentation, Willey Eastern Ltd., New Delhi.

10.8 ANSWERS TO CHECK YOUR PROGRESS

Your answers should include the following points:

Check Your Progress 1

1) i. Safety valve
   ii. Fusible Plug
   iii. Water Level Indicator

2) i. Pressure Gauge
   ii. Steam Stop Valve
   iii. Feed Check Valve

3) i. The Fusible Plug is made of a fusible alloy. When the water level falls too low in the boiler the plug is uncovered out of water. The temperature of the plug, which is uncovered by water, increases due to heat from the furnace. The fusible metal melts away at high temperatures and releases the steam over the furnace grate, thus quenching the fire.

4) i. The function of a safety valve is to safeguard the boiler from the hazard of pressures reaching higher than the design value. It prevents the steam pressure in a boiler from exceeding a prefixed value. If the inside pressure exceeds the maximum working pressure, this valve opens and automatically discharges the steam from the boiler

5) i. Water level indicator is usually mounted on the boiler at that place where it is easily visible to the boiler operator.

6) i. The category of component units, which are installed or mounted on the body of the boiler itself are known as boiler mounting. They are primarily intended for safety of boiler and for control of boiler operation. The category of components, which are installed with the boilers as auxiliary units are known as boiler accessories. They either help the boilers in their working or increase the efficiency of the boilers.

Check Your Progress 2

1) i. The function of steam stop valve is to stop or to allow the flow of steam from boiler to the steam pipeline.

2) i. To control the supply of steam from boiler to the main steam pipe line the valve is mounted on the top of the boiler in the steam space.

3) i. The function of the pressure gauge is to indicate the pressure of steam in the boiler.

4) i. To allow or stop the supply of feed water to the boiler.

ii. To stop the back flow of water from the boiler if the pressure in the boiler exceeds the pressure in the feed water line due to failure of feed water pump.

5) i. Feed check valve is fitted to the delivery pipe of the feed water pump and is connected to the boiler slightly below the operating level of water in the boiler.

UNIT 11 STEAM SUPPLY LINE ACCESSORIES AND ENERGY CONSERVATION

Structure

11.0 OBJECTIVES

After studying this unit, we should be able to:

- describe the steam pipe line system in a dairy plant
- identify various accessories installed for the safety of steam pipe lines
- describe the energy conservation accessories in the steam boiler.

11.1 INTRODUCTION

We have learnt in the earlier units that from amongst the several alternative-heating arrangements, heating of milk in the vessel with the help of steam are the most convenient and appropriate. Steam can be transported through pipe lines from its source of generation to all the places of utilization very conveniently. It is the most economical and common source heat energy and has been adapted by all the milk processing plants. We have learnt the principles of generating steam, understood the general constructional features of a boiler vessel in which the steam is generated, and are now familiar with the component units or devices, which are mounted on the body of the boiler for the safety of boiler and control of its operation.

Knowledge of steam pipeline and fittings is of great value to the dairyman because of universal use of pipes for conveying fluids. The safety and satisfactory working of steam utilization system in a milk processing plant largely depends upon the reliability and the effectiveness of the steam distribution lines. Now we shall discuss in detail the steam supply pipeline and the accessories attached to them in a dairy plant.

11.2 STEAM LINE SYSTEM IN A DAIRY PLANT

Transfer of steam from boiler to the point of steam use is the most common need in the dairy plant. Steam is transported in thicker walled conduits known as pipes.

Steam pipelines are different from sanitary pipes used in dairy plant. The sanitary pipe and fittings refers to the stainless steel tubing used for transportation of milk and milk products. These sanitary pipe fittings have sanitary design features, such as, ease in assembling and dismantling, smooth polish finish both inside and outside and hygienic characteristics to avoid product contamination. These types of pipelines are discussed separately in Block 1.

The material of construction of steam pipes is mild steel (MS). Mild steel is iron with low carbon content. Steam lines are subjected to pressure as well as thermal stresses and require extra care. The most important factors, which govern the design and installation of steam lines, are : pipe size, pipeline support system, alignment, drainage of condensate from steam lines and adequate insulation cover.

a) **Pipe size:** a pressure drop accompanies Flow of steam through a pipe. Steam pipeline must be of proper size to carry the steam load requirement without undue pressure drop.

b) **Pipeline supports:** Various types of pipe support systems are used in a dairy plant. Some of them are shown in the Fig 11.1. The pipes may be supported from the ceiling for single, double or multiple lines. It may be supported from the walls by means of brackets. Whether the support is from ceiling or from walls, flange type plates are fixed firmly into ceiling or the walls. The tubes, which are used to support the structure, are welded to these plates and the pipe lines are placed over the support structure. Pipe supports should be spaced closely enough to prevent undue sag in the span.

Fig. 11.1 Pipe Line Supports

c) **Alignment:** Poor alignment of piping is the frequent cause of leaks in pipe line joints. Leaks are also there if the joints are not designed or supported properly. Hence the pipe line is precisely aligned with due respect to all the bends and joints at the time of installation. Proper support is provided at the joints. Piping is always supported on both sides of every large valve. Screwed or the expanded type flanges are used at the joints on steam pipe lines for pressures up to 3000 kPa and temperatures up to 672 K. For higher pressures and temperatures the welded type flanges are used.

d) **Drainage of condensate in the pipe line:** As the steam flows through the pipes some condensation usually occurs. If the steam condensate is not drained out of the steam pipe it accumulates at the pockets in the pipe line. Whenever the valve in the line is opened, this accumulated water moves in a column. The sudden movement and stoppage of this water column in the pipe line results in **water hammer**. If a steam pipe is constantly hammered it is damaged. Proper drainage of condensate from the steam pipe line is thus of utmost importance.

For self draining of condensate a slope of 0.25 to 0.3 % is given to the steam pipe line in the direction of steam flow. A full bore Tee (Equal Tee) is used for trapping the condensate from the line and lead it to the traps located at vulnerable points. Any sag in the pipe line is undesirable as it would result in condensate pocket. The sag in the pipe is removed by proper spacing between pipeline supports.

e) **Pipeline insulation:** To prevent heat losses from the steam pipe lines, the pipes are insulated. The pipe insulation cover is also known as lagging. The common insulating materials used are Asbestos sponge felt, Magnesia or asbestos hair or glass wool. The details of insulation shall be discussed in section 11.6 of this unit.

An ideal piping system is that in which each part is self supported and imposes no stress on the other part. All elements in the system hold their correct relative positions and alignment despite thermal expansion and contraction. Anchors are used to fix certain points of the system, and expansion bends, joints and supports are provided for free movement for all the rest of the piping in the system. Anchors are designed to securely lock the anchored points in the piping to heavy steel or concrete work. Steam line is properly pitched for condensate drainage. It is ensured that sag in the pipe, if there is any, does not result in the centre point of span between two supports below its lower support, and otherwise it would form a condensation pocket that may lead t water hammer.

11.3 STEAM LINE EXPANSION BENDS AND JOINTS

Steam pipes carries steam at high temperature. Due to this high temperature because of the heat of steam, the steam pipe lines are subjected to thermal expansion. If the provision for this expansion in pipe lines is not made then it develops thermal stresses and eventually damages the pipe line installation.

The thermal expansion in steam lines is taken care of by installing suitable expansion bends or joints in the pipe lines. A few different types of expansion bends are shown in Fig.11.2. Expansion pipe bends are commonly used in the steam pipe lines for higher pressures. With the expansion bends the forces to be handled by the anchors are substantial. A well lubricated sliding expansion joint may reduce the resulting forces but it requires increased care and maintenance.

Fig. 11.2 Steam Pipe Line Expansion Joints

11.4 STAEM TRAPS

Steam trap is a device which is used to remove condensate from steam. It is installed at a position and in such a manner that the condensate flow freely into it.

Selecting a Steam Trap: It is necessary to have the knowledge of following factors while selecting the suitable steam trap for a given steam line installation :

a) Rate of condensate discharge.

b) Method of disposal of condensate, whether the condensate is to be reused in the boiler or it is to be discharged free into atmosphere.

c) Pressure and temperature of steam in the pipe line.

Construction of Steam Trap: Depending upon the principle of operation and construction, stem traps can be grouped into various categories. The most commonly used steam traps are the open bucket type steam trap and the ball float type steam trap.

i) **Open-Bucket Type Steam Trap:** An open bucket type steam trap is shown in Fig. 11.3a. The steam trap body has an open bucket inside it. When the condensate enters the steam trap, the bucket inside it rises with the rise in water level. This causes the closure of opening at the outlet valve. With more and more condensate entering the steam trap, the trap body and the bucket inside it get filled with water. As soon as the bucket is full of water, it sinks in the condensate and moves to the bottom of the trap body. The downward movement of bucket causes the outlet valve to open and the steam condensate is discharged out of the steam trap. This action of upward and downward movement of bucket repeats again and again with the fresh flow of condensate in to the steam trap. The trap body is provided with an air vent at the top to release air from the system in case there is an air lock.

Fig. 11.3a Open-Bucket Type Steam Trap

ii) Ball-Float Type Steam Trap: As shown in Fig. 11.3b, it consists of a trap body having a float ball in it. When the water level inside the trap body is low, the ball positions itself in front of the outlet orifice. Due to pressure of steam the ball is pressed against the orifice and seals it. As the condensate level in the trap body increases the float ball rises and changes its position relative to the outlet opening. The outlet opens and the condensate is discharged out. This discharge continues till the condensate is flushed out. As soon as the water level inside the trap body drops, the float ball again positions itself against the outlet orifice, thereby closing it. This operation repeats again and again and the condensate is discharged periodically.

Fig. 11.3b Ball-Float Type Steam Trap

Installation of steam trap: Steam trap is installed at a position and in such a manner that the condensate flows freely into it. Wherever physically possible, steam trap is installed below the equipment to be drained, so that condensate can flow by gravity. The trap should be accessible for servicing. Trap leakage represents a common cause of trouble. Other trap troubles include rusting and sticking of the mechanism, float leaks etc. Steam traps should be tested on a regular schedule basis. They should be opened at least twice a year, cleaned thoroughly and if any valve or seat is found worn out it should be immediately replaced.

11.5 STEAM STRAINER

Sometimes steam carries along with it some floating or suspended materials. Such materials results from the corrosion of steam pipe lines or the pipe or joint rust. This type of floating or suspended material is ultimately drained out with the steam condensate. The condensate will lead them to the steam trap. The steam trap will get clogged and its working will be hampered. For smooth and continuous working of steam traps such materials must be removed from the steam condensate. Installing a steam strainer, between the steam line and the steam trap inlet, does this.

Fig. 11.4 gives the detailed construction of a steam strainer. The steam condensate enters the strainer at the inlet ‘1’ and passes through the strainer mesh ‘3’ and eventually passes out from the outlet at ‘2’. The solid particles are retained inside the wire mesh and a clear condensate passes out to the out let of the strainer. The mesh is removable type and can be taken out for cleaning. This is periodically done by opening the valve screw at ‘4’. When the valve is opened the grits are blown out with the help of pressure of steam from the inlet. There is no requirement of dismantling the steam line to clear the strainer. The above arrangement eliminates the stoppage of steam to remove the strainer mesh for cleaning. Usually it is desirable to keep the spare strainer mesh in the store so that it could be replaced easily as and when required.

Fig.11.4 Steam Strainer

11.6 STEAM PIPE LINE INSULATION

To prevent heat losses from the steam pipe lines, the pipes are insulated. The pipe insulation cover is also known as lagging. The common insulating materials used are Asbestos sponge felt, Magnesia or asbestos hair and glass wool. The insulating efficiency of these materials is about 85%.The thickness of insulation varies from 2.5 cm to 7.5 cm depending upon the temperature of steam in the pipe. The higher the temperature, the larger is the thickness of insulating material. The insulation material should be able to withstand the pipe temperature and stand ordinary handling. The insulation is securely bound to the pipe and the joints are closely fitted. The lagging over the pipelines is covered with a protective covering made up of aluminum or galvanized iron sheet. The pipe lines which are laid outdoor are required to be provided with water proofing.

11.7 CARE AND MAINTENACE OF STEAM PIPE LINES

It is often assumed that piping system, once installed and connected never requires much attention there after. This is not so. It must be noted that pipe line system comprises of several component/parts, such as regulating valves, pressure gauges, expansion bends and joints, steam traps, steam strainers, etc. All of them are essential for proper functioning, efficient performance and safety of the plant. Without timely inspection and proper maintenance their performance and useful life are decreased. Therefore, while attending to the maintenance of pipelines due care must be given to all these component/parts of the system. An overall care and maintenance programme for pipelines must include the following points:

i) Drain all condensate pockets by ensuring there are no pipe sag and all the steam traps are working properly. Check the system to make sure that low points are raised. Sags caused by misalignment can be rectified by support adjustment.

ii) Attend to the cause of water hammer immediately. Inspect the pipe guides and anchor points for damage, if any.

iii) Check each hanger or other support of pipeline to ensure that it carries its share of load. Inspect that the anchors are holding and showing no signs of breaking or slipping.

iv) Supports for a horizontal pipe, far from an anchor point must allow ample slide or swing in the direction of the pipe expansion, which arises due to heat of steam inside the pipe.

v) Do not force flanges into the pipeline. It may lead to poor alignment. A poor alignment would result in leakage at pipeline joints, steam traps, steam strainer, steam valves and gauges.

vi) General routine inspection should be made to discover leaks and signs of corrosion and weakness.

vii) Steam traps should be tested on a regular schedule basis. They should be opened at least twice a year, cleaned thoroughly and if any valve or seat is found worn out it should be immediately replaced.

viii) Check that the pipeline insulation is securely bound to the pipe and the joints are closely fitted. Ensure the intactness of water proofing on the outdoor pipelines.

ix) Steam pressure gauges should be routinely tested for their accuracy, properly serviced and calibrated.

x) Maintain compete drawings of the pipeline system. All changes and corresponding dates should be indicated. Record the date of installation on all the piping elements. This will help in organizing a care and maintenance procedure.

Check Your Progress 1

1. What is the material of construction of steam pipes?

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2. What effect does a poor alignment have on the pipeline system?

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3. What is a steam trap and where is it installed?

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4. Write the purpose of installing a steam strainer.

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5. Enlist some pipe line insulation materials.

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6. Name the device to prevent the pipe line damage due to thermal expansion.

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11.8 ENERGY CONSERVATION PRINCIPLES IN A DAIRY PLANT

Energy is a critical component of processing industries. There is a total dependence on fossil fuels for this energy supply. It is also a know fact that our fossil fuel reserves are finite and we should utilize these resources judiciously. Efforts are also being made in several sectors to tap and develop new energy sources as an alternative to the fossil fuels. But until the alternative sources are put to commercial use we have to rely on the available means. Due to increased prices of fossil fuels, the cost of energy sources has increased tremendously. This has forced the industries to take the possible energy conservation measures. The concept of energy conservation is based on following general principles:

i) **Save Energy**: Economize the use of commercial energy. The amount of energy saved in a process can be equated as equivalent amount of energy generated. The wasteful expenditure of energy should be avoided. Minimize the losses of energy during its use.

ii) **Enhance Equipment Efficiency**: The energy utilization efficiency of equipments should be enhanced by incorporating regenerator, economizer, pre-heater, etc. and also by improvements in processing technologies.

iii) **Heat Recovery from Discharge Streams**: Hot condensate and exhaust air which are discharged in to atmosphere contain considerable amount of heat energy. Appropriate means and devices should be adopted recover this.

iv) **Alternate Energy sources**: Wherever possible, encourage the use of renewable energy sources, such as, solar energy, wind energy, bio gas etc. to ease the load on costly fossil fuel energy.

Dairy processing involves essentially the heating and cooling of milk and milk products. The related equipments are required to perform these operations efficiently and in doing so, the operation consumes a large amount of energy. Savings in this energy expenditure is possible if we apply the conservation measures. Energy conservation should receive attention of both the equipment manufacturer and the entrepreneurs of the processing plants, especially in view of the declining energy supply and rising energy cost.

For the milk processing plants the energy use profile is dependent on the product mix. The two major energy inputs during processing are the electricity and industrial oil fuel. There is a significant potential for energy conservation in the above two inputs with the improved engineering services and processing technologies in a dairy plant. The analysis in this section identifies areas for improvements in energy resource utilization. Following text describes some of the guidelines for conservation of energy in a dairy plant.

i) Look into the possibility to reduce peak load demand of steam and refrigeration by spreading the actual requirement over the day. This would not save energy but would redistribute the energy requirement from an expensive peak demand period to a period with low loading.

ii) Rationalize the use of cold storage rooms and shutting down rooms not required. Ensure the minimum ingress of heat into cool rooms through open doors and poor insulation. Cooled produce should be immediately moved to cold storage and the doors of the cold room be kept closed at all possible times.

iii) Production processes which involve pre-cooling with unreferigerated water should be controlled in such a way that operators will not short circuit the use of water and switch to refrigeration to meet a too rigid time schedule.

iv) The thermal efficiency of steam boilers operating in a dairy industry varies between 55 to 80%. It is not unusual for boilers to have an exhaust gas temperature of 220 to 250° C. It is worthwhile to consider the installation of feed water pre-heater or an air pre-heater which utilizes the heat in the exhaust gases down to 159 – 160 °C.

v) Insulate storage tanks, cold-water tank, chilled water pipes and steam pipe lines. Avoid water leaks through unattended losses and pipe connections.

vi) Regenerative application of heat exchangers is an effective means of conserving energy.

vii) Vapour recompression in multi-effect evaporators reduces the steam consumption and energy input. Use thermo-compression or mechanical vapour recompression in conjunction with multiple evaporators.

viii) Multistage spray drying plants equipped with heat and mass recovery system are successful in saving energy in spray drying of milk.

ix) Dairy industry mainly has small and medium sized motors with a low power factor or a high consumption of reactive power. Fitting a power factor correction system and ensuring that electric motor operate at high loads can reduce electric cost.

x) Replacing the traditional double wash procedure by a single wash procedure can reduce the energy cost in CIP-cleaning.

xi) Greater use of microprocessor based automatic controls improves the energy efficiency in food processing.

11.9 ENERGY CONSERVATION ACCESSORIES IN A STEAM BOILER

The design of water-tube and the fire-tube boilers have been perfected with time and suitably modified for the increasing industrial applications. Considering the rapidly decreasing fossil fuel availability, increased emphasis is progressively laid on increasing the heat utilization factor in the boiler. Several energy conservation devices and accessories have been evolved for the boilers to achieve the economy of heat utilization. Before studying these devices let us first discuss different types of heat losses from the boilers which could cause the decrease in thermal efficiency of the boiler and during the transmission of steam from one location to another.

i. Heat losses

These losses occur on account of many factors, some of which have been listed below.

i) Loss of unburnt or partially burnt fuel in the fuel bed or in the exhaust gases from the chimney.

ii) Poor heat transfer from hot flue gases to water due to formation of soot later on the flue gas side and water scale on the waterside.

iii) Inadequacy of insulation on steam pipe lines and removal of condensate from the pipe lines resulting in loss of heat energy during transmission of steam

iv) Heat energy losses with stack gases due to excessive temperature difference between steam and the stack gases temperature.

The greatest amount of heat loss in a boiler is the heat carried away by the hot flue gases up the chimney. A certain amount of heat loss is unavoidable as the hot gases are required to be hotter than the water in the boiler. However some of the heat being carried away by the hot flue gases can be recovered and sent back to the boiler, if the energy conservation accessories like economiser, air pre-heater and steam-superheater are installed.

ii. Economiser

It is an accessory installed with the boiler to utilize a portion of heat from the flue gases for preheating the feed water to the boiler. It consists of a series of vertical tubes through which feed water passes on its way from feed water pump to the boiler water space. These tubes are placed in the path of hot flue gases after the combustion chamber. The waste flue gases flow outside the economiser tubes. The feed water flowing into the boiler while passing through these tubes gets heated up after getting heat from the flue gases. This way a portion of heat is recovered from the flue gases, which would have otherwise gone waste to the atmosphere. The outside surface of these tubes is always in contact of hot flue gases and is prone to deposition of soot. Hence the outer surface is kept clean and free from soot by means of mechanized scrapers.

The advantages gained by installing an economiser are:

i) Fuel economy

ii) Long life of the boiler

iii) Increase in steaming efficiency

The saving of fuel affected by an economizer is proportional to the amount of heat recovered in the feed water. The average percent saving is approximately 1% for every 5.5° C increase in feed water temperature.

iii. Air Pre-heater

The function of an air pre-heater is to extract heat from the flue gases and transfer it to air entering the boiler furnace. It is installed between the economizer and the chimney. The commonly available design of air pre-heater is tubular type, in which the tubes are so placed that the flue gases pass through them. Air being heated is made to make a number of passes across and around the outside of these tubes. Designs are also available in which the hot gases flows outside the tubes and air inside.

The installation of air pre-heater increases the overall efficiency of the boiler plant. This increase in efficiency varies between 2 to 10 per cent. In addition of above advantage of increase in plant efficiency, the pre-heating of air also have additional benefits of improving the heat generation and transfer in the furnace. Some of these are:

i) It creates higher furnace temperatures.

ii) It accelerates combustion and increases the percentage of CO_2 in the furnace gases by ensuring the complete combustion.

iii) The pre-heating of air facilitates the burning of poor grade fuel.

iv. Steam Superheater

We have already read that if the saturated steam is separated from the contact of water and further heat is provided to it, keeping the steam pressure same, then the heat content of steam increases. Such steam is known as superheated steam. Due to higher heat contents the superheated steam effects the improvements and economy in the following ways:

i) Reduces the steam consumption for a given process.

ii) Reduces the condensate losses in steam pipe lines.

iii) Increases the capacity of the plant.

iv) Eliminates friction in steam lines.

Steam Superheater is the most important accessory of a boiler. It is a device in which steam is superheated. A steam superheater is a set of pipe line coils through which steam is passed after it is separated from contact of water. These coils are placed in the path of flue gases so that a part of heat in the flue gases is utilized to superheat the steam. The superheater tubes are usually 5 cm in diameter and are generally made up of carbon steel or chrome nickel alloy to withstand high temperatures. Saving in steam consumption by use of superheated steam is about 1.5 to 2% for each 5° C of superheat.

V. Soot Blowers

We have read in this unit that the accumulation of soot layer on the flue gas side of the boiler tubes reduces the heat transfer from hot gases to water. This is because the soot is bad conductor of heat. It is thus of utmost importance that the external surfaces of the tubes be kept free from soot by brushing or by mechanical blowing. The mechanical device used for removing soot is known as soot blower. In economizer the soot is removed by scrapers, which travel slowly and continuously up and down the tubes

Sometimes special free flowing powders are used which when introduced in the furnace get Vapourized. These powders contain a catalyst, which reduces the ignition temperature of the adhering carbon in the soot, and an oxidizing agent in the powder provides combustible oxygen to burn this carbon. This way the deposition of soot on the surface is reduced.

Check Your Progress 2

1. Enlist important energy conservation principles.

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2. Write the causes of heat loss during generation and utilization of steam.

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3. What is the purpose of installing economiser in a boiler?

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4. What are the advantages of superheated steam?

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5. What is the function of air pre-heater in a boiler?

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11.10 LET US SUM UP

Transfer of steam from boiler to the point of steam use is through thicker walled pipes made up of mild steel (MS). The pipe line system comprises several component/ parts, such as regulating valves, pressure gauges, expansion bends and joints, steam traps, steam strainers, etc. Steam lines are subjected to pressure as well as thermal stresses and require extra care. Factors which govern the design and installation of steam lines are: pipe size, pipeline support system, alignment, drainage of condensate from steam lines and adequate insulation cover. The thermal expansion in steam lines is taken care of by installing suitable expansion bends or joints in the pipe lines. Steam traps are used to remove condensate of steam from the pipe lines. Floating or suspended material is removed from the steam condensate by installing a steam strainer in the steam line before the steam trap inlet. To prevent heat losses from the steam pipe lines, the pipes are insulated. The pipe insulation cover is also known as lagging. Proper care and maintenance must be given to the steam pipe lines and all the component parts to enhance their performance and useful life.

The energy use profile in milk processing plants is dependent on the product mix. Savings in this energy expenditure is possible if we apply the energy conservation measures. The two major energy inputs during processing are the electricity and industrial oil fuel. There is a significant potential for energy conservation in the above two inputs with the improved engineering services and processing technologies in a dairy plant. The greatest amount of heat loss in a boiler is the heat carried away by the hot flue gases up the chimney. A certain amount of heat loss is unavoidable as the hot gases are required to be hotter than the water in the boiler.

However some of the heat being carried away by the hot flue gases can be recovered and sent back to the boiler, if the energy conservation accessories like economiser, air pre-heater and steam-superheater are installed.

11.11 KEY WORDS

Alignment	:	Arrange in a straight line
Anchor	:	Secure fixed point
Combustion	:	Process of burning
Condensate	:	Drops of liquid formed when vapour condenses
Conservation	:	Prevention of loss, waste, damage, etc.
Fossil fuel	:	Fuel formed doe to prehistoric plants and animals buried in earth
Insulating	:	Separating with a non-conducting material to prevent loss of heat
Lagging	:	Protective covering
Renewable	:	That can be renewed
Sag	:	Sink or curve down in the middle under weight or pressure
Soot	:	Black powder left by smoke on surfaces.

11.12 SOME USEFUL BOOKS

Gupta C. P. and Prakash Rajendra (1977). Engineering Thermodynamics. Nem Chand & Bros, Roorkee

Rajput R.K. (2003) Thermal Engineering. Laxmi Publication Pvt. Ltd., New Delhi.

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Eckman D. P. (1976). Industrial Instrumentation, Willey Eastern Ltd., New Delhi.

11.13 ANSWERS TO CHECK YOUR PROGRESS

Your answer should include the following points:

Check Your Progress 1

1) i. The material of construction of steam pipes is mild steel (MS). Mild steel is iron with low carbon content.

2) i. Poor alignment of piping is the frequent cause of leaks in pipeline joints.

3) i. Steam trap is a device, which is used to remove condensate from steam. It is installed at a position and in such a manner that the condensate flow freely into it.

4) i. Floating or suspended material is removed from the steam condensate by installing a steam strainer in the steam line before the steam trap inlet.

5) i. The commonly used insulating materials for steam pipes are : (i) Asbestos sponge felt, (ii) Magnesia or asbestos hair (iii) glass wool.

6) i. Expansion Bends or Expansion Joints are installed in steam lines to prevent damage due to thermal expansion of pipes.

Check Your Progress 2

1) i. Save Energy

ii. Enhance Equipment Efficiency

iii. Heat recovery from discharge streams

iv. Use of Alternate Energy sources

2) i. Loss of unburnt or partially burnt fuel in the fuel bed or in the exhaust gases from Chimney in the boiler.

ii. Poor heat transfer from hot flue gases to water due to formation of soot later on the flue gas side and water scale on the waterside.

iii. Inadequacy of insulation on steam pipe lines and removal of condensate from the Pipe lines resulting in loss of heat energy during transmission of steam

iv. Heat energy losses with stack gases due to excessive temperature difference between steam and the stack gases temperature.

3) i. It is an accessory installed with the boiler to utilize a portion of heat from the flue gases for preheating the feed water to the boiler.

4) i. Due to higher heat contents the superheated steam effects the improvements and economy in the following ways:

ii. Reduces the steam consumption for a given process.

iii. Reduces the condensate losses in steam pipe lines.

iv. Increases the capacity of the plant.

v. Eliminates friction in steam lines.

5) i. The function of an air pre-heater is to extract heat from the flue gases and transfer it to air entering the boiler furnace.

UNIT 12 INSTRUMENTS FOR MEASUREMENT OF PROCESS PARAMETERS

Structure

12.0 OBJECTIVES

After studying this unit, we should be able to:

- explain the phenomenon of pressure, temperature and flow
- enlist and identify different instruments for the measurement of above variables
- state the principle of operation of thermometers, pressure gauge and flow meter
- describe the installation of these devices on plant and machinery.

12.1 INTRODUCTION

We have already learnt in earlier units the concept, principles and construction of various milk processing equipments. We have also studied the working of steam boilers, generation and utilization of steam in a milk processing plant. During the operation of these equipment and machinery the plant operator has to keep a constant watch on various machine parameters and process variables, such as, temperature, pressure, flow, etc. For indicating these variables and parameters several devices and instruments are installed on the equipment. The satisfactory operation of the equipment depends upon the reliability of these instruments. It is thus of importance to understand the working of the devices used to measure the important process variables.

Now we shall develop the understanding of basic concept of some important process variables. This will be followed by the description of measurement instruments for these variables, which are commonly used in a milk processing plant.

12.2 PURPOSE OF MEASUREMENT

i. Improvement in the Quality of Product

The fundamental purpose of measurement of process variables is to improve the quality of product by processing it under the optimum processing conditions. The operating conditions of a process, that is, processing temperature, steam pressure, flow rates of various streams, etc., must be controlled with in specific limits. If all these process variables are maintained at their optimum values, the milk products produced would be of the best quality.

ii. Enhancing the Production Capacity and Efficiency of the Machine

All the milk processing equipment are designed to operate under given set of machine parameters, such as speed, pressure or vacuum, flow rates and heat exchanger temperature, etc. The efficiency of these equipment or machines would be maximum, if they are operated under the parameters for which they have been designed. Their production capacity and the economy of operation would also be more at the optimum machine parameters. Thus the continuous monitoring of these machine parameters through accurate measurement devices is essential for operating the machine at its optimum parameters to achieve the higher production capacity and efficiency of the machine.

iii. Control of Engineering Services

In a dairy plant there is requirement of several services, such as, steam, chilled water, fresh water, refrigerant, electricity, etc. to carry out the processing operations like pasteurization, homogenization, cream separation, evaporation, drying, freezing and the washing of equipment. There are cold storages, boiler, electricity generators, and waste treatment units to provide engineering services in a dairy plant. In all the above services, variables like temperature, pressure, flow rates etc. are needed to be controlled. In order that these process variables may be controlled, the prerequisite is that they can be measured at the desired location in the individual equipment.

iv. Cost Appraisal

Measurement of a variable is also required to compute the cost of the commodity used. Water, electric energy meters and weighing balances are installed to measure the quantity of these commodities being used to work out the cost factor.

All of the above functions require measurements. This is because proper and economical design, operation and maintenance of different processes, plant and machinery require a feedback of information. This information is supplied by making suitable measurements.

12.3 MEASURING TEMPERATURE OF FLUIDS

Temperature is the most important variable in milk processing. It is the thermal state of the product that determines whether the physical conditions of the manufactured product are correct or whether the desired chemical reaction will take place or not.

i. Temperature scales

A temperature scale represents the temperature of a body quantitatively. Designating two thermal equilibrium points by numbers forms the temperature scale. The equilibrium point of ice and water at standard pressure is called ice-point. The equilibrium point between water and steam at standard pressure is called steam point. There are a number of temperature scales each assigning a different unit values to these points.

The Fahrenheit Scale (abbreviated as °F) – This scale assigns 32° F to the ice point and 212 F° to the steam point.

The Centigrade Scale (abbreviated as °C) - Also known as Celsius Scale. This scale assigns 0° C to the ice point and 100°C to the steam point. This scale is commonly used in scientific calculations.

The Kelvin scale (abbreviated as °K) - Also known as Absolute Celsius Scale. This scale assigns 273°K to the ice point and 373°K to the steam point. This scale is widely used in technical calculations.

The interrelations between these scales can be worked out as below:

The equation relating Kelvin and Celsius scale is:

$$°K = °C + 273$$

The relationship between Celsius Temperature and Fahrenheit Temperature is:

$$°C = (5/9)\ (F - 32)$$

ii. Indicating Thermometers

Glass Thermometer: The mercury in glass thermometer is one of the simplest temperature measuring devices.

Principle of operation: It utilizes the volumetric expansion of mercury with temperature as a mean of indicating temperature.

Construction: Fig. 12.1 illustrates the construction of a thermometer. It has a bulb formed by a glass envelope. This bulb contains mercury. Bulb is attached to the stem, which contains a fine capillary tube in it. Bulb of the thermometer is inserted into the hot medium whose temperature is to be measured. As the heat is transferred from hot medium into the mercury in the bulb, the mercury expands. This expansion pushes a thread of mercury into the capillary. The glass of the thermometer is generally shaped as to magnify the apparent width of the thread of mercury. A temperature scale is put on the stem of thermometer, which indicates the temperature being measured.

Fig. 12.1 Glass Thermometer

Installation: The industrial thermometer is installed in such a way that it is protected from damage or breakage. The bulb of thermometer is inserted in a metal thermal well. The heat is transferred through the metal well into the bulb. A metal scale is mounted behind the upper end of thermometer and glass cover is provided over the scale. This type of installation provides a complete protection to the thermometer and makes it strong and rugged. Thermal well is made up of brass, steel or aluminum. Space between bulb and the well is filled up with a conducting medium such as mercury or oil, to increase the rate of heat transfer. The thermometer bulb is installed in such a manner that it is immersed to a sufficient length in the medium. This is to attain temperature equilibrium with the medium whose temperature is to be measured.

Pressure-Spring Thermometer: Based on the principle of operation and the material used this thermometer could be of any of the following types:

Principle of Operation

a) Liquid Expansion Thermometer: - It utilizes the volumetric expansion of liquid caused by temperature changes to measure the temperature.

b) Gas Expansion Thermometer: - It operates on the principle that the pressure of gas varies directly as the temperature, if the volume is kept constant.

c) Vapour Pressure Thermometer: - It operates on the principle that the 'vapour pressure' of a liquid increases with temperature.

Expansion Material: The commonly used expanding material in the liquid expansion type thermometer is ethyl alcohol. In gas expansion thermometer it is nitrogen gas and in vapour pressure thermometer it is ethyl ether. Of all the above thermometers the vapour pressure thermometer is widely used because it is less costly and simpler to maintain.

Construction: The construction of all of the above mentioned pressure spring thermometers are similar. The basic construction of these thermometers is illustrated in Fig. 12.2. It consists of a bulb which contain either a liquid or gas or liquid-vapour fluid. A metal capillary is connected to the bulb on one end and to a receiving element at the other end. The receiving element is usually a bourdon tube or pressure spring. A pointer is attached to the pressure spring through appropriate linkage. The whole system containing bulb, capillary and pressure spring is a sealed unit.

Fig.12.2 Pressure-Spring Thermometer

Working: The bulb of thermometer is inserted into the medium whose temperature is to be measured. The bulb comes in thermal equilibrium with the medium and transfer heat to the fluid inside the bulb. With this heat a pressure is developed in the fluid and the capillary connected to the bulb transfers this pressure to the receiving element, that is, the pressure spring. The pressure spring converts this pressure into a motion that moves the pointer on a scale to indicate the temperature.

Installation: The bulb of pressure spring thermometer is installed with a thermal well. The bulb and the capillary are made up of stainless steel or copper. For protection against damage the capillary is enclosed in another tubing or protective covering.

iii. Electric Temperature Indicators

Amongst the electrical temperature indicators the electrical resistance thermometer is being widely used in recent years in industries because of its accuracy and simplicity. It also makes it possible to detect very small increments of temperature to be detected. An electrical resistance thermometer is useful in wide range of temperature limits, that is, -180° to 650° C.

Principle of operation: The resistance thermometer is based on the principle of change in electrical resistance of a substance with temperature. In metals, the electrical resistance increases with the increase in temperature, where as, in semiconductor materials their resistance decreases with increase in temperature.

Construction: An electrical resistance thermometer bulb could be made up in many forms. The element may be made up of a strip of very thin foil or a coil of very fine wire wound on a frame. The industrial resistance thermometer is of a probe type as shown in the Fig. 12.3. The connection to the wires of the resistance bulb is carefully made.

Fig 12.3 Electrical-Resistance Thermometer

Material: Usually the material of a resistance thermometer is metal but non-metallic material may also be used. The industrial resistance thermometer employs platinum, nickel or copper. In processing industries the platinum-resistance element is used.

The accuracy of a resistance thermometer is better than the expansion thermometers. Measurement of temperature with resistance thermometer reduces to the measurement of electric resistance and the techniques of resistance measurement are well advanced.

Check Your Progress 1

1. Mention the important scales for measurement of temperature.

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2. Fill in the following blanks

   i) 40^{o} C = ________ ^{o}F

   ii) 15^{o} C = ________ ^{o}K

   iii) 4^{o} C = ________ ^{o}K

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3. Write the name of any two devices used to measure temperature.

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4. Which metal or liquid is generally used in glass thermometers?

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5. Write the principle on which a thermometer works.

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6. What is the principle of operation of an Electrical Resistance Thermometer?

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12.4 MEASURING PRESSURE OF FLUIDS

The measurement of pressure and vacuum has always been important in dairy processing industry. Such measurements are generally made continuously with standard industrial appliances. Before we study these pressure measuring devices, let us first understand the concept of pressure and vacuum.

i. Concept of Pressure and Vacuum

The pressure exerted by fluid is given in terms of force per unit area; the force exerted in a direction perpendicular to the surface of unit area. Following terms are generally associated with pressure and its measurement.

Atmospheric Pressure (P_{at}): This is the pressure exerted by the envelope of air surrounding the earth's surface. Atmospheric pressure is usually determined by a mercury-column barometer. Atmospheric pressure varies with altitude. At sea level, the value of atmospheric pressure is close to 1.013 Kg/cm^2 or 1.01325 bar or 760 mm of mercury column.

Absolute Pressure (P_{abs}): Pressure has been defined as the force per unit area due to interaction of fluid particles among themselves. Zero pressure intensity will occur when molecular momentum is zero. Such a situation may occur only when there is perfect vacuum, that is, a vanishingly small population of gas molecules or of molecular velocity. Pressure intensity measured from this state of vacuum or zero pressure is called absolute pressure.

Gauge Pressure (P_g) and gauge vacuum (P_{vac}): Instruments and gauges used to measure fluid pressure generally measure the difference between the unknown pressure 'P' and the existing atmospheric pressure P_{at}. When the unknown pressure is more than the atmospheric pressure, the pressure recorded by the instrument is called gauge pressure. A pressure reading below the atmospheric pressure is known as vacuum or negative pressure. Actual absolute pressure is then the algebraic sum of the gauge indication and the atmospheric pressure.

$$P_{abs} = P_{at} + P_g$$

$$P_{abs} = P_{at} - P_{vac}$$

Units of Pressure: The unit used for expressing pressure is 'Atmosphere' abbreviated as 'atm'. One 'atm' is simply the pressure in Kg/cm^2 exerted by the atmosphere. Pressure can be expressed in multiples of 'atm'.

The unit of pressure in M.K.S. system is Kg/cm^2, in S.I. units N/m^2 and in F.P.S. units is pound per sq. inch (psi). One atm is equal to 1.013 Kg/cm^2 It can also be expressed as the height of mercury column. One atm is equal to 76 cm of Hg column at 0°C.

ii. Pressure Gauge

Bourdon tube type pressure gauge is the most common for industrial use. It employs a Bourdon tube element for direct indication of pressure. The bourdon tube element can be of 'C' type, spiral type or helical type. Due to its simplicity and ruggedness the 'C' type element is commonly employed.

Principle of operation: One end of the 'C' type bourdon tube element is sealed at its tip, while the other end is connected to the process pressure which is to be measured. Because of its 'C' type shape, there is a difference between inside and outside radii of the tube and the bourdon tube presents different areas to pressure. This causes the tube to tend to straighten up when the pressure is applied to it and results in a motion of the sealed tip end of the tube. The extent of movement of the tip of tube depends upon the amount of applied pressure. The movement of sealed end of the bourdon tube is thus an indicator of the applied pressure or vacuum.

Construction: Fig.12.4 illustrates the construction of a 'C' bourdon tube as used in a direct indicating gauge. The 'C' tube usually has an arc of 250°. The process pressure is connected to the fixed socket end of the tube while the tip end is sealed. As the pressure is applied there is a movement of the sealed end of the tube. This tip motion is non-linear because less motion results from each increment of additional pressure. This non-linear motion has to be converted into linear rotational pointer response. This is done mechanically by means of a geared sector and pinion movement. The tip motion is transferred to the tail of the movement sector by the connector link. The sector tail is called the 'traveling angle'. This angle changes with the tip movement in a non-linear fashion and so the movement of the pinion and therefore pointer is linear. This type of pressure gauge is used in all industries and may be obtained in sizes from 5cm diameter up to 35 cm diameter and in many different indicating styles.

Material: The metallic materials used for construction of bourdon tube include brass, bronze, phosphor bronze, beryllium-copper alloy, alloy steel or stainless steel. The non-metallic materials are leather, neoprene and rubber.

Installation: In nearly all pressure gauges, the fluid in which pressure is measured is conducted to the inside of the pressure measuring element and is in direct contact with the element. This creates a problem of handling high temperature, corrosive, sludgy or semisolid materials. Some pressure- gauge elements can be protected by copper-plated, nickel-plated or tinned plated surfaces. But this is always possible especially on the inside of the bourdon tubes. Therefore some other method of excluding the measured fluid must be employed.

Fig.12.4 Bourdon Pressure Gauge

One of the effective methods of protecting a pressure gauge element is siphon arrangement. A single coil siphon arrangement is shown in Fig. 12.5. This is very effective in protecting the pressure-gauge element from the high temperature of steam. The brass coil traps condensate steam and limits the temperature rise in the gauge. A siphon is necessary on all steam pressure gauges.

Another arrangement is diaphragm seal as shown in Fig. 12.6. The unit is usually made up of bronze with a neoprene or thin metal diaphragm. The system is solidly filled with a liquid such as glycerin or oil. The diaphragm is quite flexible, so that the pressure on both sides of the diaphragm is equal. This way the problem of corrosive material can be tackled, as such material would not be in contact with the tube element. The line leading to pressure gauge is always filled with clean oil.

iii. Manometers

One of the oldest means of measurement of pressure is liquid column manometer. It is the simplest, most direct and most accurate of all pressure measuring means. This is a fundamental instrument for detecting the pressure and is used for calibration of other sensors. There are no moving parts, no friction or inertia involved in the measurement and therefore, its accuracy is limited only by the scale visibility.

Principle of operation: The pressure exerted by a column of liquid of height 'h' and density 'r' at the base of the cylinder containing it, is equal to 'hrg', where 'g' is the acceleration due to gravity. A manometer is shown in Fig. 12.5 below.

Fig. 12.5 U-Tube Manometer

It has two vertical tubes known as legs, which are connected at the base. The assembly is partly filled with manometer liquid, which may be water, oil or mercury. When the legs of the manometer are vertical, then:

The pressure at the bottom of the right leg = $P_1 + h_1 rg$

The pressure at the bottom of the left leg = $P_2 + h_2rg$

When the fluid is under static balance condition, then

$$P_1 + h_1rg = P2 + h_2rg$$

Therefore P_1-P_2 = $(h2-h_1)$ rg

A manometer can thus be used for measurement of pressure differential, that is, the difference in pressures P_1 and P_2. Further, if one of the legs of the manometer is connected to the vessel in which the fluid pressure or vacuum is to be measured and other leg is kept open to atmosphere then this manometer would be able to read the pressure difference between the vessel and the atmosphere.

Construction: Liquid manometers are the simplest differential pressure or vacuum detectors. A simple U-tube Manometer is shown in Fig. 12.5. It has two vertical tubes known as legs which are connected at the base through a metal fitting. The assembly is partly filled with manometer liquid, which may be water, oil or mercury. An easier-to-read scale can be is attached to the manometer. In industrial installations, the use of glass tube manometers is limited to locations where tube breakage will not create hazardous conditions for the operator.

Materials: The performance of any manometer is largely a function of the indicating fluid selected. Amongst various manometer liquids, most commonly employed are water, oil or mercury. The filling fluid has to be chemically inert and compatible with the process media and produce a clear, visible interface. The fluid should not coat the glass tube and should not be corrosive to standard material such as copper, aluminum and steel. The fluid should not freeze due to low ambient temperature be capable to maintain its density unaffected by temperature.

Installation: Glass manometer is usually mounted on the equipment or pressure vessel at that place where the operator could easily read the manometer scale. In industrial installations, the use of glass tube manometers is limited to locations where tube breakage will not create hazardous conditions for the operator. At critical locations the gauge glass tube is provided with a thick guard glass cover to protect against flying glass pieces in case of accidental breakage of tube.

Check Your Progress 2

1. Define Pressure?

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2. What is vacuum?

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3. Fill in the following blanks;

   i) 1 Kg/cm^2 = ——— psi

   ii) 1 atm = ———— Kg/cm^2

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4. Write the mutual relationship between absolute pressure, atmosphere pressure and gauge pressure.

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5. Write the name of any two devices used to measure pressure.

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6. What is the material of construction of Bourdon tube in the pressure gauge?

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12.5 MEASURING FLOW OF FLUIDS

In a milk product manufacturing process it is often required to measure the proportion of materials introduced in to a process and the amount of materials produced. For this purpose it is essential to measure the flow rate and flow quantities of fluids. Also the flow measurement is required for the purpose of cost accounting for the services like steam and water.

i. Types of meters

The flow of fluids in closed pipes can be measured by many methods, each working on separate principle of operation. These are:

a) Head meter: These meters operate by measuring the pressure differential across a suitable restriction to flow. For example, orifice meters, the venturi tube, weirs etc. These instruments found almost no application in milk processing industries.

b) Area meter: They operate on the principle of variation in area of a flow stream. For example, rotameter. These are very commonly employed in dairy industry.

c) Quantity meter: They measure the time integral of flow rate. That is, the quantity of fluid passed at a given point. For example domestic water meter.

In this section, the description of flow meter shall be restricted to the brief study of construction and working of a rotameter.

ii. Rotameter

Principle of operation: Rotameter is a type of area flow meter. It operates on the principle that the variation in area of the flow stream required to produce a constant pressure differential at a restriction of flow is proportional to the flow rate.

Construction: It consists of a tapered metering tube and a float which is free to move up or down within the tube. As shown in Fig.12.6, the metering tube is mounted vertically with the smaller end at the bottom. The fluid whose flow rate is to be measured enters the tube at the bottom, passes around the float and moves out of the tube at the top.

Fig.12.6 Rotameter

When there is no flow through the rotameter, the float rests at the bottom of the tube. At the bottom of the tube the diameter of the float is approximately same as that of the tube. Thus the area of float nearly equals the area of the tube and there is a very small annular opening between the float and the tube. When the fluid enters the tube, the pressure drop across the float increases and it raises the float. This upward movement of the float increases the area between the float and the tube until the upward hydraulic forces acting on the float are balanced by its weight. The metering float now floats in the fluid stream.

The float moves up or down in the tube in proportion to the fluid flow rate and the annular area between the float and the tube. It reaches a stable position in the tube when the forces are in equilibrium. Every float position corresponds to one particular flow rate for a fluid of a given density and viscosity. A calibration scale is provided on the tube and flow rate can be determined by direct observation of the position of the float in the metering tube.

Materials: The tapered tube is made up of Pyrex glass. Metal tapering tubes are used in applications where glass could not be used. In case of metal tubes float position is determined indirectly. This is done by magnetic or electrical techniques. The use of indirect float sensors is better than direct visual indication. The float is made up of dense material such as silver or tantalum. The shape of the float is of bob-shape or inverted cone shape so to provide constant viscous drag at all flow rates.

Installation: For proper functioning and accurate results the float must centre itself in the fluid stream. To achieve this, the tube must be installed vertically. It must be plumb to within about two geometrical degrees.

Check Your Progress 3

1. Name any two flow measuring devices.

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2. What is a quantity meter? Give example.

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3. Give principle of operation of a rotameter.

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4. When there is no flow through the rotameter what is the position of bob float?

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5. What is the material of construction of tapered tube and the float of the rotameter?

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12.6 LET US SUM UP

The fundamental purpose of measurement of process variables is to improve the quality of product by processing it under the optimum processing conditions. The operating conditions of a process, that is, processing temperature, steam pressure, flow rates of various streams etc., must be controlled with in specific limits. All the milk-processing equipments are designed to operate under given set of machine parameters. The efficiency of these equipments or machines would be maximum, if they are operated under the parameters for which they have been designed. For indicating these variables and parameters several devices and instruments are installed on the equipments.

Temperature is the most important variable in milk processing. The mercury in glass thermometer is the simplest and most commonly used temperature-measuring device. Pressure-Spring Thermometers are also widely used in measurement of temperature. They utilize the volumetric expansion of liquid or gas or increase in vapour pressure of a liquid with increase in temperature. Amongst the electrical temperature indicators the electrical resistance thermometer is being widely used in recent years in industries because of its accuracy and simplicity. It also makes it possible to detect very small increments of temperature to be detected.

Bourdon tube type pressure gauge is the most commonly used due to its simplicity and ruggedness. It employs a Bourdon tube element for direct indication of pressure and vacuum. However, the oldest means of measurement of pressure is liquid column manometer. It is the simplest, most direct and most accurate of all pressure measuring means and is a fundamental instrument for detecting the pressure and is used for calibration of other sensors.

In a milk product manufacturing process it is often required to measure the flow rate and flow quantities of fluids. The flow of fluids in closed pipes can be measured by many methods, but the most frequently employed instrument is the rotameter. It consists of a tapered metering tube and a float which is free to move up or down within the tube. The position of the float in the metering tube indicates the flow rate of the fluid

12.7 KEY WORDS

Accuracy : Exactness

Annular : Ring like

Appraisal : Valuation

Bob : Quick up and down movement

Calibration : Determine or correct the instrument with established standards

Capillary : Tube with a hair like diameter

Diaphragm : Thin disc or foil

Pinion : Small cog-wheel with teeth

Tapered : Make gradually narrower towards one end

12.8 SOME USEFUL BOOKS

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12.9 ANSWERS TO CHECK YOUR PROGRESS

Your answer should include the following points:

Check Your Progress 1

1) i. The Celsius Scale, the Fahrenheit Scale and the Kelvin scale.

2) i. 104 ii. 288, iii. 269

3) i. Glass Thermometer, Electrical Resistance temperature Indicators

4) i. Mercury

5) i. It operates on the principle that a metal, liquid or gas expands on increasing their temperature and contracts on decreasing the temperature.

6) i. The resistance thermometer is based on the principle of change in electrical resistance of a substance with temperature. In metals, the electrical resistance increases with the increase in temperature, where as, in semiconductor materials their resistance decreases with increase in temperature

Check Your Progress 2

1) i. The pressure of a fluid is defined as force exerted by the fluid per unit surface area. The force exerted should be in a direction perpendicular to the surface of unit area, otherwise normal component of force is taken into account.

2) i. A pressure reading below the atmospheric pressure is known as vacuum or negative pressure.

3) i. 14.2 psi

   ii. 1.013 Kg/cm^2

4) i. Absolute Pressure = Atmospheric Pressure + Gauge Pressure

5) i. Manometer

   ii. Bourdon Tube Pressure Gauge

6) i. Beryllium – Copper alloy, or Steel alloy

Check Your Progress 3

1) i. Orifice meter

   ii. Rotameter

   ii. Quantity meter is device to measure the time integral of flow rate. That is, the quantity of fluid passed at a given point. For example domestic water meter.

   iii. Rotameter is a type of area flow meter. It operates on the principle that the variation in area of the flow stream required to produce a constant pressure differential at a restriction of flow is proportional to the flow rate.

   iv. When there is no flow through the rotameter, the float rests at the bottom of the tube.

   v. The tapered tube is made up of Pyrex glass. Metal tapering tubes are used in applications where glass could not be used. The float is made up of dense material such as silver or tantalum.

UNIT 13 SAFETY PRECAUTIONS, WIRES AND CABLES, FUNCTION OF FUSES AND MINIATURE CIRCUIT BREAKERS

Structure

13.0 OBJECTIVES

After studying this unit, we should be able to:

- know the elementary first aids, to be provided to an electric shock victim.
- understand the necessity of safety precautions for safe use and operation of electricity.
- know the importance of earthing.
- recognize the different types of wires and cables.
- know the Importance of fuse and M.C.B to protect circuit and appliances from over-current.

13.1 INTRODUCTION

In this unit, we will study the elementary first aid to be provided to a person fainted with electric shock. The different methods of artificial respiration are available for a person feeling some problem in natural breathing. Some-times the situation becomes critical when the patient is just losing or has lost his natural breathing. Now, the question arises, why we need such type of elementary first aid. Can we avoid such types of accidents or mishaps? The answer will be definitely **"Yes we can"**. The different elementary first aid, which should be provided to an unconscious and injured person, will be explained in detail. The safe use of electricity demands certain safety precautions to be adopted and provision of different safety devices. We should handle the electrician tools for the repair and maintenance works in home and dairy industry carefully. Selection of proper tools for a particular job is most important because the use of improper tools may result in accident. So, here we will be familiarized/acquainted with the different electrician tools available in various sizes. The mishandling of tools may also cause a serious injury to the operator and the tool may also get damaged. We need wires and cables to transmit electrical power from one point to another. Depending upon the environment, use of different wires may be necessary due to change in environmental conditions. So, we also go through the different types of wires and cables that could withstand with environmental conditions. Fuses and Miniature Circuit Breakers (MCB) are the main safety devices used to protect the circuit, equipment and machines etc. from over-current. As a result of this over-current, the winding of motors and wires may catch fire. This over-current may be due to short-circuit, faulty bearings and overloading of the machines. In the age of modernization, the fuses are being replaced with M.C.B. An exposure will be given on advantages of M.C.B over general fuses.

13.2 FIRST AID

We should prepare a layout of electrical wiring circuit diagram and their controlling switches so that we can operate the switches in emergency. If a person is still in contact with live system or wires, try to switch off the main switch without any delay. It may be possible that the switch is installed away from the accident spot. Then try to separate the victim, with the help of insulated stick, from the live system. It may be a matter of chance that the insulated stick may not be available, then try to remove the victim by pulling with his hair or cloths. The person in contact with live system may be fainted with electric shock. In such unforeseen circumstances, we should have patience and try to understand the situation. The victim may be injured.

Extinguish any spark if it be there in the cloth of the victim. The victim should not be left alone and gathering of the people should be avoided, check whether the victim is breathing or not. If the patient is breathing but feeling some problems, then call the doctor immediately. The present condition of the patient and type of accident should be briefed to the doctor. The patient may have a minor injury and bleeding, if so, try to restrict further bleeding. If we observe that there is a fracture also try to support the fracture by using splints. Now there may be chances that the patient is loosing natural breathing. In such case artificial respiration should be given without any delay. Before giving artificial respiration the clothes of the victim should be loosened so that there is no pressure on the neck and chest. There are three main commonly used methods, which are detailed below.

i. Prone Resuscitation

This method is also known as **“Back Pressure-lift arm method.”** In this method the victim should be made to lie on stomach, with his hand folded under his head, as shown in figure 13.1

Fig. 13.1 Prone Resuscitation

Now we should kneels down with his left knee opposite the victim's head. Place our hands on the back of the victim with thumbs, just touching each other and gently rocks forward until our arms are almost vertical and exerting pressure on the back. Now slide back we hand up to shoulder of the victim and pull his arms until tension is felt. This process should be repeated so fast that 10 – 12 cycles should be completed in one minute, until the victim resume natural breathing.

ii. Mouth – Mouth Resuscitation Method

In this method of artificial respiration, the patient is made to lie on his back and pull his mouth upward. All the clothes should be either loosened or removed from the upper body of the victim, to ensure that there is no pressure exerted on the neck and chest. This method is more useful than the prone resuscitation, as positive movement of fresh air is assured to entered into the lungs. Therefore this method is preferred when victim can be placed on his back. We know that when a person get electric shock, some obstruction may be created by saliva foam. This saliva foam will be the main obstruction in the path of breathing and it should be removed at earliest. After removing this saliva foam, take a deep breath. We should place our mouth on the victim's mouth tightly and keep his nose shut. Start blowing air into the lungs of the victim until the victim's lungs are completely filled with air. We should remove our mouth Intermittently and observe the return rush of air from the lungs of the victim. When the expiration is complete, repeat the procedure until the victim resumes natural breathing. This process should not take more than 2 – 3 seconds.

iii. Mouth – To – Nose Resuscitation Method

This process is almost similar to mouth-to-mouth resuscitation method. In this method the air is gently blown into the victim's lungs through the nose by keeping the mouth closed. The victim is placed on his back as in the previous method and clothes are loosened so that there is no pressure on the chest and neck, as shown figure 13.2.

Fig. 13.2 Mouth to Nose Resuscitation

We should remove if any saliva foam obstruction is there in the mouth with our fingers. In some cases it has been observed that the tongue of the victim is creating obstruction in the path of breathing. We can pull it slightly upward and clear the breathing path. Now take a deep breath and place your mouth on the victim's nose. Start blowing air gently into the lungs till they are completely filled by keeping the mouth tightly closed. Remove our mouth and observe the return rush of air from the mouth and nose. This process should not take more than 2 – 3 seconds per cycle and there should be at least 10 – 12 cycles per minute. When the expiration is complete, repeat the procedure until the victim resumes natural breathing. This process should not take more than 2 – 3 seconds.

Check Your Progress 1

1. If a person is still in contact with live wire, what action you will take.

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2. Before giving artificial respiration what safety precaution should be observed**.**

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3. What are the similarities and dissimilarities in mouth-to-mouth and mouth-to-nose resuscitation?

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13.3 SAFETY PRECAUTIONS

In the previous section, we have studied the various method of artificial respiration, which are based upon the elementary first aid and to be provided to a electric shock victim, who is feeling some problem in natural breathing or the person is in fainted position. Now the question arises, can we prevent such type of mishaps or accidents? The answer will be definitely **"Yes we can".** It could be possible, only if we strictly follow the safety precautions or safety rules, framed for the safe operation and maintenance of the plant or machines etc. So, Indian Electricity (I.E. Rule) rules have been framed, matching with the International standards for the safe operation and use of electricity in our daily life.

The most important tool in safety precaution is the earthing. We know that earth wire resistance should be as low as possible, which may be 0.2 ohms. All the metallic parts of machine and equipment are connected with earth wire and kept at ground potential. Due to this low resistance path for the leakage current between the body of the machine or equipment and ground, there will be a flow of heavy short-circuit current. This short-circuit current completes its circuit through the earth and the person working on the machine will remain safe as it has high resistance as compared to earth wire. Simultaneously the M.C.B. may be tripped or the fuse wire may be blown due to flow of heavy current and supply to the equipment will be switched off.

So, all the alternators, equipment, machine, and every third pole and the neutral wire of the transformer are earthed. Human body is a good conductor of electricity. When live wire touches the body, current completes its circuit through body and earth. Muscular functions of the body are paralysed due to the current's action on the nervous system. The heart and the respiratory organs which may cease to function, causing breathing to stop serious burns and resulting in death. So, we should be careful while working on live system or handling the electrical appliance and equipment.

The portable equipment are connected with one earth wire whereas the heavy machines and equipments are connected with at least two earth wires. Some-times, one earth wire is disconnected or its resistance is increased in dry or summer season the overall resistance will remain within safe limit i.e. less than 0.2 ohms. Suppose the overall resistance is increased than the safe limit, we have to reduce it with in permissible limit by adding some normal drinking water.

While working on pole for some minor repair we should be equipped with insulated safety belt and ladder should be hold by another person so that it may not slip. If we have to work on live conductors or there is some break down in the distribution line, we should never try to complete the job without proper permission to work. So, it will be better to apply for permit to work (PTW) from the sub-station authority. Ensure that the Oil Circuit Breakers (O.C.B) and isolators are switched off properly and warning plate to this effect has been hanged on the oil circuit breaker and isolator handle that **"Man At Work and Do Not Operate"**. After getting permission to work, short-circuit all the three phases, neutral wire and earth to the ground on both the sides of the pole, with the help of specially prepared wire for the purpose. Suppose by mistake either the oil circuit breaker (OCB) or isolator is switched on. All conductors are already at almost ground potential, which acts as short circuit and heavy current will flow to the ground. This heavy current will trip the oil circuit breaker and the supply to the line is switched off. The person working on the line will be safe.

Special care should be taken while using, handling and repairing the portable equipment or appliances, such as Heater, Table fan, Iron, Microwave oven and hair dryers etc. First we should ensure that these appliances are connected with the earth wire properly. While handling these, be ensuring the supply lead has been removed from the socket, because there may be a chance that neutral line is controlled through the switch. Under such circumstances, simply switching off the supply is not enough. There may be leakage of current from the insulation of the connecting wire and also from the winding of the motor. This type of accidents can be avoided by controlling the phase wire through the switch. The person working on the equipment should be well insulated from the ground or walls so that the current circuit could not be completed through the human body. If the appliances are properly earthed the fuse wire will be blown in case leakage of current. Some time it has been observed that the fuse does not blown-out, if it is overrating fuse wire. Under such circumstances connecting wires to the faulty appliances may be over heated and may catch fire. So, we should switch off the supply immediately and throw sand or dust, instead of throwing water on the electric fire. The best way is to use carbon-Dioxide fire extinguisher to over-come electric the fire.

Finally, we know the general attitude of the people. They tie steel wire with the pole/tower or stay wire, and use to dry the wet cloths or to hang them. Secondly, some-times it has been observed that people may use the same to tie their pet animals, especially in thickly populated areas. A warning plate should be fixed with pole, showing the skeleton of human and the operating voltage.

Check Your Progress 2

1. Explain the importance of earthing.

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2. Why heavy rating appliances or machines are provided with multi wire earthing.

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3. Mention the safety precautions, which should be observed while doing major repair work.

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13.4 WIRES AND CABLES

As we know wires and cables, are the main electrical accessories for the transfer of electrical energy, from one point to another. The wires are used for transfer, very small amount of electrical energy, whereas the cables are used to transfer large quantum of electrical energy. The wires are generally used for domestic as well as commercial wiring, where as the cables are used for transmission and distribution purpose. Depending upon the number of conductors, the wires and cables may be classified as single or solid conductor and stranded conductor. The solid conductors are rigid and liable to break if frequent bending or handling is required whereas the stranded conductors are more flexible and show more breaking strength on bending.

The numbers of strands are fixed and it may be 3, 7, 19, 37 and 61. As the number of strands goes on increasing, the flexibility will goes on increasing. The size of wire may be measured in **"Standard Wire Gauge"** (SWG) number and number of strands. For example if a wire is 7/26, it means there are 7 number of strands and SWG number of wire is 26. As the SWG number goes on increasing, the diameter of the wire goes on decreasing and vice-versa. But now a day, we are using cross-sectional area of the conductor instead of SWG number. So, now the size of wire is being expressed as number of strands/cross-sectional area of conductor. The use of wire is limited up to 650 volts whereas as the use cable is restricted to 132,000 volts, due to insulation problems. The wire and cables are explained separately.

i. Wires

Now we will study the different types of wires and their suitability, depending upon the environmental conditions. The wires may be insulated wire and bared wires. The wires are available in different voltage grading such as 250 volts and 650 volts only. The insulated wires being used in electrical wiring system are detailed below along with figure 13.3

Fig. 13.3 Different Types of Wire

a) **V.I.R. (Valcanized India Rubber):** The conductor is valcanized by Indian rubber. Cotton tapes sheathe is provided over the valcanized Indian rubber. A very fine layer of any moisture proof insulating material, just as bitumen, wax or which can prevent ingress of moisture content to conductor. These wires are totally obsolete nowadays, as these wires absorb moisture quickly.

b) **C.T.S./T.R.S. (Cab Type Sheathed/Tough Rubber Sheathed):** These wires are almost moisture proof types. These are available in single core, and twin core. The conductor is covered with a layer of pure rubber, to protect from ingress of moisture. Over the layer of pure rubber, vulcanized Indian rubber layer is provided. Finally, a sheathing of tough rubber is provided to give mechanical strength to the wire. These wires are also obsolete now.

c) **Lead Sheath Wires:** These types of wires are similar in construction with T.R.S., as for as core section is concerned but having outer sheath of lead or lead alloy. The lead sheathing provides full moisture proof environment to the conductor. So, these wires can be used where the humidity is comparatively more or we may use even in snowfall area too.

d) **P.V.C. (Poly Vinyl Chloride) Wires:** In these types of wires, the conductor is insulated with P.V.C. insulation. There is no need for providing cotton tape, as the P.V.C. insulation is tougher than rubber, to protect the wire from moisture and mechanical failure. Nowadays, these wires are used for mostly batten, cleat, casing capping and conduit wiring. These wires should not be used for connecting heating appliances and pendent lights, etc.

e) **Weather Proof Wires:** These wires are used for outdoor service lines. The conductors are insulated first with rubber, then braiding of cotton thread. This braiding material is dipped in waterproof compound so that ingress of moisture could be avoided completely.

f) **Flexible wires:** The wires are used to connect the pendent lights and portable appliances. The insulation used is pure rubber or valcanized rubber on which single or double cotton or valcanized rubber layer is provided. Finally, single or double cotton or artificial silk braiding is provided or only P.V.C. layer is provided. The following are the types of the flexible wires available in the market.

ii. Cables

The power from generating station can be transmitted by cables also, if the transmission distance is less. As seen already in comparison, the underground system is costlier and its maintenance is difficult. Still, the system of transmitting the power by cables is preferred in thickly populated areas and cities. The cables are usually classified according to the voltage for which they are manufactured. According to the voltage they can be classified:

1. L.T. (Low Tension Cables) up to 1000 volts.
2. H.T. (High Tension Cables) up to 11,000 volts.
3. S.T. (Super Tension Cables) from 22,000 volts to 33,000 volts.
4. Extra High Tension Cables from 33,000 volts to 66,000 volts.
5. Oil Filled and Gas Pressure Cables from 66,000 volts to 132,000 volts.

iii. General Construction of Cable

The general construction of a cable is given below along with figure, which illustrates the various parts of the cable.

Fig. 13.4 Three Core H.T. Cable

a) **Core:** All cables have one central conductor and a number of stranded conductors of copper or aluminium, wrapped around the central conductor. Generally, there are one, two, three or four cores (three and a half). This half core is used as neutral core.

b) **Insulation:** The different insulating materials are used to insulate conductors or cores such as impregnated paper, varnished cambric and vulcanized bitumen for low voltage. Impregnated paper is an excellent insulating material and widely used. When varnished cambric is used as an insulating material for low voltage cables, petroleum jelly is applied between the layers of the cambric type. It prevents the insulation damage by friction when the cables are handled.

c) **Metallic Sheath:** A metallic sheath is provided over insulation so as to prevent the entry of the moisture into the insulating material. The metallic sheath is usually of lead or lead alloy.

d) **Bedding:** Over the metallic sheaths, a layer of bedding is provided and it consists of paper tape compounded with a fibrous material. Also, sometimes, jute strands or hessian tape (strong coarse cloth of hemp or jute) also used for bedding. The purpose of providing the bedding is to protect the metallic sheath from mechanical injury due the armouring.

e) **Armouring:** Armouring is provided to protect from mechanical injury to the cable and it consists of one or two layers of galvanized steel wires or two layers of steel tape.

f) **Serving:** Over and above armouring, fibrous material is again provided which is similar to that of bedding but is called as serving.

Check Your Progress 3

1. The size of a wire is expressed as 7/1.5 mm^2. Explain it

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2. Explain the significance of increasing number of strands.

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3. Explain the purpose of providing bedding in cables.

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13.5 FUNCTION OF FUSES AND MINIATURE CIRCUIT BREAKERS

Now, we will study the function of different fuses and miniature circuit breakers (M.C.B.'s) used to protect the appliances/circuits from over-current flow. Due to this over current flow the wires and switches starts overheating and finally catch fire. The current drawn by appliances or a circuit from the main supply depends upon its internal resistance. Under normal working conditions, the current drawn by the appliance will be within the safe limit. So the temperature of the connecting wires and switches, will remain within safe limit. Suppose the appliance or circuit starts drawing more current, due to occurrence of any kinds of fault, the heat generation in the wires and switches, starts increasing. As the temperature goes on increasing, the insulation between the wires starts melting and the circuit resistance reduces to very low and further increase in current drawn. So, the higher currents will start flowing in the connecting wires and switches, which will results in set fire to wires and even to building also. So, we have to make some arrangement to limit this current by providing a week (Thin) point in the circuit. This week point should break the connection, by melting/fusing itself, when the circuit current exceeds the safe limit. ***This device is known as fuse***. The materials, used in fuse wire, are tin, lead, zinc silver, antimony, copper, aluminium etc. Copper or lead tin alloy is mostly used in ordinary rewirable fuses.

We know that once the fuse is blown, we need to rewire it, which is a time consuming job and requires lot of safety precautions. To replace a blown fuse especially in marriages and parties becomes critical, as it requires lot of time and skill. So, keeping in view, different problems associated with fuse, another safety device is now a day is being used, known as **"Miniature Circuit Breaker"** A Miniature Circuit Breaker (MCB) is today's version of old fuses. Today in most of the homes, factories, plants and offices miniature circuit breakers are installed replacing the earlier rewirable or cartridge fuses. The miniature circuit breakers (MCB) are more safe, convenient and reliable than the old fuses. If the circuit or appliance starts drawing more than the rated current due to overloading or occurrence of any other faults, the MCB will get tripped and hence supply circuit is switched off immediately. After removing the fault, we can restore the power supply just switch on the MCB. It is so easy and safe, like putting on the light switch on that even a child can operate it.

Check Your Progress 4

1. Explain how fuse and M.C.B. protect an appliance in case occurrence of fault.

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2. Differentiate the working of fuse and Miniature Circuit Breaker (MCB).

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3. Why the fuses are being replaced with Miniature Circuit Breakers (MCB)?

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13.6 LET US SUM-UP

After studying this unit, we are able to understand the different precautions to be adopted while giving first aid to a person fainted with electric shock. Different methods of resuscitation commonly used and how. As we know that safe use of electricity demands safety precautions. Before starting any work, take necessary permission to work (PTW) on the line or equipment. Be ensure that the switch or oil circuit breaker is switch off. While working on overhead line short-circuit all the conductors and ground to earth. If by mistake the supply is switched on, the oil circuit breaker will be tripped on over current and the person working on the line will be safe. The earthing also plays an important role and acts as a safety device for preventing over current and safety of the mankind. All the transformer, machines, equipment and domestic gadgets should be properly earthed. The leakage current will be earthed to ground, as the earth resistance is too low i.e. less than 0.2 ohm.

Use of proper tools is of great importance and it should match with requirement of kind of job. The use of improper tool may be the reason of accident. The other safety devices are fuses and miniature circuit breaker (MCB). When there is a short circuit between phase and neutral wire or phase and earth wire, the excessively high short circuit current will be drawn from the supply main and earthed to ground. Due to this high current, the fuse of the circuit may be blown out or miniature circuit breaker will trip. Hence the supply to the circuit is switched off. The miniature circuit breakers are the new version of fuses. The miniature circuit breakers are replacing the old rewirable fuses and cartridge, keeping in view the various merits.

13.7 KEY WORDS

Artificial Respiration	:	Method to help in breathing, to resume normal breathing.
Fainted	:	Person turned into unconsciousness after getting electric shock.
Resuscitation	:	Process to revive from unconsciousness artificially.
Electric Shock	:	When the current completes its circuit through the living body and his breathing system starts paralyzing.
Short circuit current	:	Excessively high current drawn by the electric circuit or equipment when both phase and neutral or phase and earth wire is short-circuited.
Minimum fusing current	:	It is that minimum value of current at which the fuse element blown off or miniature circuit breaker gets trip.
Stranded Conductor	:	If the conductors are wrapped around one conductor in a definite order.
Standard Wire Gauge (SWG)	:	The tool used to measure the size of the wire.
Obsolete	:	Not in use now a day or outdated.
Fire Extinguisher	:	The instrument used to extinguish the fire.

13.8 SOME USEFUL BOOKS

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Anwani M.L. & Anwani I.M. (1980-81) Electrical Motor Winding & Repair New Heights, Hari Singh Nalwa Street, 1367/21, Nai Wala Street, Karol Bagh New, Delhi.

Singh.S (1997-98) Electrical estimating and costing Dhanpat Rai & Co. (P) Ltd. 1710, Nai Sarak, Delhi – 110006

Thareja B.L. and Thareja A.K. (1988) Electrical Technology Nirja Construction & Development Co. (P) Ltd., Ram Nagar, New Delhi – 110005

13.9 ANSWERS TO CHECK YOUR PROGRESS

Your answers should include the following points:

Check Your Progress 1

1) i. Switch off the main switch.
   ii. Use insulated stick.
   iii. Pull the victim from his heir or cloth.
   iv. Insulate yourself.
2) i. Remove or loose the upper body clothes of the victim.
   ii. Remove the saliva foam from the mouth of the victim.
   iii. Pull the tongue of the victim slightly out.
3) i. Similarities – The victim is made to lie on back.
   ii. Dissimilarities – Organ through which the air is filled in lungs gets changed.

Check Your Progress 2

1) i. Leakage current is earthed to the ground.
   ii. The fuse may be blown.
   iii. MCB may be tripped.
   iv. The operator or user may be saved.
2) i. Single earth wire may be broken.
   ii. The earth wire resistance gets reduced in summer season.
   iii. The overall resistance of multi earth wire will remain with in safe limit.
3) i. Observe the nature of work.
   ii. Obtain P.T.W.
   iii. Ensure that the circuit breaker and isolator are switched off.
   iv. Line conductors are short-circuited and properly earthed.

Check Your Progress 3

1) i. Seven stands for 7 numbers of conductors.
   ii. Cross-sectional area of conductor is 1.5 mm^2.
2) i. Flexibility is increased with increase in number of conductor.
   ii. Conductor will not break on twisting and bending of wire.
   iii. Breaking strength is increased as compared to single conductor on repeated bending and twisting.
3) i. Separator between metallic sheath and armouring.
   ii. To protect the metallic sheath from mechanical injury from armouring.

Check Your Progress 4

1) i. Describe the quantity of current starts flowing.
   ii. Describe the position of fuse.
   iii. Describe the position of MCB.
2) i. Describe the steps to be taken while resetting the fuse.
   ii. Describe the steps to be taken while resetting the MCB.
   iii. Tools required for restoring the supply.
   iv. Comment on safety, protection and outlook.

3) i. Comment on safety, protection and outlook.
   ii. Comment of time taken to switch off the supply.
   iii. Comment on sensing time.
   iv. Tools required for restoring the supply.

UNIT 14 SINGLE PHASE AND THREE PHASE WIRING

Structure

14.0 OBJECITIVES

After studying this unit, we should be able to:

- identify different electrician tools and care in their handling.
- know the different wiring accessories and domestic wiring system.
- explain how the supply comes to your houses and factories.
- state the importance of different tests before connecting a new electrical installations.

14.1 INTRODUCTION

In this unit, we will learn about different electrician tools, available sizes and their proper handling. We should use proper tools for a particular type of job. Use of improper tools may leads to serious injuries to the electrician and the tool may also be damaged. So, here we will also learn about different precautions to be taken while using and handling of these tools. The sharp edged tools, such as pocketknife, chisels etc., should never be put in pocket without proper shield. While working with such tools, care should be taken not to place hand or finger in the path of motion of the cutting tools. Also, care should be taken not to hand over the sharp edge tool with its sharp edge side. Different electrical wiring accessories are used for wiring single phase and three-phase wiring. So, we will have an exposure about shape, size and use of different electrical accessories commonly used for wiring. Fuses and miniature circuit breakers are used as safety device for any electrical circuit. When the current drawn from the circuit, increases beyond the pre-set limit, the supply is switched off. Different wiring systems are used in domestic and factories, depending upon the environmental condition. We will also study about the supply of electricity from service pole as well as internal wiring, starting from energy meter to I.C.T.P. main switch and other small capacity main switches, to have an independent control of various circuits/sections.

14.2 ELECTRICIAN TOOLS AND THEIR HANDLING

Now, we will study the different types of tools, which are required for the repair and maintenance work at our home, office, plant, etc. These tools should be handled carefully, as mishandling of tool may be the cause of serious injury to the person working with these tools. The proper size of the tool should be used for a particular type of job. So, we should be familiar with the different type of tools, their size availability, use and precautions to be taken while using. The electrician tools are generally made of iron and these should be provided with a lubricant layer, so that in rainy season or humid atmosphere, these should not get corroded. The various electrician tools, which are required for the repair and maintenance of any electrical installation along with precautions to be observed and their use are given below.

i. Different Electrician Tools and their Use

Different electrician tools, which are necessary for the repair and maintenance of electrical installations, are detailed below along with figure.

Fig. 14.1(a) Electrician Tools

Fig. 14.1(b) Electrician Tools

Fig. 14.1 (c) Electrician Tools

Table 14.1 Different Electrical Tools

S No	Name of tool and Size	Uses
1.	Screw Driver 10, 15, 20, 30 cm	Used for screwing and unscrewing of screws.
2.	Combination Plier 15, 20, and 25 cm	Used for holding, twisting or cutting of wires.
3.	Round Nose Plier or Flat Nose Plier. 10 cm	Used for holding, twisting or jointing of wires at narrow places.
4.	Side Cutting Plier 20 cm	For cutting wires at narrow places.
5.	Electrician Knife 10 cm	It has two blades, one for removing insulation of wires and other for cleaning the wire.
6.	Electric Soldering Iron 25, 40, 65 & 125 Watt.	To solder the joints of wires and winding wires.
7.	Cross Peen Hammer ¼ kg to 2 kg	Used for fixing clips and making gut ties hole in wall with the help of rowel plug tool.
8.	Ball Peen Hammer ¼ kg to 2 kg	Best suited for chipping on teak wood batten and riveting purpose in sheet metal works.
9.	Tennon or Hand Saw 30.5 and 40.5 cm	Used for cutting wooden boards, blocks, casing and capping etc.
10.	Cold Chisel 10, 15 cm	Used for chipping, boring and channeling in walls.
11.	Try Square15, 20 and 30 cm	To check the right angles of the corners.
12.	Firmer Chisel1.25, 1.9 and 2.54 cm	Used for chipping, scrapping and grooving in wood.
13.	Poker 10 and 15 cm	Used for making pilot holes for fixing wooden screw in the wood.
14.	Gimlet10 to 25 mm	Used for making holes in wooden articles (Blocks and boards)
15.	Hand Drill 3, 6 & 12 mm	Used for making holes in wooden blocks and boards
16.	Rawal Plug Tool 8, 9 and 10 Number	Used for making holes in the stone/brick or concrete wall for fibre made Rawal plugs.
17.	Hacksaw 16, 20, 25, & 30 cm	Used for cutting conduit, G. I. Pipes and mild steel.
18.	Files (Flat, Round, Half round) 3-14 Inch	Used to smooth the surface or corners of any iron board etc.
19.	Ratchet Brace1.5 cm Bit	Used to drill in wooden material. It can drill in one side rotation only.
20.	Auger Bit 7 – 25 cm	For making holes in doors, windows to pass wires.
21.	Plumb Bob	For drawing vertical lines while wiring.
22.	Pin Vice 0.7, 1.5, 3 mm	Used for holding very small jobs like pins.
23.	Pipe Vice25, 50, 100 & 150 mm	Used for holding the pipe for cutting, or threading.
24.	Bench Vice50, 75, 100, 125 & 150 mm	Used for holding any substance for cutting or fitting.

25.	Hand Vice 25, 30 and 50 mm	Used for holding wires while making joints.
26.	Centre Punch100 & 150 mm	Used for making guide holes for drilling in metals.
27.	Pipe Wrench 15 – 60 cm	Used for tightening or opening conduit pipes.
28.	Mallet	Used as a Hammer for soft metals. It is made of wood
29.	Blow Lamp 0.5, 1.0, and 1.5 lt.	Used to heat up the soldering irons.
30.	Rasp Cut File 15, 20, and 30 cm	It is a rough file used to file the wooden things, e.g. Wooden Boards, Batten etc.
31.	Spanner Set —Double Ended, Ring Spanners, Box Spanner & Slide Wrench	Spanners come in different sizes to suit different purpose. These are used to tighten or loosen the nuts and bolts, screws etc.
32.	Drill Machine with Masonry Drill Bit. Bit size – 3, 6, 12 & 20 mm and stone walls or brick walls.	Used for making holes for plastic plugs in Marble Stone tiles, other such tiles
33.	Crimping Tool 1.5, 2.5, and 6 mm	As soldering on Aluminium conductors is difficult, so this plier is used to crimp the joint or lugs
34.	Measuring Tape 10 and 20 mts.	Used for measuring the dimension of the wiring. Usually it is made of steel or cotton cloth.
35.	Pulley Puller	It is used for removing pulley from the shaft of motor, generator etc. It consists of three adjustable legs, a tightening screw and a screwed plate.
36.	Bearing Puller	Small pulley Puller with only two legs is used for pulling bearings. Hence called Bearing Puller.
37.	Snip - Straight or Bent 150, 200, and 250 mm	Used for cutting thin sheets of iron, copper and brass. It is also used for cutting the winding of burnt out machine.
38.	Neon Tester 500 Volts	It consists of a glass bulb, containing Neon gas and two electrodes. A high value of resistance is connected in series with one of the electrodes for limiting current.
39.	Reamer	It is used for removing the burs from the mouth of newly cut pipe or newly threaded pipe.
40.	Wire Stripper & Cutter	These are used for removing insulation of PVC wires and are adjustable 22 SWG and onwards. Automatic self-adjusting wire strippers are also available in the market.
41.	Pipe Cutter	Such cutters are used to cut the conduit pipes. For cutting— hold the pipe in cutters, and tighten it, then rotate it, again tighten it and rotate the cutter.

ii. Precautions while Handling the Electrician Tools

Great caution and care is required in handling the electrician's tools during working and handling. A worker is liable to injure himself in addition to the damage caused to the tools, if he at any time is slacked in handling them. The following are the safety precautions, which should be observed while handling these tools.

1. The sharp edged tools, such as pocketknife, chisels etc., should never be put in pocket without shield. While working with such tools, care should be taken not to place hand or finger in the path of motion of the cutting tools. Also, care should be taken not to hand over the sharp edge tool with its sharp edge side.
2. When cutting with a chisel, always cut away from yourself, rather than towards yourself.
3. Before using hammer, its handle must be examined carefully, whether it is properly secured or not. It should not be oily or greasy.
4. When marking a cut with hacksaw, the blade must be guided with a first finger and thumb of one hand, otherwise the blade is liable to break which may cause serious injuries.
5. After using tools, they should never be left at the top of the ladder or any other high level places since they may fall accidentally and can cause injury.
6. Only a suitable tool should be used for the proper purpose. If a particular tool does not suit the requirement, do not try to use the tool. Always go for a proper size tool matching with the requirement.
7. All injuries must be attended ~~to~~ immediately, since delay may cause infection.

Check Your Progress 1

1. Differentiate the use of combination plier and side cutting plier.

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2. Differentiate the construction and use of Pulley Puller and Bearing Puller.

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3. Why the electrician tools should be handled with care?

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4. How the sharp edge tools are handled?

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5. What precautions are to be taken while using hacksaw?

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14.3 ELECTRICAL WIRING ACCESSORIES

After studying the different electrician tools, we will study about the different electrical accessories, which are being used in domestic as well as commercial wiring. Although there are hundreds of electrical accessories available in the market but some important electrical accessories are detailed below along with figures 14.2

Fig. 14.2 Important Electrical Wiring Accessories

i. Switch

A switch is used to make or break the electric circuit. Or it is used to switch **"ON or OFF"** the electric supply. When we switch off the electric supply, the arc is produced between the switch blades and contacts terminals. This arc may burn or damages the contacts of the switch. Formation of this arc should be avoided. Usually, this arc is avoided by means of providing a spring action movement to these switching blades to have a quick switching on or off the supply. In this way, the chances of formation of arc are drastically reduced depending upon the circuit load. The switches may be one-way switch and two-way switch. The one-way switch is used to control single circuit or lamp, where as the two-way switch is used to divert the flow of current to either of two directions. The two-way switch can also be used to control one lamp from two different places (As in case of stair case wiring). The different types of switches are available in the market, depending upon the requirement, few important are detailed below

a) **Surface Switch:** The switches are mounted on wooden board, fixed over the surface of the wall. These switches are also known as **"Tumbler switches".**

b) **Flush/Piano type switch:** The switches are used where good appearance is required. The switches are fixed in flush with the wall and do not project out. These switches are also known as **"Piano Type Switches".**

c) **Bed switch:** As the name indicates, it is used to switch **"ON or OFF"** the light from the place, other than switch-board or from near the bed, while going to sleep or getting up. This switch is connected through flexible wire.

d) **Rotary switch:** This switch is used to control different lamps from one places one by one or as selector switch, to select different voltage tapping of transformer in voltage stabilizer.

e) **Push Button switch:** These switches are used to control the electric bell and indicating lamps etc. When the push button is pressed, the circuit is completed and the bell or lamp is switched on. The supply to bell or lamp is switched off as the push button is released.

f) **Pull switch:** These switches are operated with a single pull of the cord, for the on and off position. These are also used in bedroom and bathroom. These switches are fixed near the ceiling and hence these are also known as **"Ceiling Switches".**

g) **Intermediate switch:** This switch has four terminals and four different connection position. The main function of this switch is to control a lamp from three or more different places, along with ordinary two-way switch. Generally this switch is used in double stair case wiring or corridor wiring. **This switch is also known as four-way switch.**

h) **Lamp Holder:** As the name indicates, a lamp holder is used to hold the lamp, and connect it electrically to supply terminals, required for lighting purposes. The lamp holders may be bayonet cap and screw type. Depending upon our requirement, these lamp holders are also manufactured in different designs. Some important types of lamp holders are detailed below:-

ii. Lamp Holder

a) **Batten Lamp Holder:** These lamp holders may be of brass or bakelite, with brass plunger. The holders are fixed on either on round block or wooden board with the help of wooden screws.

b) **Pendant Lamp Holder:** This lamp holder is used to hang the lamp from ceiling rose, with flexible wire. Some time these holders are provided with lampshades, to divert the upward light to down ward. These may be of brass or bakelite, with brass plunger.

c) **Angle Lamp Holder:** The angle holder is used to focus the light at an angle and is fixed directly on wall or round block with the help of *gutties* and wooden screws. These may be of brass or bakelite with brass plunger.

d) **Swivel Lamp Holder:** These lamp holders are used for lighting of shop windows, show case etc. It consists of ball and socket joint fitted between back plate and lamp holder, for the purpose to move the light to a wide angle.

e) **Bracket Lamp Holder:** These lamp holders are used to focus the light on the floor or at some angle, slightly away from the walls. Light shades can also be used for diverting all light on floor. Such lamps are provided with such fittings which make them water tight so that these can be used out side the houses or for street lighting. The bracket may be of wood, aluminium and brass. The lamp holder is simply a pendant holder made of brass or bakelite.

iii. Fluorescent Lamp (Tube) Holder

These are used to hold the fluorescent tube and pin type holders are generally used.

iv. Ceiling Rose

These are fixed on walls near the ceiling. Normally these are used to provide tapping to the pendent lamp holder, ceiling fan and fluorescent tube etc through the flexible wire.

v. Socket

The sockets have insulated base with moulded base having three terminal sleeves. The two terminal sleeves having same cross-section are used to connect phase and neural wire where as the third having greater cross-section is used to connect with earth wire. These are made for 5 amps and 15 amps load. Two-pin sockets are also available, in which only phase and neutral wires are connected. These are available in 5-amp capacity. These may be surface type or piano-types. The surface type accessories are obsolete now days.

vi. Plug

The plugs are also having moulded three pins of brass or any electrically conducting material. These are also made of 5 amp and 15-amp rating. These are used for taking power from socket.

vii. Main Switch

As the name indicates that this switch is used to switch **"on or off"** the main supply. In other words these switches are used to control the whole supply for a house, office and machine. In single-phase circuit I.C.D.P. main switches are used, whereas in three-phase circuits I.C.T.P. main switches are used to control the supply. The main switches are of the following type:

a) **I.C.D.P. Switch:** Iron Clad Double Pole main switch is used in single-phase supply circuits. These are available in 15 Amp, 30 Amp, 60 Amps and 100 amperes current rating. In these switches, either two numbers of fuse links are provided or a fuse link and a neutral link is provided. The neutral wire is directly connected with the neutral link and phase wire is connected with the fuse link. Normally 15 Amp current rating main switches are made of plastic moulding instead of iron.

b) **I.C.T.P Switch:** Iron Clad Triple Pole main switches are used to control the three phase supply circuit. These are available in 15 Amp, 30 Amp, 60 Amp, 100 Amp, 150 Amp and 250 Amps current rating. Generally these switches are also known as 3 phase 4 wires main switches. In these switches, three fuses and a neutral link is available. The neutral wire is directly connected with the neutral link and phase wires are connected with these fuse links.

viii. Fuse

It is the most common and important type of safety device used for domestic and commercial installations. These fuses are of kit-Kat type and are also known as cut-out. These cut-outs are made of porcelain in current rating of 15 to 300 amperes. The material used as a fuse wire is tin, lead, silver, antimony, copper and aluminium etc. Copper or lead, tin alloy is mostly used in ordinary fuse wire.

ix. Miniature Circuit Breaker (M.C.B.)

A miniature circuit breaker is an electro-mechanical safety device which operate and disconnect the circuit supply, when the current drawn from the circuit increases to a pre-determined value. These are used in lieu of fuses and can be fitted in consumer's distribution board. An MCB will normally operates at 1.25 times its rated current value. It can be reset, by simply lifting its operational knob, where as the fuse has to replace its fuse wire. Hence the miniature circuit breaker are replacing the rewirable fuses now a days.

Check Your Progress 2

1. Differentiate the construction and use of one-way and two-way switches.

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2. Differentiate the construction and use of socket and plug.

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3. Differentiate the construction and use of I.C.D.P and I.C.T.P. main switches.

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4. Why the M.C.B's are preferred than fuses?

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14.4 DOMESTIC WIRING SYSTEM

In this sub-unit, we will come to know the various important factors, which are to be taken into considerations, while selecting type of wiring system to be used. These factors are durability, safety, appearance, cost, accessibility and maintenance cost, etc. Apart from above, the environmental conditions, such as temperature, humidity, indoor or outdoor, direct sunlight and corrosive acid fumes, etc., are also be taken into consideration. The following are the types of internal wiring usually employed in houses and industries.

i. Cleat Wiring

The wooden plugs (*gutties*) are fixed in the wall at regular interval of 30 - 60 cm apart. This distance should not increase in any case; otherwise there will be risk of wire/cable touching the wall. The cables/wires are supported and gripped between the porcelain cleat approximately 10 mm above the wall. Cleats are made in two halves, the base, which is grooved to accommodate the wire and the cap is put over it as shown in the figure 14.3

Fig. 14.3 Wires Laid in Three Groove Cleats

After placing cable between upper and lower cleat, they are screwed on wooden gut ties with the help of wooden screws. The wires must be laid by stretching between the cleats, so as to avoid contact with wall. Simultaneously the wire should not be stretched too tight, that its insulation might get damaged. V I R and P V C cables are used for this type of wiring. This type of wiring is practically used as temporary wiring.

ii. Wooden Casing Capping Wiring

As the figure 14.4 indicates, the casing is the base unit in which U shaped grooves are made usually two in number, into which wires are laid in such a way that the wires of opposite polarity are laid in different groove. The second part is **"capping"** which is a rectangular strip of same size as casing, as shown in the figure 14.4.

Fig. 14.4 Casing Capping T-Joint for Two Wires

The capping is fitted on casing with the help of wooden screw. Usually these are made from seasoned teakwood free from knots and other defects. All the sides of casing and capping should be well varnished with a good quality varnish. The size of the casing capping to be used depends upon the number and size of the wires to be accommodated. Nowadays, wooden casing capping are being replaced very fast by plastic made casing capping (Channel), as the cost of wood is too high as compared to plastic. Secondly the outer look is very good and does not require any maintenance.

iii. Tough Rubber Sheathed Wiring (TRS or CTS) or Batten Wiring

This wiring also known as batten wiring system, in which Tough Rubber sheathed or Cab Type sheathed wires are used. The batten is prepared from seasoned teakwood. The minimum thickness of batten should not be less than 13 mm. In domestic wiring normally used width is 13, 19, 25, 31, 44 and 50 mm and is suitable for 2, 3, 4, 5, 6 and 7 wires, respectively.

Joint link clips are fixed on batten with the help of nails. Wooden *gutties* are fixed in the walls at an interval of 75 cm. The batten is fixed on wall with the help of wooden screws and *gutties*. The wires are fixed on batten by means of joint link clips, already fixed on batten. This method is mostly used for all ordinary residential and non-residential installation, being cheap in cost, quick installation, fault finding and repair, etc. But it has a great disadvantage that this wiring is unsuitable where it is exposed to direct sunlight and rainfall. It is suitable where acidic and alkalis firms are present.

iv. Lead Sheathed or metal wiring

This system of wiring is also similar to that of T.R.S or C.T.S sheathed wiring system as in previous case. Here the wires are replaced by lead sheathed or metal sheathed wires/cables. Rest of the procedure such as fixing of batten on wall, fixing of lead sheathed wire in joint clips, etc is also the same. As these wires are covered, with extra coating of lead, not exceeding 15-mm thickness, this type of wiring is suitable on places exposed to direct sunlight, rain and damp situation. This type of wiring gives fairly good-looking and comparatively longer life.

v. Conduit Wiring

As the name indicates **"Conduit Wiring"** mean the wires are enclosed in steel pipe known as **" Conduit."** When this conduit is coated with enamel is known as black conduit and when galvanized it is known as galvanised conduit, to protect the pipe from corrosion and insulation damage to wires. There are three types of conduit wiring mostly in use.

a) **Concealed Wiring:** In this wiring system, the conduits are embedded into the walls and ceiling, with the plaster at the time of construction. These conduits should be mechanically as well as electrically continuous and connected to earth wire at some suitable places. The P.V.C wires are drawn into the conduit, by means of steel wire not less than 18 S.W.G. Number of inspection boxes are provided, in order to facilitate the drawing of wires in the conduits. Nowadays, P.V.C. conduit pipe is also available in the market, which do not require any threading for jointing the pipe. The joints are made with special solution. This type of wiring is not suitable for damp situation.

b) **Surface Conduit Wiring:** In this wiring the conduits are fixed on the surface of wall and ceiling with the help of conduit saddles, wooden screw and *gutties*. In damp situation, the conduit can be spaced from walls by means of wooden spacers, below the conduit along its length at regular intervals. The wires are drawn in the conduit with the help of steel wire. Junction boxes are provided to facilitate the drawing of wires in the conduit. This system of wiring is commonly used for industrial wiring, especially in three-phase wiring. As the, fault finding and repair is quick, easy in wiring, cheap in cost but not suitable for domestic wiring, as it does not give fairly good outlook.

c) **Flexible Conduit Wiring:** This wiring is carried out to provide mechanical protection to cable between conduit and machine. Generally this wiring is not used for wiring purposes. It is generally used for connecting conduit with machine terminal box in case of motor wiring, energy meter and main switches.

Check Your Progress 3

1. What are the various factors to be considered while selecting type of wiring?

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2. Why cleat wiring is practically considered as temporary wiring?

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3. Why the wooden casing capping is being replaced by plastic made casing & capping now days?

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4. Explain the similarities and differences between lead sheathed and tough rubber sheathed wiring?

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5. Which type of conduit wiring is preferred in domestic wiring and why?

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14.5 LAYOUT OF WIRING SYSTEM

In this sub-unit, we will study how the electricity comes to your house, offices and factories, starting from nearby service pole. Generally, the houses, offices and shops, etc., are connected with single-phase supply, if the total connected load is less than 5 kilowatt. If the load is more than 5 kilowatt, the three-phase four-wire system is recommended. In factories and plants, we need to connect lighting as well as three phase induction motors, hence three-phase four-wire system is used. Both the domestic as well as factory wiring diagram is detailed in figure 14.5 & 14.6

i. Domestic wiring diagram

A four-core weatherproof, 660 volts, aluminium cable is used to connect the three phase four wires (Three phase and a neutral wire) energy meter, from the service pole. This cable is supported by an 8 S.W.G. galvanised steel wire, from service pole to consumer premises, as shown in the figure 14.5.

Fig. 14.5 Wiring Diagram of a domestic Installation

G.I. pipe is used to enclose the service cable. This pipe is fixed on the wall, with the help of saddles, gutties and wooden screws and it should be so selected that the weatherproof cable is easily pulled into the pipe without damage to the insulation of the cable. The service cable is made to enter the building through the pipe and connects the main board for connecting the three-phase energy meter. The output of the energy meter is controlled through the I.C.T.P. main switch. The phase wires are connected the fuse links whereas the neutral wire is directly connected to the neutral link. The output of this I.C.T.P. main switch (one phase and neutral) is distributed through the single-phase I.C.D.P. main switches, which acts as main control switch for a room or for a power point.

ii. Factory wiring diagram

The wiring diagram for a factory or for a dairy plant is almost similar to three-phase four wire domestic wiring diagram, up-to I.C.T.P. main switch. The only difference is the output of this I.C.T.P. main switch is connected to different small capacity I.C.T.P. main switches as shown in the figure 14.6

Similar to the previous case, a four-core weatherproof, 660 volts, aluminium cable is used to connect the three-phase four wires (Three phase and a neutral wire) energy meter, from the service pole. The size of this cable depends upon the load of the entire factory. An 8 S.W.G. galvanised steel wire, from service pole to consumer premises supports this cable. G.I. pipe is used to enclose the service cable. This pipe fixed on the wall, with the help of saddles, gutties and wooden screws and it should be so selected that the weatherproof cable is easily pulled into the pipe without damage to the insulation of the cable. The service cable is made

Fig. 14.6 Wiring Diagram of a Dairy Plant

to enter the building through the pipe and connects the main board for energizing the three-phase energy meter. The output of energy meter is controlled through the I.C.T.P. main switch. The phase wires are connected to the fuse links whereas the neutral wire is directly connected to the neutral link. The output of this I.C.T.P. main switch (Three phase and neutral) is distributed through small capacity I.C.T.P. main switches, which acts as main control switch for a section, as shown in figure above.

Check Your Progress 4

1. Why the three-phase energy meter is recommended to install in a domestic installation, if the load is more than 5 Kilowatt?

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2. How G.I. pipe is fixed on walls and what precautions are to be observed while drawing cable in the pipe?

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3. What are the constructional differences between the I.C.D.P. and I.C.T.P. main switches?

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4. Why the capacity of main switches is kept greater than the capacity of main switches controlling the individual section/circuit supply.

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14.6 LET US SUM UP

After studying this unit, we are aware about the different electrician tools, available sizes and their proper handling. The selection of tool is important and improper use of tools my lead to serious injuries to the electrician and the tool may also be damaged. These tools should be provided with a layer of lubricating oil or grease etc., in rainy season or in highly humid atmosphere, to protect these from corrosion attack. The sharp edged tools, such as pocketknife, chisels etc., should never be put in pocket without shield. Also, care should be taken not to hand over the sharp edge tool with its sharp edge side. Different electrical wiring accessories such as switch, fuses, MCB, are used for wiring, single phase and three-phase wiring. Fuses and miniature circuit breakers (M.C.B.) are used as safety device for and electrical circuit. When the current drawn from the circuit is increase beyond the pre-set limit, the supply is switched off. Different factors such as durability, safety, cash maintenance etc. to be taken into account while selecting particular wiring system for domestic offices and factories. How the electricity comes to our houses, offices and factories/plants etc., from the service poles. We might have an exposure about the internal wiring, starting from energy meter to I.C.T.P. main switch and other small capacity main switches, to have an independent control of various circuits/sections.

14.7 KEY WORDS

Conductor : A wire may be flexible or rigid, used to transfer energy to any electrical appliance or circuit.

Cable : A length of insulated conductor (solid or stranded) or of two or more conductors, duly provided with overall mechanical protecting layers.

Bare Conductor : Conductor not covered with any insulating material.

Flexible Cable : Cable consisting of one or more cores of each formed a group of wires. The diameter and physical properties should afford flexibility.

Circuit : Arrangement of conductors and appliances for conveying or transfer of energy.

M.C.B : A very small than normal circuit breaker, used to switch off the supply in case over current flow in the circuit.

Cut-out : A safety device used to switch off the supply, in case over current flows in the circuit, by melting its fuse wire.

Pendant : A hanging object.

Fuse Carrier : The detachable upper part of the re-wirable kit-kat fuse.

Distribution Board : Which distribute the electricity from circuit to various sub circuits through protective fuses.

14.8 SOME USEFUL BOOKS

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14.9 ANSWERS TO CHECK YOUR PROGRESS

Your answer should include the following points:

Check Your Progress 1

1) i. Type of work combination plier can do.
   ii. Type of plier side cutting plier can do.
   iii. Difference in cutting action of both.
2) i. Number of legs of both the Pulley Puller and Bearing Puller.
   ii. Nature of work, which could be done, on both the tools.
3) i. Injury of the electrician.
   ii. The tool may be broken.
   iii. Proper tool should be used.
4) i. What will be the effect on person, If the tools are not handled carefully.
   ii. What will be the effect on tool itself, If the tools are not handled carefully,
   iii. Care to be taken while cutting with these tools.
   iv. Care to be taken while hand over a sharp edge tool to other.
5) i. Mention the position of your first finger and thumb.
   ii. The blade will be liable to break, if not guided properly.

Check Your Progress 2

1) i. Numbers of wire used in both.
   ii. Use of both the switches.
   iii. Describe the working of both.
2) i. Basic constructional differences of socket and plug.
   ii. Socket is used to give the supply whereas the plug is used to take.
3) i. Number of fuse links in both the main switches.
   ii. I.C.T.P main switch is used to control the three-phase supply whereas the I.C.D.P. main switch is used to control the single-phase supply.
4) i. Procedure to restore the supply.
   ii. Time taken to restore the supply.
   iii. Chance of accident in both.

Check Your Progress 3

1) i. Durability, cost, and appearance.
   ii. Environmental conditions.
   iii. Time taken for fault finding and repair.
2) i. Time taken in complete wiring is less.
   ii. Chances of accidents are more.
   iii. Appearance not so good.
1) i. Compare the time taken in complete wiring.
   ii. Compare the cost of both.
   iii. Compare the outlook.
2) i. Appearance of wooden casing capping is good than plastic.
   ii. Compare the type of wires used.
   iii. Method of fixing casing is same in both.
   iv. Maintenance cost is very low in case of plastic casing capping.
3) i. Concealed wiring is preferred.
   ii. Durability of wiring is more.
   iii. Chances of faults occurring are less.

Check Your Progress 4

1) i. The transformer load could be equally distributed.
   ii. Selector switch can be used to feed the supply to out of order phase load.
2) i. G.I. pipe is fixed on wall with the help of wooden gutties, saddles and wooden screws.
   ii. Cable insulation should not damage while drawing.
3) i. Number of fuse links in I.D.T.P. may be one or two, whereas the in I.C.T.P. are three.
   ii. Number of neutral links in both the main switches are one.
4) i. In case over current, the fuse of individual section's main switch will blow off if its capacity is less than the main switch.
   ii. Under such circumstances, the supply to other section will not suffer.

UNIT 15 A.C. MOTORS, STARTERS AND D.G. SET

Structure

15.0 OBJECITIVES

After studying this unit, we should be able to:

- recognize the different types of single-phase and three-phase induction motors.
- understand the working principled of single-phase and three-phase induction motor.
- reverse the direction of rotation of single-phase and three-phase induction motor.
- understand the working of D.O.L and Star-Delta Starter and function of their main parts.
- understand the working of Diesel Generating set and function of its different parts.

15.1 INTRODUCTION

In this unit, we will study about internal construction, and working principles of single-phase and three-phase squirrel cage induction motors. The single-phase motors are not self-start. How a single-phase motor can be made self-start will be discussed in detail. Single phase induction motors such as split phase, capacitor start induction run, capacitor start capacitor run and shaded pole, etc. also will be discussed in detail along with figures. We will also have an exposure about direct on line (DOL) and star delta starters used to start and reverse the direction of rotation of squirrel cage induction motors. We know that in industries certain equipment need to be run continuously. In case of emergency breakdown of electric supply or power cut off, the production is seriously effected. So, the only and instant power of source, which could serve the purpose, is **"Diesel Generator set".** This alternate source of power will be discussed in detail in this current unit.

15.2 THREE PHASE INDUCTION MOTORS

"A machine which converts three-phase electrical energy into mechanical energy based on principle of electro-magnetic induction is known as three-phase induction motor". These motors are quite different from D.C. motors, because the three-phase electric supply is given to its stator only. There is no electrical connection to the rotor from the main supply and also no other source of supply is required to run the induction motors. Whereas in case of D.C. motor, both the stators as well rotors (Armature) are connected across the supply to run the motor. These motors are mostly used in factories for different applications such as for lathe, drill, blower, printing machine, etc. The speed of an induction motors is almost constant but slightly falls with the increase in load. The starting current is 5 times higher than the full load current. Interchanging any two-phase connection to the motor or starter can reverse the direction of rotation of these motors. The working principles and different parts of induction motors are given below.

i. Working Principle

When stator winding of a three-phase induction motor is connected across the three phase electric supply, a rotating magnetic field will be produced. This rotating magnetic field, when links with the short-circuited rotor bars, an electro-motive-force (E.M.F.) will be induced in the rotor bars. This induced electro-motive-force will circulate a heavy eddy current in the rotor bars and produced its own magnetic field. By Lenz's law this induced current will oppose the cause producing it i.e. relative motion of the stator field. The combined interaction of both the magnetic fields (Stator and Rotor) will produce a net resultant moving force (Torque) in the rotor. As the current in the rotor bars is set up entirely by effect of electromagnetic induction from the stator, hence the name **"Induction Motor"**. The main parts and their use are given here figure 15.1

Fig 15.1 Different Parts of a Three-Phase Squirrel Cage Induction Motor

a) **Stator:** As the name indicates, it is the stationary part of the induction motor and made of silicon steel strips of thickness, varying from 0.3 to 1.35 mm. These strips are combined together, which are called laminated strips and the combination is known as laminated core. These laminated stampings/strips are slotted to receive the winding. These slots may be of open or semi-closed types, to facilitate the winding. The core and end covers are fitted in the cast iron frame, so that external mechanical injury may not take place to stator winding. The same stator can be used for single-phase induction motors. The stator carries three-phase winding and is fed from three-phase electric supply. The stator is wound for a definite number of poles and depends upon the speed of motor. Greater the number of poles lesser will be the rotor speed and vice-versa. This speed can be calculated by the formulae, $N_s = 120f/p$. Where $N_{s,}$ is the synchronous speed of the stator field, f, is the supply frequency, which is normally 50 cycles per second, and P is the number of poles. The synchronous speed for a 2-pole motor is 3000 r.p.m. and for a 4-pole motor it is 1500 r.p.m. Generally the speed of rotor is slightly less (up-to 5% of synchronous speed) than the speed of stator field. The difference between the speed of stator field and rotor is known as slip and it should be as low as possible.

b) **Rotor:** The rotor is the rotating part of the motor and made of silicon steel strips. The thickness of these strips varies from 0.3 to 1.35 mm, as in case of stator. These strips are clamped together to form rotor core, called as laminated core. This laminated core is slotted to totally closed type, to receive rotor winding. In large capacity motors thick aluminium bars are inserted and are short-circuited with end rings. Nowadays, melted aluminium is filled in these slots, which works as short-circuited winding. This winding is known as squirrel cage winding. As we know plain induction motor is having poor starting torque and draws heavy starting current. So, such types of problems can be over come by modifying the rotor slightly by providing double cage in the rotor as shown in the figure 15.2.

Fig. 15.2 Double Cage Rotar

As illustrated above, the rotor has been provided with double slots to accommodate two rotor windings. A low resistance copper bars are deeply embedded in the slots and brass or aluminium bars are inserted near the surface. This type of winding is known as double cage winding. The whole assembly is keyed on the shaft of the motor.

c) **End Covers:** As the name indicates these covers are used to cover the ends of the motor and are made of cast iron. These end covers are fitted with the stator frame with the help of nuts and bolts. The ball bearings are fitted in the end covers to keep the rotor exactly in the centre of the stator, so that it can move freely.

d) **Shaft and Bearings:** Mostly ball bearings are used in large capacity motors where as the bush bearings is used in small capacity motors because the noise level is high in ball bearing as compared to bush bearings. The main purpose of bearings is to keep the rotor exactly in centre and ensure free movement for the rotor. The shaft is a long circular bar, made of mild steel. The rotor assembly and cooling fan is securely keyed to the shaft of the motor.

e) **Fan:** In general, the fan is used to cool down the temperature. When the motor runs on load, the heat is produced in the motor winding as well as in the core due to copper and iron losses respectively. So, the fan serves the purpose of transferring the heat from inside to outside of the motor by forced air circulation. It sucks the air from the atmosphere through the air ducts and discharge back to atmosphere after cooling the winding and core of the motor. In large capacity motors these fans may be fitted on the rotor shaft near the winding whereas in small capacity motors these may be fitted outside the end covers. A mild steel or cast iron cover is used to cover the fan to avoid chances of accidents.

Check Your Progress 1

1. Explain the working principle of an induction motor.

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2. Why the core of stator and rotor is made of thin laminations?

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3. Calculate the synchronous speed of an induction motor having number of poles = 6 and supply frequency = 50 Cycle per second.

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4. Define slip**.**

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5. Why fractional horse-power (H.P.) capacity motors are generally provided with bush bearings.

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15.3 SINGLE PHASE INDUCTION MOTORS

In this sub-unit, we will study the different types of single-phase squirrel cage induction motors, working principle and their different parts. Single-phase motors also works on the same principle on which the polyphase (Two or three phase) induction motor works, i.e. **“whenever a short circuited conductor or coil is placed in a rotating magnetic field, the conductor tends to move.”** In construction, these motors are similar to polyphase induction motors with the exception that the stator has single-phase winding as shown in the figure 15.3.

Fig. 15.3 Different parts of a Single Phase Squirrel Cage Induction Motor

The magnetic field produced by the stator current is fixed in space instead of rotating, but its magnitude is changing sinusoidally. Such a field is equivalent to two fields of equal magnitude rotating in opposite directions at equal speed, each being half of the maximum value of the alternating field. So the single-phase motors are not self-start in the first instance. However, if the rotor of such motor is given a rotation in any direction by switching on the supply to the stator, a starting torque will be produced and motor pick up full speed in the direction in which the rotation was given.

As discussed above, these motors are not self-start. Splitting the stator field into two fields having an angle between them can solve this problem. The phase splitting up can be achieved by either providing an auxiliary winding in addition to main windings or dividing the stator field into two fields. Provision of an auxiliary or starting winding in addition to the main or running winding is easier and is spaced 90^0 electrical apart. Since the phase difference between the starting and running winding is large and hence behaves like a two-phase winding. These windings are connected in parallel and across the supply. So, according to the starting devices, the single-phase motors may be split phase motors, repulsion types motors and universal motors. And according to construction, these motors may be induction type motor, repulsion type motors and A.C. series type motors etc. Here we will discuss the different types of single-phase induction motors only, which are:

i. Split Phase Induction Motors

As the name indicates, the stator is temporarily converted into two-phase stator by providing an extra winding i.e. starting or auxiliary winding for the starting purpose only. The main winding has low resistance and high reactance whereas the starting winding has high resistance and low reactance, in order to produce phase difference between the magnetic field produced by these windings. Sometimes an extra resistance is added in series with the starting winding to increase the starting torque. These windings are connected in parallel and across the supply as shown in the circuit diagram (figure 15.4)

Fig. 15.4 Circuit Diagram of Split Phase Induction Motor

As shown above when the supply is switched on, two magnetic fields will be produced having some phase difference and hence the combined effect of these magnetic fields will produce a starting torque in the rotor. When the motor attains 75 to 80 percent of full load speed, the centrifugal switch cut off starting winding from the main supply. This switch is mounted on the shaft of the motor and connected in series with the starting winding. In hermetically sealed units, the centrifugal switch is replaced by an electromagnetic relay as shown above. The relay is connected in series with the main winding and contact pair of the switch are connected in series with starting or auxiliary winding, which are normally open (NO type). When the supply is switched on, the main winding will draw excessively higher current and the relay contacts are closed. So, the motor starts working as split phase motor. The starting winding will be cut off from the supply when the motor attains more than 80 percent of the full load speed. Because the current drawn by the main winding will be reduced to too low enough to cause the electromagnetic relay's contact open and the motor will continue to run on single winding as single phase induction motor. Generally these are available in fractional H.P. Reversing the direction of current either in starting or running winding, the direction of rotation can be reversed.

ii. Capacitor Start Induction-run Motors

Construction wise these motors are almost similar to split phase induction motors except the starting resistance is replaced by a static capacitor to produce starting torque as shown in the figure 15.5.

Fig. 15.5 Circuit Diagram of Capacitor Start Induction Motor

A centrifugal switch is connected in series with starting winding. As already explained, its function is to connect the starting winding across the supply and running winding, for producing starting torque and cut off the same when the motor picks up 75 % of the full load speed. If this winding remained in circuit it will damage due to heating. Because this winding is made of lesser number of turns of very fine copper or aluminium wire as compared to main winding. Starting and running procedure is same as split phase induction motor. In these motors also, reversing the direction of current either in starting or running winding the direction of rotation can be reversed. Generally all the small capacity motors up to 3 H.P. are widely used in domestic and industrial applications.

iii. Capacitor-start Capacitor-run Motor

This motor is also known as permanent capacitor motor. In these motors, the centrifugal switch is removed and the starting winding is so designed that it can work permanently without overheating as shown in the figure 15.6.

Fig. 15.6 Circuit Diagram of Capacitor Start Capacitor Run Motor

The resistance, inductive reactance and size of winding wires of both the windings are not exactly the same but it is almost same. So, the starting winding will remain in the circuit permanently without overheating and drawing excessive current from the supply. The overall starting and running torque is increased because the capacitor remains permanently in the circuit and hence the name.

iv. Shaded Pole Induction Motor

In such motors the rotor is same as in all the previously discussed induction motor except the stator has salient poles to accommodate the winding as given in fig. 15.7.

As shown above, the stator of the motor has four poles. The field coils connected in series for alternate polarity (North and South Pole). These poles are made of laminated silicon stampings. These stampings are clamped together to form stator

Fig. 15.7 Shaded Pole Motor

poles. Approximately 1/3rd portion of the pole is shaded to accommodate a thick copper ring, which acts as auxiliary or starting winding to produce starting torque. This thick copper ring is known as copper shading ring. When the supply is switched on, the alternating magnetic field is produced in each pole. This alternating flux will divide into two-portion i.e. shaded portion flux and un-shaded portion flux. The shaded portion flux will link with the shading ring and an electro-motive-force will be induced in the shading ring. This induced e.m.f. will circulate its eddy currents in the shading rings and opposes the shaded portion flux and hence the phase difference between the two fields will be produced. The combined effect of these fields will produce starting torque in the rotor and the motor will continue to run. These motors are available in very low capacity varying from 3 to 125 watts. The use of this type of motor is restricted due to poor starting as well as running torque, very less overload capacity and poor efficiency, etc. So, generally these motors are used for small fans, toys, ventilators, hair drier and small instruments, etc.

Check Your Progress 2

1. Why single-phase induction motors are not self-start.

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2. How the direction of rotation of a single-phase induction motors can be reversed?

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3. How single-phase induction motors can be made self-start?

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4. Explain the function of a “Centrifugal switch”.

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5. Why the shaded pole motors are available in very low capacity?

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15.4 DIRECT ON LINE AND STAR DELTA STARTERS

In this sub-unit, we will come to know about the circuit diagram, main parts, working and necessity, of **"Direct On Line (D.O.L.) and Star Delta starters".** As the name indicates **"Starter"** is used to start and stop the motor. The starter is also used to protect the motor and other connected equipment from sustained overload, under voltage, single phasing, etc., and also provide automatic control whenever required. Now the question arises why we need starter for the safe operation of the motor. As already explained that the motor acts as a transformer with secondary winding (Rotor winding) short-circuited. When the motor is started from standstill position, high starting current will circulate in the rotor winding and simultaneously the stator will draw heavy current from the supply mains. As a result of this heavy current, the system or line voltage will be drastically reduced, which is objectionable from safety point of view. The other sensitive equipments connected with same line may trip on low voltage. Therefore large capacity motors (Above 5 H.P.) should be connected through such a mechanism, which can reduce the starting voltage. If the starting voltage is reduced, the starting current drawn by the motor will be reduced automatically and thus the line voltage will remains almost constant.

Several types of starters are available in the market depending upon the type and rating of the motor. For example, Direct On Line (D.O.L.) starter is used up-to 5 H.P. motors; Star Delta starter is used from 7.5 to 20 H.P. motors and Auto-transformer/Resistance types of starter is used above 20 H.P. rating motors. Except D.O.L. starter, these starters are used to reduce the starting voltage and hence to reduce the starting current. Direct on line (D.O.L.) and Star Delta starters are discussed below.

i. Direct On Line Starter (D.O.L.)

As the name indicates **"Direct On Line Starter"** a device used to connect a motor directly on line voltage. As already discussed these starters are used up to 5 H.P. capacity motors as full load current of these motors is less and hence lesser starting current. Figure given below shows the internal connections and main parts.

a) **No-Volt-coil (N.V.C.) :** This coil is connected across two phases in series with interlock switch, overload relay, red button (off switch), green button (on switch) etc. Green button is connected in parallel with interlock switch. When green button is pressed for a few seconds the N.V.C. will magnetized and pulls the plunger down ward against the spring tension. Four copper strips will make the contacts with lower contact points and hence the motor will continue to work even after releasing the green button. When the red button is pressed for a second the N.V.C. will demagnetised and the plunger will go back to its original position. So, the motor will switch off.

Fig. 15.8 Direct on Line Starter

b) **Over Load Relay:** This relay is used to protect the motor from overload which may be due to actual overload, defective bearings and single phasing etc. Thick heating strips are connected in series with the motor. A bimetallic strip is also fixed near these strips. When higher current (more than normal) starts flowing through these heating strips, bimetallic strip will start bending due to heating and opens the over load switch contacts. Hence the electric supply to N.V.C. will interrupt and motor will stop.

c) **On Switch (Green button):** This switch is used to switch on or start the motor and is normally open (Push to on) type as shown in the figure above. When this switch is pressed, N.V.C. will magnetized and motor will start running.

d) **Off Switch (Red button):** This switch is used to stop the motor and is normally close (Push to off) type as shown in the figure above. When this switch is pressed for a second, electric supply to N.V.C. will interrupt and motor will stop running.

ii. Star Delta Starter

These types of starters are used for motors having rated capacities from 7.5 H.P. to 20 H.P. Like direct on line starter it has also off switch, over load relay, no volt coil etc. as shown in the figure 15.9.

Fig. 15.9 Star Delta Starter

Star delta starter is used to reduce the starting current drawn by the motor when it is switched on. When the handle is pressed to start position (Star), the motor's out put terminals A_2, B_2 and C_2 gets short circuited with a thick copper strip on the handle while the other terminals A_1, B_1 and C_1 gets connected across the supply. The applied voltage across the motor gets reduced to 58 % of the full voltage and hence the starting current drawn by the motor will also reduce to 58 % of the total starting current drawn by the motor if full voltage is applied. Although the starting torque will also reduced to same proportions. When the motor picks up more than 75 % of the rated speed, the handle is switched over to run position (Delta). Now the motor terminals C_1 A_2, A_1 B_2, and B_1 C_2 will get short circuit and the motor will get the full voltage. So, the motor will take full load current and develops full torque. In delta position handle is magnetically picked up and motor will continue to run on full load. An off switch is connected in series with overload relay and no volt coil. This switch is used to switch off the motor. Over load relay is used to switch off the motor by disconnecting the supply to the no volt coil.

Check Your Progress 3

1. Why starters are recommended to run the motors?

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2. Why the use of D.O.L. Starter is restricted up to 5 H.P. motors?

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3. Explain the function of "No Volt Coil" in a starter.

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4. Which type of starter will you recommend for a 15 H.P. motor and why?

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5. How much voltage and current does a star-Delta starter will give to the motor at the time of starting as compared to D.O.L. starter?

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15.5 DIESEL GENERATING SET

Diesel generating sets are used to generate electrical energy in emergency when the main supply is suddenly interrupted. In other words, we can say that these are used as standby source of electrical energy. These are available in different sizes varying from 5 to 500 Kilo-Volt-Ampere (KVA). As compared to another sources of electrical energy, these are cheap in initial cost, less commissioning time, easy to handle and very quick to start generation, as no warming time is required. Requirement of large quantity of cooling water is the main problem in all other generating sources of electrical energy but these plants require very less quantity of water. Nowadays, radiator type fan cooled diesel generating sets are available in the market, which needs too less quantity of cooling water. Although as shown in the figure 15.11, we have used the spray pond for cooling purpose. In-spite of several advantages the diesel generating sets cannot be used as continuous source of electrical energy. Because the high-speed diesel is used as fuel in internal combustion engine (I. C. Engine), which is costlier than the fuel used by other generating sources and hence, there is increase in cost of generation. Although the working of a diesel generating set will be slightly differs depending upon the KVA rating and method of starting the diesel engine. However, the working of a diesel generating set in general is explained here.

Working: When the engine is started, the alternator starts moving. The magnetic field coils are mounted on rotor, which changes its position as the rotor moves, and three-phase winding is placed on the stator. So, three-phase supply will generate in the stator winding. Initially the supply will be generated due to residual magnetism of the pole shoes. For continuous and constant voltage generation, the pole shoe requires fixed quantity of external excitation for producing alternate north and south poles. So, the initially generated a.c. supply is converted into d.c. supply by metal rectifiers and feedback to armature through slip rings and carbon brush assembly. The change over switch should be operated before starting the engine. When full voltage builds up, the air circuit breaker is switched on. Different parts of a diesel generating set and their brief use are explained here 15.10.

i. Engine

Engine is the most important part of a diesel generating set and which acts as a prime mover. The type of engine used is internal combustion engine (I.C. Enginer) and works on two stroke or four stroke cycle principle. High-speed diesel is used as fuel. The capacity of engine depends upon the K.V.A. rating of alternator and it should be capable of taking over loads for at least two hours, keeping the temperature with in safe limit. Generally high-speed diesel engines are preferred because the over all generation cost is reduced due to reduction in cost of engine and alternator, etc. Multi cylinder engines are also preferred to reduce the noise level and vibrations produced in the engine while working.

ii. Alternator

Alternator also known as **“A.C. Generator”** operates on the same principle of Faraday’s law of electro magnetic induction as d.c. generator. In these a. c. generators salient poles are keyed on rotor and field windings are mounted over it to produce permanent magnetic field with alternate north or south. The stator also consists of circular silicon stampings, having slots on its inner periphery for accommodating the stator winding may be single phase or three phase depending upon requirement. Slip rings are mounted on the rotor shaft to feed d.c voltage for excitation to produce magnetic field. This excitation may be supplied from small d.c. generator coupled to the same shaft or from metal rectifier. The alternator is used to generate a.c. voltage.

Fig. 15.10 Diesel Generating Set

iii. Air Circuit Breaker and Bus Bar

The air circuit breaker is used to switch on or off the main supply generated by the alternator. The circuit breaker should be switched on when the alternator builds up full voltage. When it is switched on, the supply will energise the bus bar. A bus bar is a bundle of conductors or thick copper strips, used to distribute the generated voltage with the help of change over switch. The change over switch is used to select the source of generation i.e. either generated or external source of supply.

iv. Engine Cooling System

This includes jacket water tank, used to make up the quantity of cooling water, jacket water pump for forced circulation of cooling water. Heat exchanger to exchange the heat of cooling water with circulating water, circulating water pump to spray the water in the spray pond and spray pond to cool down the temperature of circulating water.

v. Engine Fuel System

This system includes diesel tank to store the fuel and fuel transfer pump to transfer the fuel from fuel tank to engine. The strainer is used to restrict the flow of highly viscous liquid; fuel filter is used to filter the fuel and heater to main viscosity of fuel especially in winter season within limit.

vi. Engine intake and exhaust system

To ensure fresh and dust free air for the combustion of fuel, air filters are provided which may be cleaned by air pressure or replaced depending upon the conditions. To exhaust the burn out gases from the engine, exhaust pipe is used and muffler is used to reduce the noise level of exhaust gases. The exhaust pipe should be discharge to the atmosphere outside the room.

vii. Engine starting system

Depending upon the rated capacity of diesel generating sets, different types of starting systems are used. Small capacity D.G. sets (5KVA) are started manually with handle and above 5 KVA are started with 24 volts D.C motors, which are generally know as **"Self-starter".** For this purpose higher A.H. capacity batteries are used to supply the d.c. voltage and are recharged with dynamo coupled with same shaft of alternator. Big capacity diesel generating sets also uses compressed air motor to start.

Check Your Progress 4

1. Why diesel-generating sets are used as standby source of generation of electrical energy?

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2. How the electrical energy is generated during starting when there is no excitation is available?

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3. Why multi cylinder engines are preferred for big capacity diesel-generating sets?

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4. Why alternators are known as a.c. generator?

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6. Explain the use of change over switch and air circuit breaker.

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15.6 LET US SUM UP

After studying this unit, we are familiar with internal construction, and working principle of single-phase and three-phase squirrel cage induction motors. We can reverse the direction of rotation by interchanging any phase wires either at motor terminals or at start terminals. We know the reason that why the single-phase motors are not self-start and how we can also make them self-start. We can differentiate and run the single-phase induction motors such as split phase, capacitor start induction run, capacitor start capacitor run and shaded pole. The direct on line (DOL) and star delta starters used to start and reverse the direction of rotation of squirrel cage induction motors. These are the important tools for the safe operation of the motor. In case of emergency breakdown of electric supply or power cut off, the production is seriously effected. So, the only and instant power of source, which could serve the purpose, is **“Diesel Generator set”.**

15.7 KEY WORDS

Electro Motive Force (e.m.f.)	:	Induced voltage in the secondary of the transformer or rotor winding.
Single Phasing	:	If the motor burn out due to missing of one phase out of three.
Synchronous Speed (Ns)	:	The speed of stator fields, which is equal to 120f/p.
Copper Losses	:	I^2R losses in the winding.
Iron Losses	:	Power loss in the core of the motor/ transformer/alternator/generator etc.
Auxiliary Winding	:	It is used to start the motor or to produced rotating magnetic field in a single-phase motor at standstill.

Centrifugal Switch	:	It is used to switch on the auxiliary winding when the motor is at standstill and switch off when the motor picks up more than 80 % of the full load speed.
Phase Voltage	:	The potential difference across any phase and neutral wire.
Line Voltage	:	The potential difference between any two-phase wires and it is 58% higher than the phase voltage.
Laminated Core	:	Core consists of very thin sheets.
Slip	:	Difference between speed of stator field and rotor speed.

15.8 SOME USEFUL BOOKS

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Singh.S. (1997-98). Electrical estimating and costing Dhanpat Rai & Co. (P) Ltd. 1710, Nai Sarak, Delhi – 110006

Thareja.B.L. and Thareja.A.K. (1988). Electrical Technology Nirja Construction & Development Co. (P) Ltd., Ram Nagar, New Delhi - 110005

15.9 ANSWERS TO CHECK YOUR PROGRESS

Your answer should include the following points:

Check Your Progress 1

1) i. When a short-circuited or close circuit conductor or coil, is placed in a rotating magnetic field, the conductor tends to rotate.

2) i. To reduce hysteresis losses.

3) i. We know $N_s = 120f/p$.

$$N_s = \frac{120 \times 50}{6} = 1000 \text{r.p.m.}$$

4) i. Difference in speed of rotor and synchronous speed of stator field.

Slip = Stator field speed – Rotor speed

5) i. Noise level and cost is very less as compared to others.

Check Your Progress 2

1) i. The magnetic field produce is fixed instead of rotating but its magnitude is changing sinusoidally.

ii. The torque produced is equal and opposite.

2) i.. By reversing the direction of current in either running or starting winding.

3) i. By splitting the stator magnetic field into two fields having some phase difference.

ii. By providing auxiliary or starting winding with some phase difference in the field.

4) i. Disconnecting the starting winding when the motor picks up more than 75 % of the rated speed.

5) i. Starting and running torque is very poor.

ii. Poor overload capacity and efficiency.

Check Your Progress 3

1) i. Starting current is reduced.

ii. To reduce the effect on line voltage due to high starting current drawn from the line.

2) i. Starting current is less as the full load current is also less.

ii. System or line voltage remains almost constant.

3) i. Always connected across the supply.

ii. N.V.C. energise and pull down the circuit breaker contacts and hence motor is switched on.

iii. When either the phase is out of order, the no volt coil will demagnetised and switch off the motor.

4) i. Star-Delta Starter.

ii. Starting current is reduced to 58 % to that of direct on line starter.

iii. If switched on by direct on line starter, the motor will draw heavy starting current.

5) Both the voltage and currents will be reduced to 58 % to that of D.O.L. starter.

Check Your Progress 4

1) i. Cost per unit generation is quite high.

ii. Quick and easy start.

iii. Low capital cost.

2) i. Due to residual magnetism.

3) i. To reduce noise level.

ii. To reduce vibrations in the engine and hence in adjoining also.

4) i. It works on the same principle.

ii. Rotors (Armature) are almost same.

5) i. Change over switch is used to select the source of generation.

ii. Air circuit breaker is used to connect or disconnect the alternator from bus bar.

UNIT 16 SUB-STATION, TRANSFORMER, DISTRIBUTION SYSTEM AND POWER FACTOR

Structure

16.0 OBJECTIVES

After studying this unit, we should be able to:

- recognize the various types of sub-stations and their working.
- explain the working principle of transformer and its different parts.
- state how the electrical energy is transferred from generating station to the ultimate consumers.
- explain the importance of power factor and how it can be improved.

16.1 INTRODUCTION

In this unit, we will study the various sub-stations used for transmission and distribution of electrical energy. Use and working of isolators, circuit breakers, lightning arresters, earth switches, bus-bars, bus-couplers, step-up and step-down transformers etc. we will also be have an exposure about different types of distribution systems used for distribution of electrical energy. This includes the single-phase two wires system, three-phase three wires system and three-phase four wires system, used to transfer and distribute the electrical energy from generating station to the ultimate consumer. Transformers play an important role to transfer and distribute large quantum of electricity and we can step up and step down the voltage with the help of transformer. We will also see the internal construction of transformer and various safety devices used to protect the transformer from increase in temperature and moisture. Power factor is an important factor, which should be monitored for the safe and efficient operation of any electrical installation. In this unit we will study, how power factor effects the efficiency of generating station, transformer and substation etc. Different methods to improve the low power factor by installing static capacitor bank and synchronous condenser (Synchronous motor) will be also discussed in detail.

16.2 SUB-STATION

We know that the electrical energy is generated in different types of generating stations located at distant places from the consumer's premises. For example, nuclear and coal fired based thermal power generating stations are commissioned far away from the populated area from safety point of view. So, to transfer such a huge quantum of electrical energy from generating stations to the ultimate consumer, number of transformers and other switching equipments are required to step up or step down the voltage. Any station comprising of transformers and switching equipment is known as sub-station. In general the sub-station are of following three types: -

i. Pole Mounted Type Sub-station

As the name indicates, this type of sub-stations is mounted on Reinforced Cement Concrete (R.C.C.) pole structure consisting of H-type (Double Pole) or square-type (Four Pole). A platform is prepared at suitable height by rolled steel joist, for placing the 11/0.440 kilovolts distribution transformer as shown in the figure 16.1.

Fig. 16.1 Pole Mounted Substation

A gang-operated switch (G.O. switch) is used to energise the transformer. These types of sub-station are commissioned on roadsides and hence do not require any building structure and sub-station attendant for its operation. So, these are cheapest and most economical as compared to other types of sub-station. These sub-stations are most widely used for rural electrification and small colonies or medium consumers in urban areas. The input voltage to this type of sub-station is 11 kilovolts and output is 440 volts between any two-phase wires and 230 volts between any phase and neutral wires.

ii. Outdoor Type Sub-station

These types of substations are commissioned away from the populated areas from safety point of view and is used to control the 11kv to 132 kv supply. Transformers, circuit breakers and other accessories are commissioned out side the building but are controlled from a building through wires by using remote instrumentation as shown below in the figure 16.2

Fig. 16.2 Out-Door Sub-Station 132/11KV

As shown above, we have two 132 kv incoming feeders from two different sub-stations or generating stations. Both the incoming feeders terminate on separate 11 kv bus bars through isolators, main oil circuit breakers (MOCB) current transformer (CT), potential transformer (PT) and 132/11 kv step down transformers, etc. All these equipment are commissioned in a closed boundary. The current transformer and potential transformers are used to monitor the line potential and current and hence the units supplied to the sub-station. We can shift the entire load on either feeder by selecting the proper bus bar and bus-coupler. Both the source can also be used independently. This bus coupler is used to couple both the bus bars to use single incoming feeder. Lightning arrester (LA) is used to discharge the excessively induced voltage in the line conductors to ground, induced due to the lightning effect. Earth switch is used to connect all the conductors to ground, to avoid accidents when the line is under permit to work (PTW). The output of this sub-station is connected to 11/0.440 kv distribution transformer. Sub-station attendants are required for the operation of the outdoor type sub-stations.

iii. Indoor Type Sub-station

In this type of sub-station, the 11/0.440 kv distribution transformer, main oil circuit breaker (MOCB), L.T. air circuit breaker (ACB) and distribution panels are commissioned in a building whereas the isolators and gang operated switches are commissioned outside the building. Transformer may be located outside the building in shed duly covered boundaries. The circuit diagram of the indoor type sub-station is given in the figure 16.3.

Fig. 16.3 Indoor Type Sub Station II K.V.

As shown in figure, we have two incoming feeders from different outdoor sub-stations. Gang operated. switches are used to select the incoming source of supply. Isolators are used to physically isolate the transformer from incoming or outgoing feeders/circuits. Main oil circuit breaker is used to switch on or off the 11/0.440 kv distribution transformer whereas the air circuit breaker is used to operate the low-tension distribution panel. We can operate both the circuit breakers under fully loaded conditions whereas the isolators should be operated when the load is switched off. Oil circuit breaker 1 and 2 are used to energise the two different distribution transformers. Lightning arrester (LA) is used to arrest and discharge excessively induced voltage in the line due to lightning effect.

Check Your Progress 1

1. What do you understand by the term sub-station?

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2. Why pole mounted sub-station is cheap and most economical than the other?

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3. Explain the function of lightning arrester.

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4. Explain the function of earth switch.

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5. Explain the function of isolator and main oil circuit breaker in a sub-station.

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16.3 TRANSFORMER

A transformer is a static electrical device used to transfer electrical power from one circuit to another keeping the supply frequency constant. We can increase or decrease the voltage in the secondary of the transformer with the corresponding changes in current and hence the power transfer will be almost constant if we neglect the losses. This transfer of power and change in secondary voltage will take place due to linkage of common magnetic flux and mutual induction between the two coils as explained below in working principle of transformer.

Working Principle: A transformer works on the principle of Faraday's laws of electro magnetic induction, which states that **"whenever a closed circuit coil is placed in an alternating magnetic field, an electro motive force (e.m.f.) will induced in that coil and magnitude of this induced e.m.f. will depends upon the number of turns in the coil."** To understand the working principle of transformer please refer to the figure 16.4.

Fig. 16.4 Single Phase Transformer

When the primary winding of the transformer is connected to a.c. supply, the magnetic flux (F) will be set up and circulate in the laminated magnetic core. This magnetic flux will be alternating in nature as the supply frequency and links with both the windings (Primary and secondary) of the transformer. Now according to faraday's laws of electromagnetic induction an e.m.f. will be induced in the secondary winding due to mutual induction. This induced $e = n\ dF/dt$ in the secondary winding will depend upon the rate of change of flux and number of turns. If the number of turns in the secondary winding is greater than primary, the transformer will act as step up transformer and vice-versa. Whether a transformer is step up or step down depends upon the transformation ratio (K), which is explained below.

Transformation Ratio (K): As discussed above, when the primary winding of the transformer is connected across the a.c. supply, an alternating current will flow in the primary winding. And as a result of this alternating current, an alternating magnetic field (F) will be set up and circulate in the laminated core as given in the figure 16.5.

Fig. 16.5 Circuit Diagram of Single Phase Transformer

This circulating alternating magnetic flux will link with both the primary and secondary windings of the transformer and as a result of it; an alternating electromotive force (e.m.f.) will be induced in these windings, due to self and mutual induction respectively. Induced e.m.f. (E_1) in the primary winding will be almost equal and opposes the applied voltage and hence known as back e.m.f. This induced e.m.f. (E_2) in the secondary winding depends upon the rate of change of flux and number of turns ($e = n\ dF/dt$).

Let $N_1 \longrightarrow$ Number of turns in the primary winding.

$N_2 \longrightarrow$ Number of turns in the secondary winding.

$E_1 \longrightarrow$ Induced e.m.f. in the primary winding.

$E_2 \longrightarrow$ Induced e.m.f. in the secondary winding.

$V_1 \longrightarrow$ In put a.c. voltage to the primary winding.

$V_2 \longrightarrow$ Out put a.c. voltage across the load.

$$\text{Induced voltage in the primary winding per turn} = \frac{E_1}{N_1} \text{ volts}$$

Since the same flux will link with both the primary and secondary windings.

So, this induced e.m.f. in the secondary winding will be

Where K is called the transformation ratio.
If K is greater than 1, the transformer is step-up transformer and
If K is less than 1, the transformer is step-down transformer.

For an ideal transformer input power = out put power

$$\text{Or } V_1 I_1 = V_2 I_2$$

$$\frac{V_2}{V_1} = \frac{I_1}{I_2} = K$$

Where K is known as transformation ratio of the transformer.

16.4 DISTRIBUTION TRANSFORMER

A distribution transformer is used to step down the 11 kv a.c. supply to 230/440 volts a.c. and are available in different KVA rating depending upon the requirement of the consumers. The main parts of a distribution transformer are explained here in (figure 16.6).

Fig. 16.6 Different Parts of a Distribution Transformer

a) **Primary Winding:** The primary winding of a distribution transformer is connected in delta as shown in figure. There are three different windings and is circular wound. These are placed on the three different limbs of the transformer core. The size of primary winding wire used is thinner than secondary winding but having larger number of turns.

b) **Secondary Winding:** The secondary winding of a distribution transformer is connected in star as shown in figure. There are three different windings and is circular wound. These are placed on the three different limbs of the transformer core. The size of winding wire used is thicker than primary winding but having lesser number of turns.

c) **Transformer Oil:** The transformer oil is used to transfer the heat generated due to copper losses in the winding as well as in the transformer core due to eddy currents and hysteresis. Due to passage of time, the transformer oil loses its dielectric strength due to absorption of moisture through the breather. The solid impurities present in the oil also reduce its dielectric strength. A good remedy is to filter and dehydrate the transformer oil with a special technique and machine, known as **"Transformer oil Filtration Machine"** to increase its dielectric strength.

d) **Conservator:** It is used as reservoir mounted on the top of the transformer as shown above. It is connected to the transformer through the buchhol's relay. This relay is only used in large capacity transformers. An oil level indicator is provided to observe the oil level in the reservoir. The oil level can be maintained by adding more dry oil in the conservator. It provides a reserve space for the expended oil due to increase in temperature of the winding and core. When the temperature is reduced the expended oil starts contracting and goes back to the transformer tank and hence it acts as a reservoir.

e) **Breather:** As the name indicates, it is used for providing breathing passage for the transformer. The air present in the empty conservator is forced to escape to the atmosphere through the breather, when the oil level in the conservator increases due to increase in temperature and vice versa. This air is escaped to atmosphere through a box containing silica gel in the form of crystals. The colour of fresh or fully activated gel gets changed from blue to bright pink as it absorbs the moisture. It absorbs the moisture from the atmosphere, when the transformer oil starts contracting or during inward rush of air. This pink deactivated silica gel is removed from the breather and baked in a baking oven for reactivation. After reactivation its colour will again converted into blue.

f) **Oil Drain Point:** It is used to drain the transformer oil in a container when it becomes necessary to drain all the oil from the tank for visual inspection or repair and maintenance of winding. Sometimes we have to replace the transformer oil when the dielectric strength gets reduced. A screwed cap and valve is also provided on the out let, for opening and closing the drain point.

g) **Cooling Tubes:** As the name indicates, these tubes are used to cool down the temperature of the transformer oil. The shape, size and number of tubes depend upon the KVA rating of the transformer. In small capacity transformers cooling is provided by natural convention of heat generated, through the cooling tubes but in large capacity transformers the fans are provided for forced air-cooling.

h) **Oil Level Indicator:** The oil level indicator is used to indicate the minimum oil level in the reservoir. The level may be top up by adding new or dehydrated transformer oil.

i) **Earth point:** The earth point is used to connect the neutral wire and body of the transformer to ground potential. It is mandatory from safety point of view.

j) **Explosion Vent:** When there is sudden increase in oil level due to any external or internal faults, the oil level in the reservoir will increase sharply. Although the buchhol's relay is provided to meet such type of eventualities or emergencies but in the event of failure of all other protections the safety plug will burst and oil is allowed to flow out through the explosion vent.

k) **Tap Changer:** The tap changer is used to increase or decrease the a.c. out put voltage of the transformer depending upon the requirement and conditions. It is always connected in the low current winding so that minimum arc is produced, while changing the voltage tapings. We can change the tapings with or without load. In small rating transformer it can be operated manually where as the large capacity transformers are motor operated through remote instrumentation.

Check Your Progress 2

1. Explain the working principle of transformer.

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2. Explain the term back e.m.f.

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3. Explain the term transformation ratio and its importance.

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4. Describe the function of conservator in a transformer.

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5. Explain the function of breather in transformer.

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16.5 DISTRIBUTION SYSTEM

The system used to distribute the electrical energy to various consumers safely is known as distribution system. Generally 3-phase 4-wire a.c. system is adopted for distribution of electrical energy in industries where as single-phase two-wire system is used in home, offices and commercial purpose. There are three different systems of power distribution detailed below.

i. Single Phase Two wire System

This system of distribution is widely used in homes, offices and commercial installation having total connected load less than 5 kilowatts. Single-phase two-wire system consists of one phase and one neutral wire. The potential difference between the phase and neutral wire is 230 volts. To understand this system of distribution of electrical energy, kindly refer to circuit diagram given in the figure 16.7.

Fig. 16.7 Wiring diagram of a single Phase Two Wire System

Twin core PVC cable is used to energise the single-phase energy meter. The cross-sectional area of the cables depends upon the load requirement of the consumer and it varies from 4 to 10 mm^2. This cable is supported by galvanised steel wire. The output of energy meter is controlled by I.C.D.P. (Iron Clad Double Pole) main switch. The phase wire is connected with fuse link and the neutral with neutral link, made of thick copper strip. The output of this I.C.D.P. main switch is connected to main distribution board, which may be fixed on the same iron sheet or wooden board. Then the out put of I.C.T.P. switch is sub-divided into different sub circuits and connected to different small capacity double pole switches depending upon the number of rooms and power points. It should be ensured that all the phase wires are controlled through the fuse links.

ii. Three Phase Three wire System

This distribution system is used to transfer the large quantum of electrical energy from the generating station to different sub-stations by using three-phase wire only. The generated voltage of an alternator may be 6.6, 11 and 15.7 kilovolts. This generated voltage is generally step up to 220 kv depending on distance between generating station and ultimate consumer. If the distance is too more, this generated voltage can be step-up to 440 kv. To understand three phase three wires system kindly refers to the circuit diagram detailed in the figure 16.8.

Above given figure itself explains its working. The working of isolators and circuit breakers has already been described in the working of indoor and outdoor sub-station.

The generated voltage is stepped-up from 11 kv to 220 kv at the generating station and then this voltage is transferred to distribution sub-station. Here, it is step down to 11 kv with the help of 220/11 kv sub-station.

iii. Three Phase Four wire System:

This system of distribution uses three Phase and one neutral wire. The out put of three phase three wire distribution system as explained above, is the input of this system. This system is most widely used for industrial and medium consumer having total connected load of less than 5 KW. However this system is explained below along with circuit diagram (figure 16.9)

Fig. 16.8 Line diagram of 3-Phase 3-Wire Distribution System

Fig. 16.9 Wiring Diagram of a Three Phase Four Wire System

In this system of distribution we have only one source of electrical energy. 11/0.440 KV step-down transformer is used to step down the voltage. The voltage between any two-phase wires is 440 volts approximately whereas between any phase and neutral wire it is 230 volts. The primary winding of the transformer is delta connected whereas the secondary is star connected, to form the three phases and one neutral wire and hence the system's name. Three phase and neutral wire is connected to three-phase energy meter to record the total energy consumed. The output of energy meter is connected to distribution panel through air circuit breaker, for effective distribution. Small domestic consumer having total connected load less than 5 KW can use one phase and neutral wire.

Check Your Progress 3

1. Which type of distribution system is used for industrial consumer for distribution of electrical energy?

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2. Which type of distribution system is generally used for domestic consumer?

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3. Name the distribution system for transfer of electrical energy from generating station to 11/0.44 kv sub-station.

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4. In three phase four-wire system, the potential difference between any two-phase wire is?

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5. In single-phase two-wire system, the voltage between phase and neutral wires is?

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16.6 POWER FACTOR

"Cosine of the angle between applied voltage and current drawn in any electrical circuit is known as power factor" and it is denoted by "Cos F". When a purely resistive circuit is connected across the a.c. supply, the current drawn from the main supply will be in phase with applied voltage and hence the power factor will be unity. But in case of purely inductive and capacitive circuit, the current drawn will lag behind and lead the applied voltage, by an angle of 90^0 respectively. Now, to understand the power factor in detail, let us take an example of inductive circuit given in the figure 16.10.

Fig. 16.10 Power Factor

When alternating current (a.c.) supply is connected across the purely inductive circuit as shown above in figure (a). The alternating current will flow in the circuit through the inductance coil. The resistance represents the internal resistance of the inductive coil, as resistance is directly proportional to length of coil, which may be very less. The current drawn (I) by the coil will lag behind the applied voltage by an angle F. This lagging current can be resolved into two components i.e. one I Cos F along the X-axis and I Sin F along the Y-axis, as shown in figure (b). If we multiply these values by KV, as given in figure in (c) then we have

KW = KVI Cos F = KVA Cos F = Active Power or True Power
KVA = Apparent Power
KVAR = KVI Sin F = KVA Sin F = Reactive Power or Watt-less Power

So from the triangle OAB (Figure d)
Cos F = OA/AB = KW/KVA = Active Power/Apparent Power

So, we can say the power factor is ratio of active power to the apparent power.

We can also explain the power factor by an impedance triangle OAB as shown in **figure (e)** given above.

Cos F = OA/AB = R/Z

So, we can also say that power factor is the ratio of resistance to impedance.

Where $z^2 = R^2 + Z^2$

The inductive reactance (X_L) and capacitive reactance (X_C) of an electric circuit depends upon supply frequency, because X_L = 2pfL and X_C = 1/2pfc.

So, the inductive reactance increases with the increase in supply frequency where as capacitive reactance decreases and vice versa. With the change in the value of X_L and X_C, the value of Z changes. Because in this case

$$Z^2 = R2 + (X_L{}^2 \pm X_C{}^2)$$

So, they create a phase difference between applied voltage and current drawn from the main circuit. In other words for same power more current is needed in ordered to overcome the inductive and capacitive effect. Mathematically we can say cosine of the angle of lag or lead of current with applied voltage is known as power factor.

i. Disadvantage of Low Power Factor

The disadvantages of low power factor are given here.

a) We know that P = VI Cos F In case of single-phase supply.
Also P = Ö3 V_L I_L Cos F In case of three-phase supply.

The current drawn from the supply mains will be

I = P/V Cos F In case of single-phase supply. ———— equation no. 1
I = P/Ö3 V_L Cos F In case of three-phase supply. ————— equation no. 2

It is evident from equation 1 and 2, that the current drawn is inversely proportional to the power factor. If the values of power factor increase the value of current decreases and vices versa and hence the cost per unit will increase.

b) Due to increase in current drawn from the supply mains due to decrease in power factor, the rating of transformer, alternator, all the transmission and distribution system will be over load. So, all these equipment need to be upgraded and hence increase in cost per unit.

c) The efficiency of transmission lines, alternator and transformer reduces with increase in current drawn due to low power factor because the copper losses (I^2R).

d) The voltage drop in transmission line increases due to increase in current and hence the voltage regulation will be poor. To improve the regulations either reduces the current drawn from the main supply or increase the diameter of transmission line conductor. The cost per unit will again increased.

Thus we can say, due to decrease in power factor, the cost of transformer, alternator, transmission lines and its accessories will increase and hence costs per unit will increases.

ii. Causes of Low Power Factor

The main causes of low power factor are given here.

a) All the induction motors running on lesser load than the full load is responsible for poor power factor. Approximately, the power factor of motor running on full load is 0.85, at half load, 0.5 and at 25 % of full load, is too low as on no load approximately. Arc lamps and arc furnaces are highly responsible for reducing the power factor drastically.

b) Some time due to defective bearings, the rotor may touch the stator. To overcome such problem, some material removed from the outer surface of the rotor by turning on lathe, which leads to increase in air gap between stator and rotor. So the power factor of the motor will increase due to increase in magnetizing current.

iii. Methods of Improving Power Factor

The main methods of improving the power factor are given here.

a) **Static Capacitor:** The power factor is generally improved by installing static capacitor bank in parallel with the application having poor power factor as shown below.

Fig. 16.11 Power Factor Improvement

When the supply is switched on the capacitor bank, which is permanently connected in parallel with the application responsible for low power factor starts drawing leading current and hence the phase angle of the resultant current is improved as shown above in figure (b). So, the power factor will increase. In case of three-phase supply, the capacitor is connected either in star or delta as shown in figure above.

b) Synchronous Condenser: - Synchronous motor with over excited can be used to improve the overall power factor of the complete installation by compensating the lagging components of the current drawn due to inductive loading, as shown in figure 16.11.

iv. Advantages of improved power factor

The advantages of improved power factor are as follows.

a) Voltage regulation is improved.

b) More output power can be taken from the same plant and equipment associated with generation, transmission and distribution of energy.

c) Efficiency of alternator, transformer and transmission lines is improved due to reduction in copper losses.

Check Your Progress 4

1. Explain the term power factor.

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2. State the effects of low power factor on current drawn from the supply.

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3. Explain the effect of low power factor on the efficiency of transmission lines, transformers and alternators, etc.

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4. Why power factor is reduced when some material is removed from the surface of rotor?

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5. How the power factor is improved by installing static capacitor bank and synchronous condenser in an installation?

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16.7 LET US SUM-UP

After studying this unit, we are able to appreciate the working of different types of sub-stations, used for transmission and distribution of electrical energy. It is important to note that the isolators should not be operated when the line is energized whereas the circuit breaker can be operated. We can increase or decrease the transmission/distribution voltage with the help of transformer. When the voltage is increased the current will decrease in proportions, to keep the power constant. Generated voltage is increased from 11 kv to 220 kv at the generating station and then transmitted to various substations. Now this increased voltage is step-down to 220/11 kv and distributed to various consumer through 11/0.440 kv sub-stations at the consumer premises. Single-phase two-wire system is used for the domestic consumer having total connected load less than 5 KW, whereas three-phase four-wire system is used for industrial consumer. The power factor is the main important factor in distribution of electrical energy. If the power is reduced the current drawn from the circuit increases and vice versa. With the increase in current drawn, whole the system of generation, transmission and distribution will be overloaded. Lightly loaded induction motors and arc furnaces are mainly responsible for poor power factor and we should try to improve it by installing proper capacity motor as per requirement. The power can be improved by installing the static capacitor bank and synchronous condense (Synchronous Motor) at the consumer premises. Because these applications draws leading current from the main supply and cancelled out the lagging components of already current drawn.

16.8 KEY WORDS

Lightning Arrester	:	A device used to protect the electrical equipments from the excessively induced high voltage in the line conductors due to lightning effect. This excessively high voltage is discharge to ground.
Earth Switch	:	A device used to connect the short-circuited conductors to ground potential by discharging the voltage induced due to lightning or by any other means to the ground.
Isolator	:	An isolator is used to physically isolate the transformer from incoming and outgoing feeders or circuits, when the circuit breaker is in off position.
Main Oil Circuit Breaker	:	A triple switch used to switch off or on the supply to the transformer. The switching action between the blades takes place in oil to quench the arc produced.
Bus Bar	:	Thick copper or aluminum conductors or bundle of conductors, used for parallel operation of transformer, generating station and feeder.
Bus-Coupler	:	As the name indicates, a device used to couple two independent bus bars in parallel for sharing of load on single incoming feeder.
Back E.M.F.	:	The induced e.m.f. in the primary winding of the transformer due to self induction of alternate magnetic flux, which is equal and opposite to applied voltage. This induced voltage opposes the applied voltage and hence the name.
Synchronous Condenser	:	A over excited motor running without load at synchronous speed and draws leading current from the supply. This leading current cancelled out the lagging component of already drawn current and hence the power factor is improved.
Static Capacitor Bank	:	Two or more capacitors used to improve the power factor of the installation by drawing leading current from the supply.
Permit To Work (PTW)	:	It is a permission to work on line or any other electrical equipment by an authorized person for a specified period.

16.9 SOME USEFUL BOOKS

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Singh.S. (1997-98). Electrical estimating and costing Dhanpat Rai & Co. (P) Ltd. 1710, Nai Sarak, Delhi – 110006

Thareja.B.L. and Thareja.A.K. (1988). Electrical Technology Nirja Construction & Development Co. (P) Ltd., Ram Nagar, New Delhi - 110005

16.10 ANSWERS TO CHECK YOUR PROGRESS

Your answers should include the following points:

Check Your Progress 1

1) i. Any station comprising of transformers and other switching equipments, required for transfer of large quantum of electric energy safely, is known as sub-station.

2) i. These types of sub-stations are commissioned or mounted on roadside.

   ii. Do not require any building structure and sub-station attendant for its safe operation.

3) i. A lightning arrester is used to discharge the excessively induced voltage in the transmission line conductors to the ground.

   ii. This is induced due to lightning effect.

4) i. An earth switch is used to connect all the transmission/distribution conductors to ground potential when the line is under permit to work (PTW).

5) i. An isolator is used to physically isolate the transformer when the supply is switched off.

   ii. A circuit breaker is used to switch on or off transformer from the incoming and outgoing feeders.

Check Your Progress 2

1) i. Whenever a close circuit coil is placed in an alternating magnetic field, an electro-motive force (e.m.f.) is induced in that coil and magnitude of this induced e.m.f. will depend upon the product of number of turns and flux linkages.

2) i. The e.m.f. induced in a coil due to self-induction, energized by a.c. supply is known as back e.m.f.

   ii. The back e.m.f. is almost equal and opposite to applied voltage.

3) i. If K is greater than one, the transformer will be step-up transformer.

   ii. If K is less than one, the transformer will be step-down transformer.

4) i. A conservator is used to provide reserve space for the expanded transformer oil when the temperature increases due to internal or external faults.

   ii. It is also used to maintain the oil level in the transformer by toping up the extra oil as per requirement.

5) i. Breather is used to provide breathing passage for the transformer.

   ii. The air present in the conservator is forced to escape to atmosphere when the oil level is increased due to increase in temperature, through the breather.

   iii. Fully activated silica gel changes its colour from blue to bright pink, when it absorbs moisture entering in the breather when oil starts contracting.

Check Your Progress 3

1) i. Three-phase four-wire system.

2) i. Single-phase two-wire system.

3) i. Three-phase three-wire system.

4) i. 440 Volts.

5) i. 230 Volts.

Check Your Progress 4

1) i. Cosine of the angle between applied voltage and current in any electrical circuit is known as power factor.

2) i. The current drawn from the supply is inversely proportional to the power factor.

   ii. The current drawn will increase if power decrease and vice-versa.

3) i. The efficiency will increase due improvement in power factor and vice-versa.

4) i. Air gap between stator and rotor will increase.

   ii. Magnetizing current will increase.

   iii. Power factor will decrease.

5) i. Both the static capacitor bank and synchronous condenser draws leading current.

   ii. Cancelled out the lagging component of already current drawn.

UNIT 17 TUBE WELL, WATER STORAGE AND SUPPLY

Structure

17.0 OBJECTIVES

After reading this unit we should be able to:

- list the sources of water supply
- describe the construction of a tube well and its evaluation
- explain the characteristics of different types of pumps used for pumping water
- outline the water storage and distribution systems.

17.1 INTRODUCTION

Life is evolved in water. Therefore, water is essential not only for human beings but for all forms of life. Though fossil fuels are considered important for economic growth, water is the real fuel which brings prosperity to a country or community. This is more pertinent to our country as well as other countries where economy largely hinges on agriculture. Most of the industrial activities also need water extensively. As the civilization of society progresses, the domestic water consumption also increases. That is why per capita water consumption is considered as one of the indices of development. Quality of water and quantity of available water are two important factors for water supply. Besides the primary uses such as drinking, cooking and washing, it is needed for most of industrial activities as well. In a dairy plant, water is used as feed for boiler to produce steam, for cooling and heating in heat exchangers and for cleaning and washing. Proper planning, designing, construction, maintenance and operation of water works is needed for reliable supply of water. First thing in any scheme of water supply is the source of water. Identification and development of a permanent source of water supply is prerequisite for reliable water supply. We will discuss the aspects related to water quality and water treatment technologies in the next unit (Unit 18). The purpose of the unit is to provide some basic information related to water supply system to help you understand basic principles when you work with a professional driller, consultant, or well servicing agency for well drilling and maintenance.

17.2 SOURCES OF WATER SUPPLY

Water moves in a cycle from earth to the air then to the earth again in a process known as the "**hydrologic cycle**" (Detailed discussion on hydrologic cycle is given in Unit 20). This cycle is the ultimate source for all water resources. While on the earth, water for drinking comes from two sources: ***surface water*** from streams, rivers or lakes, and ***groundwater*** from underground aquifers. The rain that falls on the earth can be divided in to three parts: a) Infiltration b) Run off and c) Evaporation. Runoff and infiltration contribute to the augmentation of water resources on earth.

i. Ground Water

As the land surface is permeable, part of the precipitation or run off will infiltrate through the surface downwards. This infiltration water reaches the groundwater. The surface of this water under the ground is known as the ground water table. This ground water table fluctuates up and down with the variation in rainfall and withdrawal of water from the nearby wells. When water from a well is being pumped out, the water from surrounding area flows into the well. The condition of groundwater and the knowledge geological formations of the area form basis for development of groundwater supply.

Water may be withdrawn from following ground water sources:

a) springs

b) infiltration galleries

c) porous pipe galleries

d) wells

In springs, the ground water reappears at the surface of earth depending on the geological formation in the area. The level of outlet of ground water at the surface will be lower than the ground water table level in the aquifer. Groundwater is generally pumped to the earth's surface from wells. The water usually requires little treatment before its intended use because it was filtered through sand and rock as it settled into the earth.

ii. Surface Water

The water form the precipitation remaining after evaporation into atmosphere and infiltration into groundwater flows in the form of streams on earth surface and reaches surface water sources such as rivers and lakes. This water is generally more polluted than the groundwater due to their exposure to environment. Some additional treatment processes are usually needed for making this water suitable for different uses. If the water source is a river or stream, then the water is in flow and generally carries sand, silt and clay. Sedimentation, flocculation and filtration are strongly recommended for water from these sources. If the water is from stagnated sources such lakes and ponds, the sediments will not be there but the water is more prone to microbial contamination. Disinfection processes are more critical in water treatment schemes of such sources.

Whenever good quality water is available as a surface water, it should be used as source of water supply to save the cost of construction of well and pumping of ground water to earth surface. Surface water sources can be further classified as

a) streams

b) lakes

c) ponds

d) reservoirs

e) river and

e) rainwater harvesting system

17.3 CLASSFICATION OF WELLS

Based on the type of construction, wells are classified as given here.

i. Dug Well

These are shallow wells which are usually constructed in soft ground and soils having sand and gravel. Usual dimensions are up to 4 meter in diameter and up to 20 meter depth. The walls of these wells may be constructed with preset RC blocks, bricks or stone masonry. Cost of these wells is low. Hence they are popular in rural areas and small towns. The yield of these wells is low. The yield can be increased by providing a borehole in the center of the well.

ii. Driven Well

This is also a shallow well. A casing pipe with a sharp point at the bottom is driven into a water bearing stratum. The lower portion of the casing is perforated. The perforated portion of the pipe is covered with a fine mesh to retain sand particles inside the well. The discharge of these wells is very small.

iii. Tube Well

Factories and industrial units need lot of water. Tube wells are popular in such situation because of their higher yield. These wells are constructed using blind pipes and strainer pipes to tap water from many water bearing aquifers. The depth of tube well will be in the range of 50 meter to 500 meter. Depending on geological formation of location, the maximum yield from a tube well may be about 20 liters per second.

Depending on the type of construction, the tube wells are classified as follows:

Strainer Type Tube Well: This type of tube well taps water from all water bearing formations in the well. Strainers are installed in all water bearing formations in the well to allow entry of sand free water. The strainer is nothing but fine wire mesh wrapped around a slotted pipe and soldered or welded to it. Sometimes gravel is packed around the outside of strainer pipe, if the formation contains fine sand or silt.

Slotted Type Tube Well: If the water bearing strata are very deep, then slotted type tube wells are constructed. It consists of slotted wrought iron pipe passing through the main water bearing formation. This pipe is surrounded by gravel packing.

Cavity Type Tube Well: It essentially consists of a blind pipe in its entire length. The bottom is extended up to the aquifer where sufficient water is available. The well is developed by pumping at a faster rate after construction. Loose formation material surrounding the bottom will flow with water and a cavity is formed. The size of the cavity influences the yield of a well.

Perforated Type Tube Well: This type of tube well is constructed by installing perforated pipes. Perforations are made by drilling the pipe. Then the perforated portion is covered with coir or jute rope. The purpose of the rope is to act as a strainer. These are recommended only when water is very near to the ground surface or for temporary water supply.

Check Your Progress 1

1. What are the different sources of water?

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2. Give the classification tube wells?

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3. Describe strainer type tube well?

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17.4 HOW TO CONSTRUCT A TUBE WELL

i. Operations in Tube Well Construction

Tube well construction can be divided into four major operations. These are drilling operation, casing installation, well screen installation and well development for getting clear water without sediments.

ii. Drilling Methods

The different methods of drilling include cable tool percussion drilling, rotary drilling, hammer drilling and core drilling. Depending on the geological formation, suitable drilling method is selected and drilling rigs of various capacities are available in each category. Cable tool drilling and rotary drilling are the commonly used methods. Sometimes, particularly for large production wells and where water quality is particularly important, drill a small-diameter pilot hole before drilling the well bore. From information obtained from the pilot hole, determine aquifer formations and groundwater quality at various depths and then optimize the final well design for the specific hydrogeological conditions at the site. Appropriate materials (screen, casing, gravel) can then be ordered in a timely fashion prior to the final drilling.

Cable Tool Percussion Drilling: In cable tool drilling, bore hole is made by lifting and dropping a string of heavy tool suspended on a cable. A bit at the bottom of the tool string strikes the bottom of the hole, crushing and breaking the formation material. Water is added to form slurry of the crushed material. If there is water in the bore hole from formation material, then no external water is added. Due to reciprocating motion of the tool, the crushed material is mixed with water and forms slurry. The slurry formed is removed from the bore hole at some intervals. Otherwise, the accumulated slurry decreases the impact of falling bit which results in retarded penetration of tool. This method is suitable for all types of formations but takes more time. It is the most preferred method for drilling in boulders and hard rocks.

Rotary Drilling: Rotary drilling is very fast and is suitable for making large bore holes. In this method a rotating drill bit is forced downwards. Drilling fluid is circulated through this drill bit. This method is more economical for making deep holes in unconsolidated formations. However, it is not recommended for drilling in boulders and hard rocks since progress of drilling will be very slow in these formations. This method needs lot of water for circulation and could pose difficulties in water scarce areas.

The major items of rotary drilling method are the drill bit and the drilling fluid. Different kinds of bits are tailor made to suit drilling in different types of formations. The drilling fluid could be either simple mud water or carefully prepared special solutions of desired viscosity. This drill fluid is pumped down through the drill pipe and come out through nozzles in drill bit. The drill fluid then moves upward in the annular space around the drill pipe to the ground surface. On its way to the surface, the drill fluid picks up the cut material of formation and carry it in suspension. The fluid is then diverted to a sedimentation pit where bulk of the cut material settles down. The drill fluid is then pumped back to the drill hole. Thus the main function of drill fluid is to remove the cut material from bore hole. The drill fluid also prevents the caving in of the bore hole due to its fluid pressure.

iii. Well Log

As drilling proceeds, various kinds of formation materials are encountered. The record of chief characteristics and depth of each formation layer from surface is called a well log. This well log gives information on where water bearing formations are located. Well log information will help in finalizing the well design, which includes a determination of the depth of the well screens, the size of the screen openings, and the size of the gravel pack material. Well casings and well screens are arranged in sequence on the basis of well log to tap good quality water from different aquifers. If the water bearing layer contains fine sand and silt, gravel packing around the screens can be employed to get the water free from particles. If saline or brackish water is there in some layers, these layers need sealing so that the brackish or saline water does not enter the well. The next step after installation of casings and screens is the well development.

iv. Well Development

Tube wells need to be developed to prevent entry of sand, increase the yield of a well and to extend the life of a well. It involves reversing the flow of water from the tube well in to water bearing formations with force and then allowing back flow in normal direction. This results in loosening of small particles between large particles during reverse flow and flow back in to well during normal flow. These small particles from well are removed. After well development the formation material in water bearing layer becomes more porous which allows easy flow of sand free water in to well.

17.5 WATER YIELD OF A WELL

After development of well, it should be evaluated to determine the yield and drawn down to how much water is flowing in to a well. Flow of water in to gravity well is shown in figure 17.1. If the well is not disturbed for sufficient time, the water level in the well will stabilize at the level of groundwater in the aquifer. Few holes, called observation wells, are drilled in the ground surrounding the well. The water in these observation wells is also at the same level as in the well before pumping is started. After water is pumped from the well for sometime, the water in the observation wells will stand at different levels. The water in observation well near will be at lower level than that in observation well farther away from the well. If the level in these observation wells is joined, it will form a free surface curve. The free surface curve is the boundary of the cone of depression. This is the region from where water flows in to the well and is pumped out. If the pumping is continued at a uniform rate, the water level in the well fall for some time and then it will become stationary at one level. At this level, the rate of pumping will equal the rate of flow in to well from the aquifer. If the rate of pumping is increased, the water level in the well will fall down further and region influenced by cone of depression also increases. The draw down is the difference in static ground water level and stationary level of water in well. Yield is nothing but the rate of pumping and is generally specified as liters per minute. As the pumping rate increases, the velocity of inflow in to the well also increases. As the velocity of inflow increases, the soil particles get disturbed and begin to flow in to the well. This velocity is called critical velocity. The yield, available before this velocity is reached, is the maximum permissible yield from the well. The draw down, at which the critical velocity is reached, is defined as critical head. Normally wells are pumped at working heads much lower than critical head.

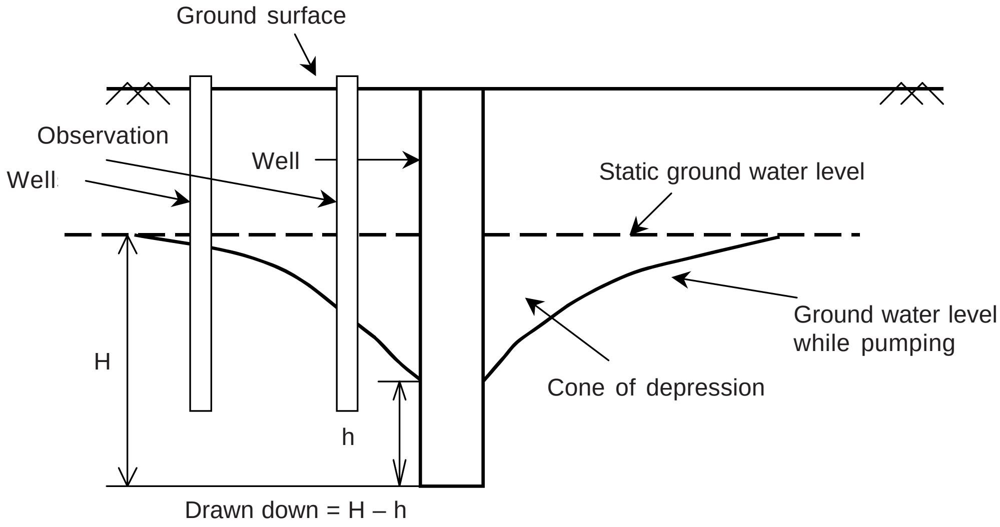

Figure 17.1 Flow into a Gravity Well

Check Your Progress 2

1. What are the different drilling methods used for drilling tube wells?

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2. Describe the rotary drilling?

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3. Describe the well development?

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4. What is critical head?

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17.6 TYPES OF PUMPS

Pumps are machines that move fluids by transferring mechanical energy to a fluid. The term pump is used for machines that transport incompressible fluids. Compressor is the term used for machines used for handling compressible fluids or gases such as air, oxygen, etc. In a pumping operation, the pressure of the fluid will increase and cause it to flow downstream in a direction of low pressure. In order to transport the fluid, it is necessary that enough energy be added to overcome frictional losses in the piping system. The selection of pump is dependent on following factors:

1) the delivery pressure required
2) volume flow rate
3) properties of the fluid handled such as density and viscosity
4) temperature of fluid

The pumps used for moving water can be broadly classified as positive displacement pumps and kinetic pumps. Kinetic pumps can be further subdivided into centrifugal pumps (the vast majority of kinetic pumps) and special effects pumps. Jet pumps, gas lift and electromagnetic pumps are examples of special effect pumps, which are not widely used. The operating principle of centrifugal pumps and positive displacement pumps are quite different. Positive displacement pumps discharge constant volume of water without depending on delivery pressure. These generally produce low flow rates against high pressures. In case of centrifugal pumps, the discharge flow rate will be high for low pressure and the flow rate decreases as discharge pressure increases. Before attempting to select a pump for a particular application, it is important to understand the types of pumps available and how they operate.

i. Centrifugal Pumps

Centrifugal pumps are the most common type of pumps found. Centrifugal pumps enjoy widespread application partly due to their ability to operate over a wide range of flow rates and pump heads. Developing centrifugal force to move up liquid is basis of operation of these pumps. When circular motion is induced in water, it has a spiral flow towards the axis of rotation.

In a centrifugal pump, the water is admitted to the centre of rotation by the suction pipes, and is then rotated with the help of spiral vanes. This results in increased pressure head due to centrifugal force and the water can be pushed ahead in delivery pipe.

For these pumps, the discharge flow rate, discharge pressure, power required for pumping and efficiency of pump are interrelated. These pumps are popular and have lot of applications where flow rate is high and delivery head is low. Ease of operation and maintenance are advantages of these pumps.

Figure 17.2 Volute Type Centrifugal Pump

The volute type centrifugal pump consists of two basic parts; the impeller on a rotating shaft and a stationary pump casing as shown in figure 17.2 . The pump casing provides a pressure boundary for the pump and contains channels to properly direct the suction and discharge flow. The pump casing has suction and discharge penetrations for the main flow path of the pump and normally has small drain and vent fittings to remove gases trapped in the pump casing. From the suction inlet of casing, the fluid moves to the centre of impeller, from where it is moved by the revolving blades or vanes of the impeller. Because the impeller blades are curved, the fluid is pushed in a tangential and radial direction by the centrifugal force. This force acting inside the pump is the same one that keeps water inside a bucket that is rotating at the end of a string. Due to this centrifugal force, the liquid moves to the outer periphery of the pump casing where it is collected in the outer part of the pump casing called the volute. The *volute* is a region that expands in cross-sectional area as it wraps around the pump casing. The purpose of the volute is to collect the liquid discharged from the periphery of the impeller at high velocity and gradually cause a reduction in fluid velocity by increasing the flow area. This converts the velocity head to static pressure. The fluid is then discharged from the pump through the discharge connection. By changing the form of the vanes, different characteristics are obtained.

Figure 17.3 Diffuser Type Centrifugal Pump

Some centrifugal pumps contain diffusers. A *diffuser* is a set of stationary vanes that surround the impeller as shown in figure 17.3. The purpose of the diffuser is to increase the efficiency of the centrifugal pump by allowing a more gradual expansion and less turbulent area for the liquid to reduce in velocity. The diffuser vanes are designed in a manner that the liquid exiting the impeller will encounter an ever increasing flow area as it passes through the diffuser. This increase in flow area causes a reduction in flow velocity, converting kinetic energy into flow pressure.

ii. Positive Displacement Pump

A Positive displacement pump has an expanding cavity on the suction side of the pump and a decreasing cavity on the discharge side. Liquid is allowed to flow into the pump as the cavity on the suction side expands and the liquid is forced out of the discharge as the cavity collapses. This principle applies to all types of Positive Displacement Pumps whether the pump is a rotary lobe, gear within a gear, piston, diaphragm, screw, progressing cavity, etc.

A positive displacement pump, unlike a centrifugal pump, will produce the same flow at a given RPM no matter what the discharge pressure is. A positive displacement pump cannot be operated against a closed valve on the discharge side of the pump, i.e. it does not have a shut-off head like a centrifugal pump does. If a positive displacement pump is allowed to operate against a closed discharge valve it will continue to produce flow which will increase the pressure in the discharge line until either the line bursts or the pump is severely damaged or both. These pumps find wide applications in process industries where accurate flow rate is needed or when the pump acts against high discharge pressure. These pumps are generally not used for pumping water in water supply systems.

iii. Vertical Turbine Pump

A vertical turbine pump is vertical axis centrifugal or mixed flow pump. The pump is located below the ground water level in the well. It is driven by a long shaft, which connects the pump to motor drive on ground surface. Relatively small diameter of pump makes it more suitable for tube wells. If the tube wells are deep, the length suction pipe of a centrifugal pump becomes very long and the centrifugal pumps cannot pump water from deep tube wells. A more effective solution in such a case is to move the pump down into the well so, instead of lifting the water, it's pushing water up. Vertical turbine pumps are constructed to operate in this way. These pumps have three major parts: the pump element, the discharge column and head assembly as shown in figure 17.4. The pump element consists of one or more stages or bowls. Each bowl consists of an impeller and a diffuser. A screen is provided at the bottom of pump for entry of sand free water. The discharge column connects the pump element and pump head assembly and convey water. It has a discharge pipe and a line shaft of pump with couplings and bearings. The shaft is located at the center of the discharge pipe. The lubrication of pump is done either by water or oil. For oil lubricated pumps, the drive shaft is covered by another pipe which transports the oil to parts which need lubrication. The pump head assembly is a base from which the discharge column pump assembly, shaft assembly are suspended. Motor or gear drive is generally mounted on it. The performance curves are similar to those of volute type of centrifugal pumps. The limitations of this pump are that it needs proper alignment.

Figure 17.4 Vertical Turbine Pump

The correct alignment of pump with both well casing and motor or drive is the most important requirement for trouble free operation of vertical turbine pump.

Otherwise, parts of the pump may touch well casing and get damaged. To achieve this proper alignment, a strong foundation is used for mounting the motor or drive and for suspending the discharge pipe and pump with shaft. The pump bowl assembly is placed well below the maximum draw down level so that it is always under water.

iv. Submersible Pump

With ever falling ground water levels, the tube wells are drilled deeper and deeper to fetch water. Running a vertical turbine pump with long drive shaft in such very deep wells is a tough engineering challenge. A more effective solution in such a case is to closely couple the motor and pump and move them together down into the well. In this way, the requirement of long shaft is avoided. A vertical turbine pump close coupled to a small diameter submersible electric motor is called submersible pump. Submersible pumps are designed to be fully immersed within a well or tank. As shown in figure 17.5, the submersible pump consists of a pump and motor assembly, a delivery pipe and other accessories such as water proof cable. These pumps are single stage or multi stage centrifugal pumps with impellers of mixed or radial flow. The motors of are normally sealed in oil-filled cavities that are protected from contact with the liquid.

Figure 17.5 Submersible Pump

Submersible pumps can be applied to many distinct applications, from pumping water from bore wells, to transferring wastewater at large flow rates or high pressures, to simply pumping up water off the floor or the bottom of a tank; depending upon submersible pump design.

Some of the more common submersible pumps designed for specific applications include water submersible pumps, sewage submersible pumps, sand submersible pumps, irrigation submersible pumps, and solar submersible pumps.

There are four main specifications to consider when selecting between the available submersible pump types (beyond specific pump type or application). These submersible pump specifications include :

1. Maximum discharge flow, which is the maximum flow the pump is designed to generate. This value is dependent on the system or pressure head the pump must enter.
2. Maximum discharge pressure, which is the maximum pressure the pump is designed to generate.

3. Horsepower (hp), which is used to express the rate at which mechanical energy is expended. Horsepower is the work done at the rate of 745.7 watts
4. Discharge size, which is the size of the submersible pumps' discharge or outlet connection.

In these pumps both the pump assembly and motor are of same size which easily fit in to a tube well. Also these pumps can tolerate deviations in vertical alignment of tube well casing. Since there is no working part above the ground, these pumps are suitable for flood prone areas and public grounds where an above ground pump house would be inconvenient. Although the pumps run for years without trouble in case of proper installation, withdrawal and overhauling of after every two or three years is recommended.

17.7 WATER STORAGE

The purification processes deliver clear and clean water at a constant rate. Where as the water consumption varies with time. The hours during which the rate of demand is very high are called peak hours. If there is no storage facility, then all the treatment processes should be designed for higher capacity to meet the rated of demand of peak hours. When storage tank or reservoir is provided, the treatment processes can be installed with a capacity equal to the average rate of demand instead of maximum rate of demand. Thus the sizes of piping system and capacities of pumps in treatment processes also get reduced. In this way storage facility in a water supply scheme leads to an overall economy. The storage tanks also provide buffer capacity, allowing repair and maintenance of parts of distribution system.

After purification processes are over, the water is moved to storage tanks or reservoirs. The capacity of storage structures is after taking in to consideration the peak hour demand and water demand during other eventualities such as fires, break down of pump, etc. The capacity of storage tank also depends on the maximum pumping rate and safe yield of the source of supply. The storage tank may be located at an elevated position or at the ground level. Elevated tanks are installed to obtain pressure head. Water is pumped up in to these tanks. Due to higher elevation, the water in tank will have a pressure head which should be sufficient to overcome the pressure losses in water distribution system.

Material of Construction : Different materials of construction used for storage tanks include masonry, reinforced cement concrete (R.C.C.), plastic, steel and fiberglass. The material should be inert and durable. Tank should be covered properly to prevent evaporation, mosquito breeding and to keep insects, rodents, birds, and children out of reach.

Tanks at ground level are generally constructed with masonry or R.C.C. Elevated tanks could be of steel, plastic or R.C.C. Steel tanks are made by welding steel plates together. The usage of steel tanks for water storage is declining. Pre formed plastic tanks are popular and are used when storage capacity is small. When capacity is big, R.C.C. tanks are the best choice. These have long life, aesthetic appearance and require less maintenance.

Accessories : The major accessories of the storage tanks include the overflow outlet, drain pipe, float switch, man hole and ladder. These are provided to serve different purposes. The over flow outlet is provided to prevent spillage of overflow and connected to a drain. Drain pipe is provided at the bottom of the tank and used for emptying the tank for cleaning or repair. This is also connected to drain. Float switch is activated by float installed near the top of storage tank. When tank is filled up to the capacity the float will move up and switch off the motor to stop the pumping. Provide a manhole for tank inspection and cleaning. Ladder or steps are provided for access of top and bottom of the tank. Vents also may be provided in tanks for air circulation.

17.8 WATER DISTRIBUTION SYSTEMS

The water distribution system of a public water supply scheme will be entirely different from that of a distribution system within a processing plant or factory. However, the principal objectives and design procedures are similar. In municipal water supply system there are a number of pumping stations, reservoirs and elevated storage tanks located throughout the distribution system to pump and store water at sufficient pressure to meet all needs. These stations and reservoirs are operated so that peak water-consumption demands can be met while a sufficient supply of water is available to meet extraordinary demands, such as fire-fighting requirements. The reservoirs and elevated tanks also provide storage space, allowing occasional repairs to the supply and distribution system to be carried out without major impact on water supply. An efficient water distribution system is the one in which the water reaches each and every point of use with sufficient residual pressure.

Residual Pressure : Residual pressure is defined as the difference between the pressure at the beginning of distribution system and pressure loss due to frictional losses in the piping system.

Gravity Distribution : If the level of treated water is well above all the points of use, then the distribution could be achieved through gravity alone. Otherwise, the treated water is pumped to an elevated storage tank from where the water is distributed by gravity.

The distribution system consists pf pipes of various sizes, valves, fitting, pumps, hydrants etc. The pipe lines carry the water to each destination and valves in pipe line are provided to control the flow of water.

The purpose of pumps is to transport with sufficient pressure. Hydrants are connecting points for fire fighting equipment to draw water from main supply pipe.

Hydroflow System : In process industries, there is modified efficient way of distribution known as hydroflow system. This system is shown in the figure 17.6. The treated water is pumped in to hydroflow tank by a pump. This pump is controlled by two level sensors through pump controller. When the level falls below the low level sensor, the pump is switched on and water is pumped into tank.

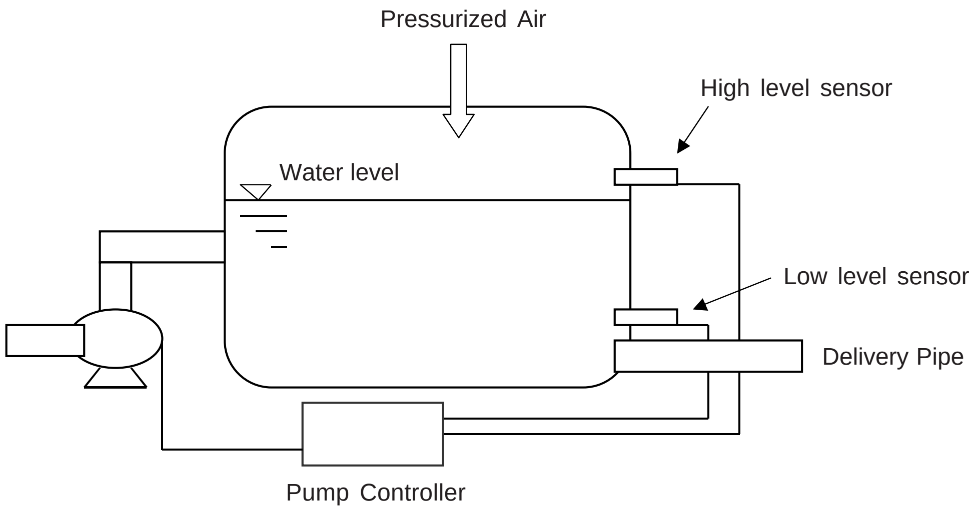

Fig. 17.6 Hydroflow System

When the water level reaches high level, the high level sensor switches off the pump. The water from hydroflow tank is transported to distribution pipes through delivery pipe by pressurized air which is there above the water level. This air pressure imparts energy to the fluid necessary to overcome the frictional losses in pipes and desired residual pressure.

The network of pipes for water distribution should be such that, it will not obstruct the repair and maintenance of pipe lines of other utilities. The distribution system should be designed according to layout of the points of use in the processing plant. Ease of operation and maintenance should be considered in design of distribution system. The future expansion should also be kept in mind while designing. The design involves the preparation of layout of pipes and position of valves and fittings. Now the minimum water pressure desired at each point is marked on the layout. The next step is the determination of the pipe sizes. This is a cumbersome and tedious job as there is no straight forward design procedure. First of all, you have to assume the diameters of all pipes. Then, you calculate the residual pressure at the end of each pipe section after taking in to consideration of frictional losses. If the residual pressure available is not adequate, then frictional losses in pipes can be decreased by increasing the pipe diameter. Otherwise the diameter can be reduced because it reduces the cost of piping. As the cost of distribution system is quite substantial, the sizes of pipes and layout are finalized after careful analysis to minimize the costs. These calculations are done for various diameters of pipes and solution is reached by trial and error.

Check Your Progress 3

1. Give classification of pumps?

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2. Describe the principle of volute type centrifugal pump?

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3. What are the advantages of submersible pump?

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4. Why storage tanks are needed?

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5. What is the main requirement of a good distribution system?

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17.9 LET US SUM UP

Water is obtained from surface water sources and/or ground water sources. For industrial units, a reliable and independent water supply source is preferred which is generally ground water extracted by drilling a tube well. The tube wells are drilled by cable tool percussion drilling or rotary drilling. The choice is made depending on hydrogeological formations of the area. A well log is maintained to keep record of the depth and other characteristics of these formations. Well log information will help in finalizing the well design, which includes a determination of the depth of the well screens, the size of the screen openings and the size of the gravel pack material. After construction, the well is developed by reversing the flow direction in well with force. Then a suitable pump is installed for extraction of water. Centrifugal pumps, vertical turbine pumps and submersible pumps are the main type of pumps used for water pumping. Depth of water level in well and the required volume flow rate are the important factors that influence the selection of a pump. The water pumped is then treated and treated water is stored in storage tanks. The storage tank gives buffer capacity to meet peak demand of treated water. The water is then distributed, through a system of pipe lines, valves, fittings and pumps, to each point of use at required delivery pressure.

17.10 KEY WORDS

Aquifer : Water bearing soil layer below the ground.

Discharge : The volume of water that passes a given location within a given period of time. Usually expressed in liters per minute.

Domestic water use : Water used for household purposes, such as drinking, food preparation, bathing, washing clothes, dishes, and dogs, flushing toilets, and watering lawns and gardens.

Draw down : A lowering of the ground-water surface caused by pumping.

Evaporation : The process of liquid water becoming water vapor, including vaporization from water surfaces, land surfaces, and snow fields, but not from leaf surfaces

Ground water : Water that flows or seeps downward and saturates soil or rock and stored underground in rock crevices and in the pores of geologic materials. The upper surface of the saturate zone is called the water table.

Potable water : Water of a quality suitable for drinking.

Residual pressure : Pressure available at the point of use in a water distribution system

Transpiration : Process by which water that is absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface, such as leaf pores.

Water table : The top of the water surface in the saturated part of an aquifer.

Well : An artificial excavation put down by any method for the purpose of withdrawing water from the underground aquifers.

17.11 SOME USEFUL BOOKS

Michael A.M. (1978). Irrigation : Theory and Practice. Vikas Publishing House, New Delhi.

Birdie G.S. and Birdie J.S. (2003). Water Supply and Sanitary Engineering. Seventh Edition. Dhanpat Rai Publishing Company, New Delhi.

Vigneswaran S. and Viswanathan C. (1995). Water Treatment Processes: Simple Options. CRC Press, New York.

17.12 ANSWERS TO CHECK YOUR PROGRESS

Your answer should include the following points:

Check Your Progress 1

1) i. Ground water and surface water and their further classification.

2) i. Strainer type, slotted type, cavity type, perforated pipe tube wells

3) i. Your answer should include description of strainer, its function and tapping water from different aquifers.

Check Your Progress 2

1) i. Rotary drilling and Cable tool percussion drilling.

2) i. Your answer should include, downward forcing of rotating drill bit, drill fluid circulation and drill fluid functions.

3) i. After construction, flow reversal with force in well to loosen small particles surrounding well

4) i. Draw down when inflow of water into well is at critical velocity.

Check Your Progress 3

1) i. Positive displacement ii) Kinetic – Centrifugal and special effect pumps

2) i. Imparting energy to the fluid by impeller, conversion of velocity in to pressure head by volute casing

3) i. Suitable for deep tube wells

   ii. No requirement of special pumping house

4) i. To meet peak hour demand with smaller capacity treatment processes.

   ii. To provide buffer in case of repair and maintenance, fire fighting etc.

5) i. Water should reach each and every point of use with sufficient residual pressure.

UNIT 18 WATER QUALITY, TREATMENT AND PURIFICATION

Structure

18.0 OBJECTIVES

After reading this unit you should be able to:

- enlist physical, chemical and biological characteristics of water
- explain the hardness of water and its effects
- describe the various treatment processes used in water purification

18.1 INTRODUCTION

Quality of water is an important criterion in water supply. Water as it exists in nature contains many impurities. Water in clouds is very pure but it picks up various gases, dust and other impurities while falling in the form of rain through atmosphere. Some of the rain water seeps through the ground and reaches the ground water. On its way, the water picks up minerals and other impurities. The other part of the rain water which flows on the surface in the form of streams in to water bodies such as ponds, lakes and rivers. This water while flowing dissolves organic and inorganic impurities from rocks and land surface. As discussed earlier, water is tapped for supply form either ground water sources or surface water sources. When water is drawn from these surface water sources or ground water sources, it needs some purification process to remove these impurities.

Most industries will have to treat all or part of the water for specific usage. Feed water for boilers is of particular importance and requires many treatments. Water used as ingredient obviously requires treatment specific to the product. This normally includes removal of odours, colour, chlorine, and turbidity. Water used in cooling towers or can cooling systems requires treatment to inhibit corrosion of surfaces and deposits or stains on surfaces. Treatment will include removal of hardness and specific ions such as iron and manganese, removal of gases, and addition of substances such as chromate. Usually, surface water requires a greater degree of treatment compared with ground water due to the larger amount of impurities present. However, ground water sometimes requires special water treatment processes, e.g., removal of Fe, Mn, fluoride, etc. Physical, chemical and biological characteristics of water give the indication of impurities present and play a vital role in design of water purification processes. We will discuss some of these processes in this unit.

18.2 PHYSICAL, CHEMICAL AND BIOLOGICAL CHARACTERSICS OF WATER

i. Physical Characteristics

Physical properties of water include

- temperature
- colour
- turbidity
- taste and odours.

Temperature : The saturation levels of dissolved solids, and gases in water and rates of chemical, biochemical reaction depend on temperature. The temperature of surface water is generally at atmospheric temperature. The temperature of ground water will be more or less than that of atmospheric temperature.

Colour : Colour of water is due to both dissolved and suspended solids in water.

Turbidity: These dissolved and suspended solids also determine the extent of turbidity. For drinking water, even slight turbidity is objectionable. Turbidity will also interfere with the action of chlorination which is the principal method of disinfecting water. It can either react with most of the available chlorine or keep pathogenic organisms from being killed by the chlorine. Ground water is usually less turbid than the surface water. Surface waters are frequently high in turbidity where colour is caused by colloidal clay particles. Turbidity is measured by determining the resistance of water to the passage of light through it.

Taste and odour : Decomposition of organic matter in water, dissolved gases such as hydrogen sulfide and other inorganic compounds contribute to taste and odour of water.

ii. Chemical Characteristics

The chemical characteristics include

- pH
- hardness
- chlorides
- fluorides
- iron and manganese

Hardness and pH are two important characteristics of water.

Hardness : Hardness of water has great implications for process industries and it will be discussed in detail in next section.

pH : Hydrogen ion concentration in water determines the pH value. The hydrogen ion concentration is affected by the ions of dissolved salts and minerals.

Other chemicals : Presence of excess amounts of nitrates and fluorides cause adverse health effects. The presence of heavy metals and toxic compounds such as lead, cadmium, chromium and mercury even in low concentrations is detrimental to public health. These tend to accumulate in food chain.

iii. Biological Characteristics

Biological characteristics of water mainly refer to microbiological quality. Knowledge of type of microorganisms present in water is essential for design and operation of water disinfection processes. If pathogens (disease causing micro organisms) are present, they should be killed before consumption of water. It is not feasible to test for all micro organisms that are present in water and indicator organisms are used for detection of pathogens. When water is contaminated with fecal matter, bacteria of the coliform group serve as indicator organisms. *Escherichia coli*, *Aerobacter aerogenes*, and *Streptococcus pyogenes* are found in fecal matter of warm-blooded animals. Their presence in water indicates a strong possibility of sewage pollution. The organisms mentioned will cause only a mild or no disease, although they are indicators of the presence of Salmonella and Shigella, which can cause serious disease. Experience has shown that treatment that will kill the coliforms will kill the pathogens and render the water safe.

Water contaminated with human waste always contains coliforms, and it is likely to contain pathogens excreted by infected individuals in the community. One pathogen of special concern is the virus that causes hepatitis. It will survive in water - even in 100^{o}C water for 5 min. If coliforms are not found in the water, we assume that the water is also free of pathogens. When the coliform count is low, there is little chance that pathogens are present in the water.

Various testing methods are used to indicate and enumerate the presence of coliforms in water. The number of organisms must be less than 1 in 100 ml. This number is only achievable in treated water. Water must be checked on a daily basis for coliform and chlorine residual. A free chlorine residual of at least 0.2 mg/l must be maintained throughout a water distribution system. This will not always inactivate viruses.

18.3 HARDNESS OF WATER

Water is a good solvent and is, therefore, full of solubles. Hardness of water is the property, which reduces the cleaning effect of detergents and soaps. Hardness in water is expressed in terms of equivalent calcium carbonate measured in mg/l (ppm or mg dm^{-3}). Hardness is not harmful to humans but is objectionable if calcium deposits build up on every thing. In industrial applications the hardness also causes fouling of heat exchangers and boiler tubes.

Hard water gives less lather with soap when compared to soft water. Presence of carbonates and sulphates of calcium and magnesium in water causes the hardness of water. Sometimes salts of chlorides and nitrates also cause hardness. The most common dissolved minerals are calcium bicarbonate, magnesium bicarbonate, calcium chloride, magnesium chloride, and magnesium sulfate. Bicarbonates of calcium and magnesium are soluble, and we refer to their presence as temporary hardness. When water with bicarbonates is heated, the bicarbonates will change to carbonates. Carbonates are not very soluble and will deposit out of solution, forming scale or precipitate. Scale on heat transfer surfaces decreases heat transfer. When scale accumulates in pipelines, it will eventually reduce the pipe diameter sufficiently to reduce the flow of water.

Carbonic acid is formed when carbon dioxide dissolves rainwater. Carbonic acid dissolves limestone and forms bicarbonates. The reactions are shown below:

$$CO_2 + H_2O \longleftrightarrow H_2CO_3$$

$$Ca\ CO_3 + H_2CO_3 \longleftrightarrow Ca(HCO_3)_2$$

On boiling, this reaction is reversed, and the low-solubility calcium carbonate will precipitate. At the same time, reaction with sulfates and chlorides in the water will cause permanent hardness. This will cause a hard scale in pipelines or on equipment. To avoid this, the water is softened to remove the dissolved salts. If the source of water is near to saline water zone, the water may contain more chlorides.

Check Your Progress 1

1. List the physical characteristics of water?

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2. How turbidity is measured?

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3. What contribute to the hardness water?

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4. What are indicator organisms?

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18.4 WATER PURIFICATION

i. Gravity Settling

Gravity settling is the process in which suspended particles are settled down in large tanks by gravity. It is also called as sedimentation. This process is simple and achieved by detaining water in tanks. After settling is over, the water is withdrawn from the tank without disturbing the settled particles. Settling velocity is an important criterion in sedimentation. All the particles heavier than water will move downward due to gravity force. If we consider a single particle, it experiences drag force while settling down. It also experiences the upward buoyancy force. The particle attains a uniform velocity called settling velocity, when the sum of drag force and buoyancy forces equals the gravity force.

ii. Filtration

Filtration is used to remove microorganisms, colour and odour from water. For large scale water treatment, the filter generally consists of thick layers of fine and coarse layers of sand. Size of the sand used is very important . If very fine sand is used, the sand layer will clog quickly and you need to clean frequently. The washing could be achieved by back flow of water called backwashing or scraping the clogged top layer and washing and then reusing it. If the size of sand is large, the sand layer cant filter the water effectively.

However getting all the sand particle of same size is difficult. The sand is graded using a set of sieves of different sizes. The effective size of sand particles is defined as the size of sieve that allows passage of 10 per cent of sand by weight. The sand used should be hard and should be free from impurities. The depth of sand bed is the next critical parameter in design and operation of filter. The sand bed is supported by layer of gravel. Under drains are installed in this gravel layer to collect the water filtered through sand bed. The sand filters are generally used after sedimentation tanks. Water from sedimentation tank is uniformly distributed over entire sand bed without disturbing it. This water is filtered through sand bed and the filtered water is collected by under drain system. In the initial period of operation, the filtration rate is more. The filtration rate gradually decreases due to clogging of sand bed.

iii. Removal of Specific Contaminants

Neither iron nor manganese in water presents a health hazard. However, their presence in water may cause taste, staining and odour problems. In fact iron is an essential element for the formation of hemoglobin, which is essential in transporting oxygen from the lungs to tissue cells. In addition to stains and taste, iron and manganese decrease the efficiency of ion-exchange softening unit by clogging and coating the exchange medium, interfere with plumbing fixtures by leaving deposits. Excess iron in water will support the growth medium for certain bacteria that require high iron concentrations. These bacteria may increase the deposition problems and may produce sulfides. This could clog pipelines and cause taste and odor problems.

After magnesium and calcium bicarbonates, iron is third in line for causing problems in water supplies. Iron is frequently found in acidic water with manganese and sulfur. This combination makes treatment more difficult. In most cases, the iron content of water is less than 5 mg/l. In severe cases, it can be as high as 60 mg/l. Very low iron concentrations can still cause problems. In concentrations of 0.3 mg/l, it can cause stains on equipment, walls, and floors. For final rinse water and sanitizing solutions, iron content in excess of 0.2 mg/l will cause problems.

In well water, iron will be in the ferrous form due to deprivation oxygen in ground water. In surface water, iron is normally in the ferric state. Both the ferrous and ferric states of iron are objectionable. The precipitate formed by the growth of these organisms can cause blocked pipes.

Manganese can be found in well water with iron. In surface water, manganese dioxide is formed and precipitates. Manganese is present in small amounts, normally not exceeding 3 mg/l. Even at that low amount, it will cause black stains that are difficult to remove.

The partial removal of iron can be achieved in other treatment processes also. Water softening with lime removes iron and carbon dioxide. Chlorination for disinfection will aid in the iron and manganese removal.

In surface water, due to presence of oxygen, the iron and manganese are found in oxidized form and can be removed relatively easily. Ground water generally is deprived of oxygen and so has high content of reduced iron, which can be removed by aeration or chemical oxidation. Commonly used processes for iron removal include aeration followed by, chemical oxidation, conventional treatment combined with lime softening and biological treatment methods. These processes are usually followed by filtration to remove precipitates.

Among the above techniques, aeration-filtration is more common. Chemical precipitation is more suitable for water with a higher concentration (Fe>5.0 mg/L). The potassium permanganate-manganese greensand method is suitable for low to moderate concentrations of iron and manganese, about 0-5 mg/L. The prechlorination-filtration process is generally recommended for low iron concentrations (e.g., less than 2.0 mg/L). The ion exchange method is used only for small quantities, while activated carbon adsorption is relatively expensive. Biological treatment involves a combination of both physicochemical and biological removal mechanisms.

When raw water contains manganese in addition to iron, the above-mentioned iron removal processes are practically ineffective for efficient removal of manganese. Precipitation in the form of hydroxide, or oxidation by oxygen, are generally feasible only at high pH (at least 9.0-9.5) values; oxidation by chlorine is sometimes possible, but only in the presence of large excess of chlorine, which then requires neutralization. The high residence time required for removal of manganese is also a problem.

Check Your Progress 2

1. What is settling velocity in gravity settling?

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2. Describe the construction of a sand filter?

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3. What are the main problems posed by presence of iron and manganese?

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4. What are the different processes used for iron removal?

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18.5 WATER SOFTENING

When water is treated to remove turbidity, some of the hardness is also removed. Sodium aluminate will not only act as a coagulant, it will also add alkalinity to the water to reduce some of the non-carbonate hardness:

$$Na_2\,Al_2\,O_4 + 4H_2O \longrightarrow 2Al(OH)_3\downarrow + 2NaOH$$

$$MgSO_4 + 2NaOH \longrightarrow Na_2\,SO_4 + Mg(OH)_2\downarrow$$

When sodium aluminate is used as a coagulant in turbidity treatment, the amount of lime required to reach the softening pH in the cold lime method of softening can be reduced by about 10%.

i. Cold Lime Method

Cold lime softening is a proven process and is more than 150 years old. In this process, calcium oxide (CaO) is added to hard water to form calcium hydroxide. Calcium hydroxide reacts with magnesium and calcium bicarbonates and free CO_2 to form insoluble calcium carbonate and magnesium hydroxide.

$$CaO + H_2O \longrightarrow Ca(OH_2)$$

$$CO_2 + Ca(OH_2) \longrightarrow Ca\,CO_3\downarrow + H_2O$$

$$Ca(HCO_3)_2 + Ca(OH_2) \longrightarrow 2Ca\,CO_3\downarrow + 2H_2O$$

$$Mg(HCO_3)_2 + Ca(OH_2) \longrightarrow Mg(OH)_2\downarrow + 2Ca\,CO_3\downarrow + 2H_2O$$

Magnesium hydroxide has good flocculating properties and helps to precipitate calcium carbonate particles. Excess lime is converted to calcium carbonate by adding carbon dioxide to the water as it leaves the primary settling tanks. At the same time, magnesium hydroxide will be converted to magnesium carbonate. After this carbonation step, sodium carbonate is added to react with noncarbonate salts to form calcium carbonate, which will precipitate. The other compounds are soluble and will stay in the water:

$$Na_2\,CO_3 + Ca\,SO_4 \longrightarrow Na_2\,SO_4 + Ca\,CO_3\downarrow$$

$$Na_2\,CO_3 + Ca\,Cl2 \longrightarrow 2Na\,Cl + Ca\,CO_3\downarrow$$

After this treatment, water hardness will be about 80 mg/l, placing it in the moderately hard category. Sand and gravel filters are used to remove precipitated salts from the water.

ii. Ion Exchange

Many ion exchange processes are used to treat water. Water softening is one of the common treatments. In the system, calcium and magnesium ions in the water are exchanged with sodium ions, while the water flows through a resin bed. After a time, the sodium ions will become depleted and the resin will require regeneration, a process where calcium and magnesium ions are removed and sodium ions are replaced. This is done by pumping brine solution through the resin. This process will not reduce turbidity or remove other chemicals.

The exchange reactions may be written as follows:

$$\begin{array}{llcll}
Ca^{++} & (HCO_3)^-_2 & & Ca^{++} & 2Na+HCO_3^- \\
| & SO_4^{--} + Na_2^+Z^- & & |\,Z^- + & Na_2^+SO_4^{--} \\
Mg^{++} & Cl_2^- & & Mg^{++} & 2Na+Cl^-
\end{array}$$

And the regeneration reaction is as follows:

$$\begin{array}{c}Ca^{++}\\|\\Mg^{++}\end{array} Z^{-} + Na_2^{+}\,Cl^{-} \quad | \; Cl_2^{-} + \begin{array}{c}Ca^{++}\\ \\Mg^{++}\end{array} \quad Na_2^{+}\; Z^{-}$$

Where Z = zeolite radical.

The ion-exchange process can be used with cations and anions, both organic and inorganic. However, most of the applications of ion exchange involves inorganic species which often require the use of extremely highly concentrated regenerant and/or the use of organic solvents to remove organic species. Different varieties of cation and anion exchangers are available for exchange with a particular ion of different stabilities. Generally, ions with higher charge will form more stable salts with the exchanger than those with lower charge; hence, polyvalent species can more frequently be removed from a solution than monovalent ones.

Base exchange resins used in the food industry utilize an ion exchange bed of natural or synthetic zeolites that are hydrous silicate or styrene-based resins. In sodium exchange resins, sodium from the resin is exchanged for calcium and magnesium in the water. Some exchange of iron, copper, manganese, and aluminum will also occur.

Many modern resins are based on a sulfonated styrene divinylbenzene structure. There are resins for almost every kind of application. Selection is based on water analysis, operating temperature, and required outflow water quality. Resins are costly, and durability under usage conditions is one of the important selection criteria.

The sulfonic groups in styrene-based resins are responsible for the cation exchange property. The resins are able to operate over a wide pH range. Water flows through a bed of spherical resin beads. After some use, the resin is regenerated in three steps.

1. The resin is backwashed to remove solids that could have accumulated on the resin bed surface. The beads are suspended in the upward flow that will loosen any packed bead clumps.
2. A saturated salt solution is introduced on top of the resin and allowed to flow downwards. The salt will remove calcium and magnesium ions and replace them with sodium ions. This leaves the resin in the sodium condition.
3. In the final step, the resin is rinsed to remove excess salt and calcium and magnesium chlorides. The softener is ready to return to service.

In plants, more than one softener are usually available so that some will be regenerated while others are operational. Regeneration can take from 35 to 70 min. In most plants, the regeneration of softeners is completely automated. This ensures a continuous supply of soft water at the lowest operating cost.

18.6 TREATMENT OF BOILER FEED WATER

After the removal of calcium and magnesium hardness, iron, copper, colloidal silica, and other contaminants, the water is further treated for making it boiler feed water. The first step involves removal of corrosive gases. Dissolved oxygen and carbon dioxide are the targets. The corrosion caused by these gases is frequently the lesser problem; deposition of metal oxides in the boiler is a bigger problem.

Products of corrosion will become concentrated within the boiler, especially in areas where the heat transfer is high. Metal oxides will cause resistance to heat transfer in the most vulnerable part of the system. This can lead to local overheating and failure of the components. The deposits will also become heavier over time, causing pipe restriction and reduced circulation. The easiest way to deal with the problem is to avoid it, get rid of the oxygen and the carbon dioxide in the feed water.

The removal of oxygen, carbon dioxide, and other gases from feed water can be accomplished in more than one way. The feed water can be heated to reduce the solubility of the gases. This will also increase the efficiency of the boiler.

Small amounts of oxygen in feed water can cause localized pitting that can cause boiler failure even when only a small amount of corrosion took place. Boilers are constructed from carbon steel, and water is the heat transfer medium. The potential for corrosion is, therefore, high. Iron in feed water is normally in the form of an oxide. The two types of oxides are red iron oxide (Fe_2O_3) and black magnetic oxide (Fe_3O_4). Red oxide is formed in oxidizing conditions, while black oxide is formed under reducing conditions. Red iron oxide is converted to an insoluble hydroxide as soon as it gets into the high temperature, high alkalinity area of the boiler.

Black iron oxide is a normal product of corrosion. In new boilers, this reaction will occur and a film of iron oxide will cover the surface of the boiler. This film of magnetite will inhibit further reaction and will protect the boiler plate. The layer will be about 0.025 mm in thickness when further oxidation is inhibited. Obviously, oxidation will still take place, and a boiler will show about 1 mm of corrosion per year. This is one of the reasons why we use boiler plate that is much thicker than what is warranted when new.

Water is frequently deaerated in a system where a fine spray of water comes in contact with steam. The steam will heat the droplets and sufficiently to remove the dissolved gases. The gas is then vented, and the deaerated water is ready for use.

18.7 DEMINERALIZATION OF WATER

Water softening is a process that is common in the food industry. In some sectors like the beverage industry, it is also required to demineralize the water. The systems used for demineralizing utilize multi-bed systems. Mixed-bed systems are more compact and require less space, while producing high-quality water. Multi-bed and mixed-bed exchangers are sometimes used in sequence to produce high-quality demineralized water.

The mixed-bed system works well on water with limited alkalinity or acidity caused by mineral acids. It will produce water with low conductivity. When the raw water has high alkalinity or mineral acidity, water with high purity can be obtained with a two-bed followed by a mixed-bed system. The water passes through a cation exchanger, where cabonates are converted to carbon dioxide that is removed in a decarbonator. In the anion exchanger, anionic impurities are removed. For final purification, the water passes through a mixed-bed ion exchanger. Mixed-bed exchangers have both cation and anion exchange resins in the same vessel. Here most of the dissolved, ionizable solids will be removed.

The removal of silica (SiO_2) in a demineralizing system depends upon the use of a strong base anion exchanger.

18.8 WATER DIS-INFECTION

When water contains disease-carrying pathogenic bacteria, these bacteria have got to be killed before the water is supplied to the consumer, otherwise, it would lead to the outbreak of epidemics like typhoid, dysentery, cholera, etc. Sterilization of water means the killing of these bacteria. Common disinfection processes include the addition of chlorine or chlorine and ammonia, ozone treatment and ultraviolet ray treatment.

i. Chlorination

Chlorine is almost universally used for disinfecting water. It is cheap and reliable, and has a more lasting effect on the disinfected water. When chlorine is added to water, the following reactions take place:

$$Cl_2 + H_2O \quad HOCl + HCl$$

$$HOCl \quad H^+ + OCl^-$$

The hypochlorous acid HOCl, breaks up into H^+ ions and OCl^- hypochlorite ions. It is the hypochlorous acid and the hypochlorite ions which carry out the disinfection. The amount of the hypochlorous acid and the hypochlorite ions in water is called free available chlorine.

When chlorine is added to water, some of it is wasted in reacting with the organic and inorganic matter present in the water. Organic and inorganic matters react with the chlorine to neutralize it, and thereby they prevent the formation of hypochlorous acid. Chlorine also reacts with ammonia to form chloramines. This chlorine in water, in chemical combination with ammonia or other nitrogenous compounds, is known as the combined available chlorine.

The chlorine demand of a water is the difference between the amount of chlorine added, and the amount of chlorine left after the reactions are over. About ten minutes are sufficient to carry out disinfection after adding chlorine.

The application of chlorine to an alkaline solution of water with high pH is more effective than the application of chlorine to acid solution with a low pH. If there are two samples of water, one with a pH of 4 and another with a pH of 8, and if other conditions are the same for both samples, then for the more acidic water, the amount of chlorine required will be about 150 times the amount of chlorine required for the alkaline water, to produce the same sterilizing effect. That shows that the effect of chlorine is more pronounced with an alkaline water with pH more than 7.

Chlorine is used mainly for sterilizing the water, but it can also be used in the removal of iron and manganese, or for the sterilization of water mains.

Chlorine may be applied to water as a gas or in solution, or in the form of bleaching powder. The method of application does not affect the results. The factors that affect the results is whether the water is acidic or alkaline; and the amount of organic and inorganic matter present in the water.

Chlorine Dosing : The chlorine gas may be applied directly to the water coming out of the filters. Direct feeding of chlorine as gas is less satisfactory. Instead, it is preferable to dissolve chlorine gas in a small amount of water, and then to feed this solution to the water to be disinfected. For this, liquid chlorine stored in a steel cylinder is allowed to expand to become chlorine gas by passing it through a number of pressure-reducing valves. The chlorine gas is then mixed with water to form a solution with the help of an apparatus known as a solutionizer.

Bleaching Powder: Chlorine and quicklime, when reacted, produce chlorinated lime or bleaching powder ($Ca(OCl)_2$). Addition of bleaching powder to water yields hypochlorous acid. which kill the bacteria. Due to easy availability of gas and liquid chlorine, bleaching powder is already obsolete.

Amount of Chlorine Required: The amount of chlorine required depends upon the hydrogen-ion-concentration of the water, organic impurities present in it, the temperature of the water, and other factors. After mixing with other compounds, and after killing bacteria, whatever chlorine still remains in water is known as residual chlorine. Chlorine is applied in such a dose that the residual chlorine, found in the disinfected water ready for the consumer, is between 0.1 and 0.2 ppm. The dosage of chlorine required is generally between 0.2 and 1 ppm. The presence of residual chlorine in the water is considered desirable to ensure against future contamination of the water while it is on its way to the consumer through the distribution network.

ii. Chloramination

Chlorine alone, when fed to water, produces tastes and odours which are objectionable. As a remedy, ammonia is fed together with chlorine. The feeding of ammonia before adding chlorine to the water is known as chloramination. When chloramination is carried out, tastes and odours due to chlorine are removed. Chlorine with ammonia forms monochloramine (NH_2Cl) and dichloramine ($NHCl_2$) compounds which remain stable in water and are disinfectants, though to a lesser extent than HOCl.

Chlorine first reacts with water to form hypochlorous acid, and hypochlorous acid then reacts with ammonia. The reactions are:

$$HOCl + NH_3 = NH_2Cl + H_2O$$
$$2HOCl + NH_3 = NHCl_2 + 2H_2O$$

Ammonia and chlorine are generally added in the ratio of one part of ammonia to four parts of chlorine.

iii. Ozone Treatment

One single atom of oxygen, called nascent oxygen, is very active. It reacts with other substances immediately. Ozone (O_3) is a molecule containing three atoms of oxygen. It is highly unstable. It breaks down into oxygen (O_2) and an atom of nascent oxygen. The nascent oxygen oxidises the organic matter of bacteria and kills them. In chlorination, residual chlorine remains in water When chlorine is used, and causes taste and odours. In the case of ozone, tastes and odours are absent. But no disinfecting chemical remains in the water after sterilization (like residual chlorine), and so there is no proper safeguard against recontamination after the treatment. When compared to chlorination, ozone treatment costs more. Due to its highly unstable nature, ozone cannot be manufactured or stored or transported. It has to be produced just before use right at the place of treatment.

iv. Ultra Violet Ray Treatment

Ultra-violet rays can also be used for disinfecting water. These invisible light rays beyond the violet of the spectrum denature the Deoxy ribo Nucleic Acid (DNA) in microorganisms and there by kill them. These are very effective in killing all types of bacteria. These rays can be generated by passing an electric current through mercury enclosed in quartz-bulbs.

The water to be disinfected is passed round the bulbs through a spherical container, so that the ultra-violet rays fall on the water several times, through a distance of not more than four inches. The rays are effective only over a short distance. The water should be free from turbidity and colour, otherwise the rays cannot pierce through, and cannot kill bacteria. For this reason, the turbidity of the water should not be more than 15 ppm.

No tastes or odours are produced by this process, but the cost is greater. The process can be used for small quantities of water. It may be used in pharmaceutical works or in industrial houses.

Check Your Progress 3

1. Describe ion exchange process?

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2. What is the procedure for regeneration of ion exchange resin?

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3. How will you deaerate boiler feed water?

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4. What are the different disinfection processes?

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5. How addition of ozone kills bacteria in water?

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18.9 LET US SUM UP

Water is obtained from surface water sources or ground water sources or both. Usually, surface water requires a greater degree of treatment compared with ground water due to the larger amount of impurities present. However, ground water sometimes requires special water treatment processes, e.g., removal of Fe, Mn, fluoride, etc. Conventional technologies such as filtration, sedimentation, coagulation, etc. have proved to be successful for normal water treatment, while advanced technologies such as activated carbon adsorption, membrane processes, flotation, ion exchange, etc. can be utilized for specific treatment purposes. The suitability of these processes, however, depends primarily on the objective, type of impurity, and mainly on economics.

18.10 KEY WORDS

Contaminant	:	Substance which interfere with intended use of water
Denaturation	:	Process in which a biological molecule is inactivated.
Disinfection	:	Killing of all micro organisms including disease causing ones.
Hardness	:	A water-quality indication of the concentration of salts in water, mainly calcium and magnesium.
Pathogens	:	Disease causing micro organisms.
Toxic substance	:	Which has adverse health effects.
Water Quality	:	A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

18.11 SOME USEFUL BOOKS

Metcalf and Eddy (1995). Wastewater Engineering: Treatment, Disposal, and Reuse. Tata McGraw Hill Publishing Company Ltd., New Delhi.

Birdie G.S. and Birdie J.S. (2003). Water Supply and Sanitary Engineering. Seventh Edition. Dhanpat Rai Publishing Company, New Delhi.

Vigneswaran S. and Viswanathan C. (1995). Water Treatment Processes: Simple Options. CRC Press, New York.

18.13 ANSWER TO CHECK YOUR PROGRESS

Your answer should include the following points:

Check Your Progress 1

1) i. Temperature, colour, turbidity, taste and odours are the physical characteristics of water.

2) i. By determining the resistance of water to the passage of light through it.

3) i. Carbonates and sulphates of calcium and magnesium in water causes the hardness of water. Sometimes salts of chlorides and nitrates also cause hardness.

4) i. Not actual disease causing organism but their presence indicates the presence of pathogens.

Check Your Progress 2

1) i. When drag force and buoyancy force balance the down ward gravity force.

2) i. Layers of fine sand, coarse sand, gravel and under drains.

3) i. Colour, taste, odour and deposits

4) i. Aeration, chemical oxidation, conventional treatment combined with lime softening and biological treatment methods. All these are followed by filtration.

Check Your Progress 3

1) i. Resin exchanges sodium for calcium, magnesium and other ions. In regeneration this is reversed with brine solution.

2) i. Back wash the resin, load with saturated brine solution and then rinse with water.

3) i. Spray water in fine spray infuse steam in to the spray. Vent out heated gases.

4) i. Chlorination, chlorine and ammonia treatment, ozone treatment, ultra-violet ray treatment.

5) i. By denaturing DNA in cell of micro organism.

UNIT 19 WASTEWATER TREATMENT, REUSE AND DISPOSAL

Structure

19.0 OBJECTIVES

After reading this unit we should be able to:

- characterize the waste water in terms of physical, chemical and biological attributes
- describe various biological processes used in waste water treatment
- list the various options available for reuse of treated wastewater.

19.1 INTRODUCTION

The Dairy Industry in India has grown to a large size after independence. As we know, dairy industry is water intensive and uses water in the range of 3 to 4 liters for processing one litres of milk. Other food processing plants also use large volumes of water to process food products and to clean plant equipment. This results in generation of large volume of wastewater. This wastewater will be discharged into a big body of surface water. In areas where land is cheap, wastewater can be disposed of in surface irrigation systems. Whatever the means of disposal, wastewater should not affect the ecological balance of the large body of water.

In order to understand the environmental impact of dairy wastewater, it is useful to briefly consider the nature of milk. Milk is a complex biological fluid that consists of water, milk fat, a number of proteins (both in suspension and in solution), milk sugar (lactose) and mineral salts. The wastewater from a dairy plant carry these components and need to be removed before the effluent is disposed off.

To preserve the ecology of the natural water body, wastewater must be treated.

Any substance or organism in wastewater that will pose a health risk to the public must be removed, destroyed, or reacted to make it harmless. In the same way, any substance or organism that could pose a threat to the ecosystem must be rendered harmless before the wastewater is introduced into the surface water. Suspended solids and particulates must be removed. Soluble solids must be diluted to a level where they will not hard the ecosystem. Nitrates and phosphates must be removed to stop excessive proliferation of fungi or algae in the water bodies. All natural surface waters are public property, and no one is allowed to pollute our common resources of water. To protect our environment, statutory regulations are made and objective of effluent treatment is to meet these legal requirements of environment protection.

It is imperative to reduce the waste to decrease the load on effluent treatment plant. It also makes a good business sense to reduce waste since waste is nothing but loss of product. Whey is a good example of this change in thinking. Whey disposal was considered as a problem. Now whey processing is considered as an attractive option to obtain high value nutraceutical products.

Proper understanding of characteristics of wastewater, physical, chemical and biological unit operations and options available for use of treated waste water is essential for efficient management of dairy effluent system. Depending on these characteristics, various unit operations will be selected for treatment purposes. We will discuss these aspects in this unit.

19.2 CHARACTERSTICS OF DAIRY WASTEWATER

An understanding of wastewater characteristics will be quite handy in design and operation of wastewater treatment system. Wastewater is characterized in terms of physical, chemical and biological constituents. These characteristics are also useful in checking whether the final effluent coming from treatment plant is suitable for reuse and disposal.

i. Physical Characteristics

Important physical characteristics include total solids, odour, temperature, density, turbidity and colour.

Total solids: Information on total solids in wastewater plays a vital role in design and maintenance of wastewater collection system and treatment facilities. The constituents of total solids are floating matter, settle able matter, colloidal matter and matter in solution. The total solids can be determined by evaporation of sample at 103 to 105 degree Celsius. Settle able solids are determined by measuring the solids that will settle to the bottom of a cone shaped container in a 60 minute period. The total solids can further be classified by filtering through a glass fiber microfiltration membrane, as filterable or dissolved solids (which pass through the membrane) and suspended solids (which pass through the membrane). Volatile portions of filterable solids and suspended solids are determined by igniting the solids at around 600 degree Celsius.

Colour and Odour: With passage of time, the chances of anaerobic conditions waste water conveyance system increase. The anaerobic breakdown organic matter in wastewater gives offensive odour as well as changes the colour to black. This is called septic condition. Thus colour and odour indicate the age of waste water.

Density: The density of wastewater is usually same as that of water. It will vary if wastewater contains large amounts of industrial waste.

Turbidity: The turbidity indicates the concentration of suspended solids in wastewater.

Temperature: The waste water temperature is an important parameters because it affects the biochemical reaction in waste water, the soluble limits of gases decreases. Thus dissolved oxygen, which is necessary in aerobic digestion processes, will be less at higher temperatures and needs to be taken care in design of aeration system.

ii. Chemical Characteristics

The chemical characteristics of the effluent can be specified in terms of organic matter content, inorganic matter and gases. The organic matter content is the general way of estimating the strength of wastewater. Biochemical Oxygen Demand (BOD) is the one analytical parameter that is mostly used to measure the strength or organic matter content of wastewater. In dairy plant effluent, the organic matter comprises of butterfat, casein and other milk proteins, lactose and inorganic salts. These components may be present in solutions or as a colloidal suspension, depending upon the type of process applied to the milk. Inorganic constituents such as alkaline metals, chloride, heavy metals, nitrogen, PH, phosphorous, priority pollutants, sulfur and gases such as hydrogen sulfide, methane and oxygen contribute to the chemical characteristics.

Biological Oxygen Demand : The BOD of wastewater determines the milligrams per liter of oxygen required during stabilization of decomposable organic matter by aerobic bacteria action. Also, the total milligrams of oxygen required over a five-day test period to biologically assimilate the organic contaminants in one liter of wastewater maintained at 20 degrees Centigrade. Another related parameter is Chemical Oxygen Demand (COD) which is the milligrams of oxygen required to chemically oxidize the organic contaminants in one liter of wastewater. This can be determined in hours as compared to days of BOD.

iii. Biological Characteristics

Biological constituents in wastewater include animals, plants and protists. Protists are important because the bacteria and other microorganisms which degrade the organic matter present in wastewater fall into this category. In wastewater treatment processes, not one but many different types of microorganisms coexist to carry out breakdown of organic matter. Knowledge of type of micro organisms present in waste water is essential for design and operation treatment processes. If pathogens (disease causing micro organisms) are present in waste water, they should be killed before the treated waste water is disposed off. Due to presence of large number of different micro organisms, the isolation of pathogens in waste water is difficult and indicator organisms are used. Use of different indicator organisms in water was discussed in Unit 18 and it holds good for wastewater also.

Check Your Progress 1

1. If colour of the wastewater is black and has foul smell, what you can say about the wastewater?

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2. How temperature of wastewater affects the aerobic treatment processes?

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3. What is BOD?

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4. What are the practical uses of physical, chemical and biological characteristics?

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19.3 REDUCING WASTE AND WASTEWATER IN A DAIRY PLANT

The dairy industry involves processing raw milk into products such as market milk, butter, cheese, curd, condensed milk, dried milk (milk powder), and ice cream, using processes such as chilling, pasteurization, homogenization, evaporation and drying. Lot of water is used mainly to clean the equipment after these processes. Using more water than what is essential will produce excessive volumes of waste-water, which adds financial and ecological burdens to the processing plant and to the environment. There are many ways to reduce water use and waste water production, which will also eliminate many problems and costs associated with waste water.

The wastage of product should be avoided. This will not only reduce the product losses but also reduces the organic matter load on wastewater treatment systems. This can be achieved by adopting better production control measures as follows:

- Use of disposable packaging (or bulk dispensing of milk) instead of bottles where feasible.
- Minimize spills of ingredients and of raw and finished product on the floor; always clean up the spills before washing.
- Collection of waste product for use in lower grade products such as animal feed where this is feasible without exceeding cattle feed quality limits.
- Optimization of use of water and cleaning chemicals; recirculation of cooling waters.
- Segregation of effluents from sanitary installations, processing, and cooling (including condensation) systems; this facilitates recycling of wastewater.
- Use of condensates instead of fresh water for cleaning.
- Recovery of energy by using heat exchangers for cooling and condensing.
- Use of high-pressure nozzles to minimize water usage.
- Avoidance of the use of phosphorus-based cleaning agents. Removal of phosphorus from wastewater generally needs a special treatment process.
- Minimizing losses of raw material and products by preventing tanks from overflowing, due to foam generation (for example in the separators).
- Draining of milk residues from cans into special catch troughs.

19.4 PRE-TREATMENT OF DAIRY WASTEWATER

i. Treatment Methods

The treatment methods can be categorized as physical, chemical and biological treatment. Since the major part of dairy wastewater are biodegradable organic substances, the biological treatment forms the backbone waste treatment. To increase the efficiency of biological treatment, the load of organic substances should be decreased as much as possible by using physical and chemical methods in pretreatment. Pretreatment of wastewater generally consists of screens, grit chamber, oil and grease trap, chemical precipitation, neutralization, and air flotation (to remove fats and solids) and flow equalization.

ii. Screening and Removal of Oil and Fat

Screens help in retaining bigger particles, pieces of damaged packaging material, rags, and other large debris. These will clog the pipe lines and damage pumps if screens are not installed. The matter is continuously scraped off the screen and disposed off separately, usually as landfill. After screening, the effluents are led to a grit chamber. Grit chamber is a basin in which coarse separation takes place. It is dimensioned and operated in such a way that sand and other heavy particulates have time to settle down to the bottom. The effluents from grit chamber flow to oil and grease trap. Being hydrophobic material and lighter than water, free floating oil and grease will accumulate at the top. Provision will be there in oil and grease trap to skim the top layer. Fat removal is done before any pumping or chemical addition for pH correction, since de-emulsified fats are removed easily at lower pH. Lime addition raises the pH and again emulsifies the fats and also pumping has a churning effect, which emulsifies the fats.

iii. Flow Equalization

The wastewater is then directed into flow equalization tank. The flow rate and the organic matter content of the wastewater is not constant and varies with time during a day. The purpose of flow equalization tank is to reduce these variations. Two tanks are generally provided, so that even when cleaning of one of the tanks is in progress, the equalization of effluent does not suffer. It is remarkable that in case of dairy effluents a holding time of 10-12 hours is sufficient, more holding of this effluent may lead to septic conditions and release foul odours. Equalization tank of waste water containing biodegradable organic matter is generally provided with aeration mixing in order to promote aerobic micro organisms thus reducing the chance of these nuisance odours.

iv. Chemical Treatment

If the pH of wastewater is expected to vary too much, then provision should be made to adjust pH by addition of acid or alkali. This is important because all the treatment processes are affected by pH. Limestone is generally used for neutralization of acidic waste water and sulphuric acid is commonly used for basic waste water.

v. Chemical Precipitation

Another optional chemical treatment is chemical precipitation. Addition of chemicals leads to the alteration of physical state of dissolved and suspended solids which facilitates their easy settling in sedimentation tanks. The principal purpose of this chemical treatment is to remove the phosphorus and other settleable organic matter from wastewater. The precipitation stage starts with flocculation tanks where the flocculants are added and vigorously mixed into the water by agitators. This results in precipitation of insoluble phosphates and organic matter, initially in the form of very fine particles which, however, gradually aggregates into larger flocs. The flocs settle out in pre-sedimentation basins from which a clear effluent overflows into the basin for biological treatment. Pre-sedimentation is the final step in the combined physical and chemical treatment. The water is allowed to flow slowly through one or more basins where the finer particles gradually settle to the bottom as primary sludge. The sedimentation basins are equipped with devices that continuously scrape the sediment into a sump and transverse gutters that carry off water from the clarified surface layers. The key to success of this treatment is the correct dose of lime and coagulant. Excellent results can be obtained and are being achieved using the combination of like alum, Lime-$FeSO_4$ in the correct doses. About 30% of organic matter is removed by this treatment. The chemical treatment requires a constant feed back from the laboratory for dose optimization based on application of varied doses of lime and alum to the effluent from the equalization tank. Once the optimum dose is established and the flow rate of effluent is known, the proportionate chemical flow rate to achieve a desired dose can be easily worked out.

Check Your Progress 2

1. How you can reduces the amount of solid wastes in the wastewater of a dairy plant?

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2. List the categories of wastewater treatment processes? Which type of treatment processes is more important for dairy wastewater?

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3. What is the purpose of flow equalization?

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4. How chemical precipitation works?

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19.5 AEROBIC AND ANAEROBIC BIOLOGICAL TREATMENT

Depending on the availability of oxygen the processes involving growth of microorganisms can be classified as aerobic and anaerobic. Though these two are important, there is another process called anoxic which is a biological environment that is deficient in molecular oxygen, but may contain chemically bound oxygen, such as nitrates and nitrites is called anoxic. Biological waste treatment processes are also classified as suspended growth and attached growth processes.

Suspended Growth Processes: In suspended growth processes, the microorganisms, which are responsible for the conversion of organic or the other matter in the wastewater to gases and cell tissues are maintained in suspension with in the liquid.

Attached Growth Processes: In attached growth process, the microorganisms, which are responsible from the conversion of organic or the other matter in the wastewater to gases and cell tissue, are attached to sum inert material.

Sludge Treatment: Sludge produced in biological treatment processes of liquid effluents needs further treatment. The sludge from the various stages of treatment is collected in thickening tanks to which chemicals are added to facilitate further aggregation of the solid particles. To further break down organic matter and to reduce foul-smelling substances, the sludge is eventually pumped into a digester, where the organic substances are broken down under anaerobic conditions into carbon dioxide and methane are the main components of digester, which can be utilized as fuel for heating. Digester sludge is a homogeneous, practically odourless, dark-coloured substance which still has high moisture content of 94-97%. It is therefore dewatered most effectively in a decanter centrifuge which discharges a solid phase of about one-eighth of the original volume. The dewatered sludge can then be utilized as fertilizer or landfill or simply deposited as waste.

Aerobic Biological Treatment : Biological means can be utilized to rapidly and efficiently remove bio-degradable organic materials from waste water if a suitable environment is provided. Treatment processes that occur in the presence of oxygen are called aerobic process. Supply of air or oxygen is important in these processes. Aeration and mixing are the two high energy demanding operations in aerobic processes. Optimal conditions of food, oxygen, nutrients and pH, and mixed culture of microbes are the essential factors for proper aerobic systems. pH ranges between 5 and 9. The waste water should not contain toxic substances. With prior removal of fat, dairy effluent can be easily made suitable for aerobic biological treatment system. In the aerobic biological treatment of dairy waste, three distinct phases have been identified:

- Rapid initial incorporation of the milk constituents, both dissolved and suspended, into the biomass block. This may be due to an adsorption phenomenon or possibly formation of a complex between the bacterial cells in the flock and the protein and lipids. The extent of this rapid incorporation or adsorption depends on the organic loading ratio (mass of BOD_5 in the waste water per unit mass of suspended cells) and the ecological condition of the organic matter.
- Oxidation of the organic material, both adsorbed and in solution, by bacterial assimilation. The organic material in the dairy waste is partially synthesized to new cell material and partially oxidized to supply the energy needed for the growth of new cell material. The rate of assimilation (oxidation) is only about 10% of the adsorption in the first stage. It is reported that protein in milk waste is not utilized until all the lactose has been degraded in this phase.
- Near exhaustion of organic matter in waste water results in death of some microbes due deficiency of nutrients. Endogenous respiration in which the living cells feed on the substances of the dead bacterial cells. These are oxidized, with the production of simple compounds such as water, ammonia and carbon dioxide. The rate of oxygen consumption in this phase is 10% of that required during the assimilation phase.

Anaerobic Biological Treatment: The decomposition by microorganisms of organic matter in wastewater in the absence of dissolved oxygen is classed as anaerobic digestion. Anaerobic digestion is a process, which occurs widely in nature. Anaerobic digestion is generally considered to take place in two stages - acid formation and gas formation. In the first stage a group of microorganisms breaks down carbohydrates, fats and proteins into simpler substances such as alcohols and volatile fatty acids. Some of the substances are used as food by the organisms and some persist in the sludge, but most of the lower volatile fatty acids (acetic, propionic, and butyric acids) will be converted to methane and carbon dioxide by a different group of organisms. This operation constitutes the second stage of the digestion process. The actual processes are in fact much more complex than this.

The anaerobic microorganisms are very sensitive to pH and other environmental conditions. In anaerobic conditions, the growth of microorganisms is slow. While the first factor results in loss of biomass, the second factor inhibits the replenishment lost biomass. Various types of reactors have been developed in an attempt to improve the treatment efficiencies and to overcome the loss of anaerobic microbes. Among the important factors believed to affect the treatment efficiencies are the type of reactors used, the characteristics of wastewater to be treated, the hydraulic regime in the reactor, the concentration of microbes and types of microbes in the reactor. High rate anaerobic reactors are becoming popular for the treatment of various types of wastewaters because of their low initial and operational cost, smaller space requirement, high organic removal efficiency and low sludge production, combined with a net energy benefit through the production of biogas. The term 'high-rate' was once used for the designs of sewage sludge digesters, but it is now widely used to refer to anaerobic treatment systems meeting at least the following two conditions:

a) High retention of viable sludge under high loading conditions, and

b) Proper contact between incoming wastewater and retained sludge. Among the various anaerobic reactors developed so far, the Upward Anaerobic Sludge Blanket (UASB) Reactors have been found to be relatively superior because it is simpler and more economical and it neither requires added substratum as in anaerobic filters, nor effluent recirculation as in fluidized bed reactors. Also, solids retention times can be maintained at a high level even at a low hydraulic retention time (HRT) by the development of a granular sludge bed.

The biological treatment systems generally used in dairy wastewater treatment include aerated lagoon, trickling filters, rotating biological contactors, Upward Anaerobic Sludge Blanket (UASB) and activated sludge treatment. These will be discussed in the following sections.

19.6 AERATED LAGOON

An aerated lagoon consists of a large pond or tank equipped with mechanical aerators to maintain an aerobic environment. Aeration also keeps the organic materials suspended. When allowed to settle, facultative bacteria can rapidly deplete the oxygen supply in the sediment and allow anaerobic organisms to start growing. This will give rise to all the horrible smells or odours that are frequently associated with treatment lagoons.

Aerobic digestion results in complete biological oxidation leading to breakdown products with low or no odors. The breakdown in an aerated lagoon is slower than in an activated sludge system, but it allows an appropriate amount of time for the breakdown of complex materials. The microbial population is also less sensitive to changes in effluent strengths and types. The effluent from the lagoon is normally channeled to settling tanks to remove suspended solids.

19.7 TRICKLING FILTER

It falls into the category of attached growth process. Trickling filters take advantage of the rapid adsorption of organic material on microbial slime layer. These slime layers consists of active microorganisms - a balanced flora of bacteria, fungi, algae and protozoa. Higher animals such as fly larvae, insects, snails and worms may also be present. Settled influent to be treated is passed down through a packed bed countercurrent to a flow of air as shown in figure 19.1. Older plants employ rock, slag or other low cost materials to provide a support with large specific surface area and a high void volume. Typically, filter depths vary from 1.0m to 2.5m. Microorganisms attached to the packing matrix adsorb oxygen from the up flowing air and organic matter from down flowing influent. This way the organic matter in the influent is metabolized and its BOD gets reduced. Organic matter is adsorbed by the biological film also called as slime layer. The organic matter is degraded at the surface of the film by aerobic microorganisms. Gradually the thickness of the slime layer increases, the organic matter is metabolized before it can reach the microorganism near the packing matrix. As a result these microorganisms deep in slime layer die and loose ability to adhere to the packing matrix. The liquid then washes the slime off the matrix and a new slime layer starts growing. This process of slime layer removal is called sloughing.

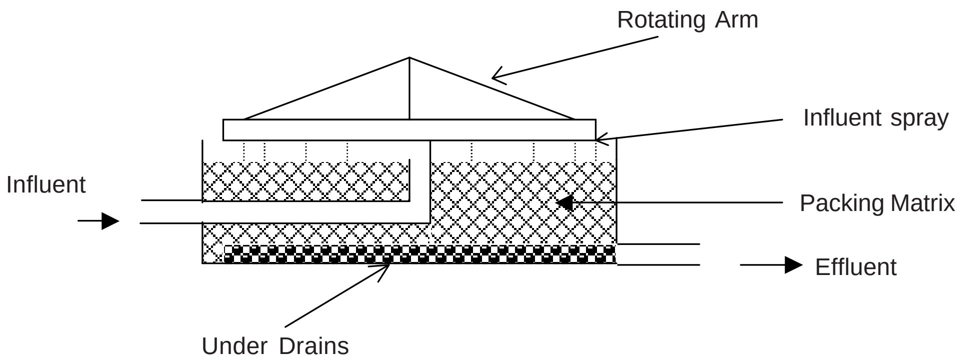

Figure 19.1 Schematic diagram of Trickling Filter

The trickling filter usually consists of a cylindrical tank. The tank is packed with a bed of stone or special plastic packings. The underdrains are provided at the bottom of the bed for collecting the treated wastewater and any biological solids that have become detached from the packing matrix. The underdrains also serve as a porous structure for air recirculation. The trickling filter is always followed by secondary sedimentation tank to remove the suspended matter from the treated effluent. Modern plants use various types of low mass per unit volume, high specific surface area plastic, medium either in sheet form or randomly packed. Plastic packing depths upto 12m have been used.

19.8 ROATATING CONTACTORS

This is also an attached growth process. Rotating contactors consist of closely spaced discs on a central drive shaft. These disc are rotated very slowly (0.5 to 15 rpm) through the effluent so that about 40-50 percent of disc surfaces are submerged. The discs may be flat or corrugated to increase the area. Generally synthetic materials such as PVC and polystyrene are used for manufacture of these discs. The discs are stacked and provided with baffles to minimize the short circuiting. As the discs rotate through effluent, a microbial film forms. These films will be alternately exposed to air and submerged in wastewater during rotation. During the submergence the nutrients are absorbed from wastewater. Oxygen needed for metabolism is absorbed during aeration.

19.9 ACTIVATED SLUDGE PROCESS

The term activated sludge refers to the brownish flocculent culture of organisms developed in an aeration tank under controlled conditions. Also, sludge floc produced in raw or settled wastewater by the growth of bacteria and other organisms in the presence of dissolved oxygen. A good quality of activated sludge is shown by brown colour, good settling characteristics, and DO (Dissolved Oxygen) present.

The process consists of aeration and agitation of wastewater in the presence of flocculated suspension of microorganisms on particulate organic matter. Vigorous mixing and incorporation oxygen into effluent is achieved using bubble diffusers, paddles, stirrers, surface aerators, etc. The effluent passes through this aerator after it spends required residence time in the aerator to a secondary sedimentation tank for removal of flocculated solids. Part of the sludge from this sedimentation tank is recycled to the aeration tank to maintain biological activity. The other part is sludge waste, which goes into sludge treatment process. The process is schematically represented in figure 19.2.

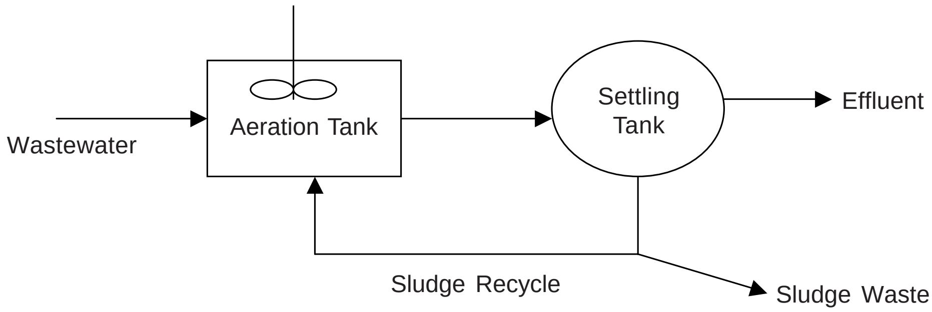

Figure 19.2 Schematic diagram of Activated Sludge Process

The start up process includes, aeration of the effluent in the aeration tank and seeding with cow-dung. Further seeding maybe required till the micro-organisms get accustomed (acclimatized) for taking the dairy waste organics as food material. The main control in this treatment is the micro-organism population for which the measure is Mixed Liquor Suspended Solids (MLSS) which can be determined by analyzing effluent from the aeration tank daily by settling test. If the population is more, MLSS will be higher and vice-versa. Remember that any upset due to acidic effluent condition would mean repetition of the start up procedure and plant may take one to one and half months to mature. Avoid such an eventuality. Change of sludge colour or settling ability is another indication of undesirable conditions; dark brown colour and easy settling sludge is the best in an aeration tank

19.10 UPFLOW ANAEROBIC SLUDGE BLANKET (USAB) PROCESS

USAB is short form of Up-flow Anaerobic Sludge Blanket. The advent of UASB process enabled the design engineer to evolve an anaerobic treatment system for medium strength wastewaters like those from the dairy industry. In the UASB concept, treatment is carried out in an upflow reactor. The wastewater is taken either to a distributing inlet chamber of 4.5-5 m depth and

released it uniformly in the lower part of the reactor allowing it to rise at a desired velocity up to the outlet which is at the upper periphery of the unit or alternatively, the feed could also be pumped up from the bottom. A schematic diagram of a UASB reactor is shown in figure 19.3. In the lower part of the tank, a blanket of active anaerobic sludge is maintained. The wastewater is evenly distributed over the reactor bottom and is forced to percolate upwards through this bed of anaerobic sludge. During passage through the sludge bed suspended solids are entrapped (sedimentation and adsorption of organic waste matter in the sludge bed) and biodegradable material is consequently digested.

Key feature of the UASB is the formation of a dense sludge bed in the bottom of the reactor in which all biological processes take place. This sludge blanket is initiated by accumulation of incoming suspended solids and bacterial growth. If proper conditions are maintained during start up, different species of bacteria are observed to form flocs or granules in upflow anaerobic systems. These dense aggregates have good settling properties and are not susceptible to washout from the system under practical reactor conditions. Retention of active sludge, either granular or flocculent, within the UASB reactor enables good treatment performance at high organic loading rates. Natural turbulence caused by the influent flow and biogas production provides good wastewater-biomass contact in UASB systems. Dissolved organics are removed from the solution by the anaerobic bacteria and converted into biogas and a small fraction in new bacterial biomass. The biogas provides a gentle mixing in the sludge bed, therefore no mechanical mixing is required. In the upper part of the reactor, A-shaped structures are placed that collect the produced biogas, from where it is withdrawn. Consequently, between two adjacent 'A's a quiescent zone is provided, that serves as an internal settler, where the treated water is freed of sludge particles.

The water-sludge mixture enters the settling compartment where the sludge can settle and flow back into the digestion compartment. After settling the treated water is collected in gutters and discharged. Since the 'A' structures separate the treated wastewater from gas and sludge, they are commonly referred to as 'GLS (gas, liquid, solids) separators'. A salient feature of the UASB concept is that anaerobic flocculent or granular type of sludge inherently has or will attain good settling properties provided the process is operated in the proper way during the reactor start-up.

Higher organic loading can be applied in UASB systems than in aerobic processes. Therefore, less reactor volume and space is required while, at the same time, high-grade energy is produced as biogas. The UASB reactor may replace the primary settler, the anaerobic digester and the secondary settler of a conventional aerobic treatment plant.

However, the effluent from UASB reactor usually needs further treatment, in order to remove remaining organic matter, nutrients and pathogens. This post treatment can be accomplished in conventional aerobic systems.

The advantages of UASB is that you do not need to fill with any stone or other media in reactor and no mixers or aerators are required, thus conserving energy and giving very low operating costs.

The gas produced can be collected and used if desired. Anaerobic systems function satisfactorily when temperature inside the reactor/ digester is above 18-20^{o}C. However, optimum temperature is 38-40^{o}C under mesophilic and 50-60^{o}C under thermophilic conditions. Thus, in most parts of India, temperature is no problem. In colder countries, the reactor needs to be heated and hence the use of UASB is generally limited to high BOD industrial wastes from which gas recovery is more than adequate for heating.

Excess sludge is removed from time to time through a separate pipe and sent to a simple sand bed for drying. The nutrients, nitrogen and phosphorus are not removed but are in fact conserved in the process and, to that extent, make irrigation use of the effluent more valuable.

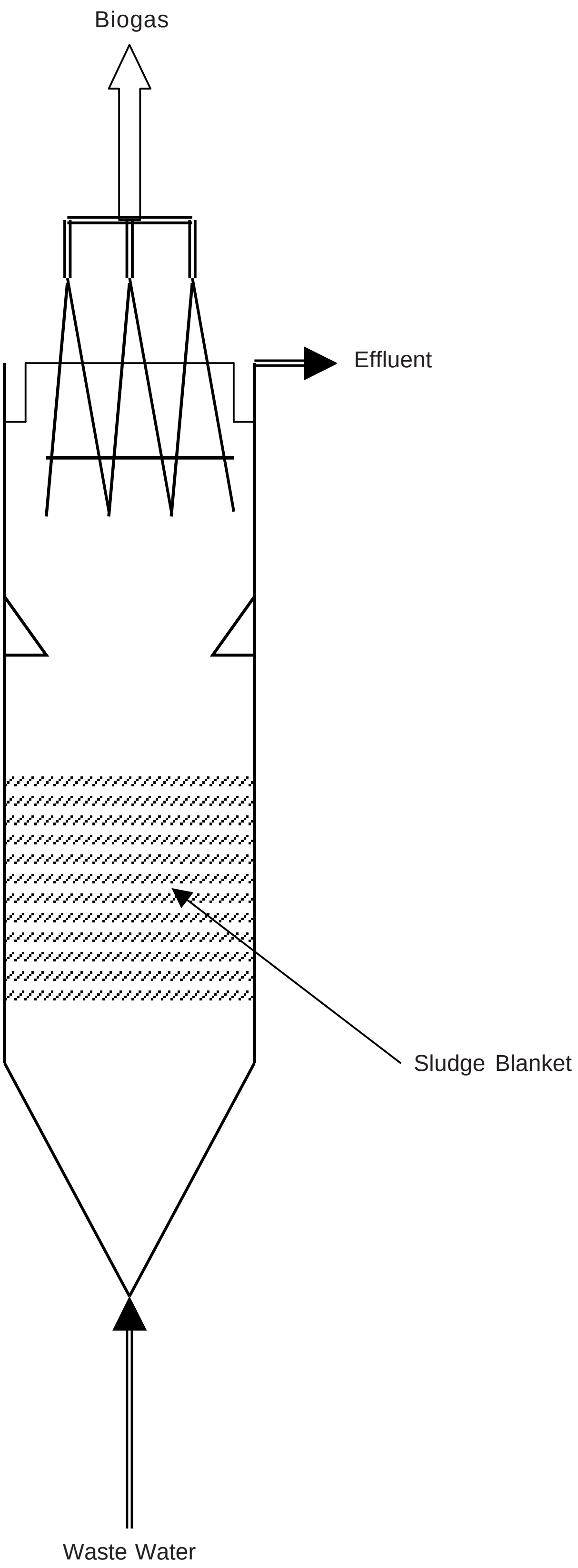

Fig. 19.3 Schematic diagram of UASB Reactor

Check Your Progress 3

1. Define aerobic and anaerobic processes?

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2. Describe the construction of trickling filter ?

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3. Draw the schematic diagram of activated sludge process?

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4. What are desirable colour and settling characteristics of good sludge for activated sludge process?

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5. What are advantages of UASB process?

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19.11 WASTEWATER RECLAMATION AND REUSE

With increasing population, the demand for fresh water is growing. Contamination of surface and ground water, uneven distribution of water resources, unreliable rain fall are the major factors forcing us to think innovatively to reclaim waste water for reuse. In any planning of wastewater treatment scheme, use of highly treated wastewater for different applications must be evaluated.

Wastewater reclamation is defined as the treatment or processing of wastewater to make it suitable for reuse. The reuse of treated wastewater in the same application from where the wastewater generated is called wastewater recycling. This is more predominant in industries. Wastewater reuse is the actual use of treated wastewater for a beneficial use such as agricultural and landscape irrigation. The wastewater reuse could benefit the society indirectly also in applications such as navigation and groundwater recharge.

The potential applications of wastewater reuses include:

a) Agricultural irrigation for crops and commercial nurseries.

b) Landscape irrigation of public places such as parks, schools, golf courses, green belts.

c) Recycling of industrial wastewaters includes reuse of cooling water and process water, treated wastewater as boiler feed.

d) Groundwater recharge

e) Recreation and environmental uses where treated water is used to augment water in lakes, ponds and streams

f) Nonpotable urban uses such as fire fighting, air conditioning, toilet flushing.

g) Potable reuse which involves blending of treated wastewater in water supply reservoir.

At present, the major applications using treated wastewater are agricultural and landscaping irrigation, reuse of industrial activities and recharge of groundwater. The other applications are not very popular and the volume of reuse is less in these. The major constraint in reuse is that the quality of treated wastewater should always be monitored. The effect of salts and total dissolved solids on crops and soil is a major concern in agricultural and landscape irrigation. This will be accentuated by hot and dry climate where higher evaporation losses and transpiration of water leave more salts deposited. Presence of toxic chemicals and pathogens is another major concerns in almost all reuse applications. In industrial applications fouling, corrosion and biological growth are the problems which need to be tackled.

19.12 EFFLUENT DISPOSAL

The wastewater after treatment is called an effluent. This effluent can be reused for some application as discussed in previous section. Otherwise, it is disposed in to environment, where it becomes part of hydrologic cycle. There are mainly two modes of disposal. The most common mode of effluents disposal is by discharge and dilution into natural water bodies such lakes, sea or natural water courses such as streams and rivers. The other mode is land application where the effluent is spread on the land. The water seeps down and reaches groundwater. Before selecting the method of disposal, its impact on environment should be evaluated so that the effluent conforms to various environmental regulations and criteria that are fixed for effluent disposal. The major criteria are biological oxygen demand (BOD), suspended solids, acidity and coliforms.

Check Your Progress 4

1. Define reclamation and recycling?

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2. What are the major applications where large quantity of treated wastewater can be reused?

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3. What are the problems in recycling of treated wastewater in industrial applications?

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4. What are the main modes of disposal of treated wastewater can be reused?

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19.13 LET US SUM UP

For reducing the environmental impact of wastewater disposal, it should be treated before disposal. As dairy wastewater is rich in organic matter, biological processes are more important in treatment. However, some pretreatment in the form of physical and chemical processes is required before biological treatment. The aerobic and anaerobic biological treatment systems generally used in dairy wastewater treatment include aerated lagoon, trickling filters, rotating biological contactors, Upward Anaerobic Sludge Blanket (UASB) and activated sludge treatment. After the treatment, the effluent should be considered for reuse for some of applications. If reclamation and reuse is not possible, then it should be disposed off in to environment as per statutory regulations.

19.14 KEY WORDS

Effluent : Water that flows from a sewage treatment plant after it has been treated

Evaporation : The process of liquid water becoming water vapor, including vaporization from water surfaces, land surfaces, and snow fields, but not from leaf surfaces

Ground Water : Water that flows or seeps downward and saturates soil or rock and stored underground in rock crevices and in the pores of geologic materials. The upper surface of the saturate zone is called the water table.

Ground-Water : Inflow of water to a ground-water aquifer from the surface. Infiltration of precipitation and its movement to the water table is one form of natural recharge. Also, the volume of water added by this process.

Hydraulic : Time of stay of a liquid element in a reactor

Potable Water : Water of a quality suitable for drinking.

Solids Retention : Time of stay of solids of wastewater in a reactor

Transpiration : Process by which water that is absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface, such as leaf pores.

Wastewater : Water that has been used in homes, industries, and businesses that is not for reuse unless it is treated.

19.15 SOME USEFUL BOOKS

Metcalf and Eddy (1995). Wastewater Engineering: Treatment, Disposal, and Reuse. Tata McGraw Hill Publishing Company Ltd., New Delhi.

Birdie G.S. and Birdie J.S. (2003). Water Supply and Sanitary Engineering. Seventh Edition. Dhanpat Rai Publishing Company, New Delhi.

Vigneswaran S. and Viswanathan C. (1995). Water Treatment Processes: Simple Options. CRC Press, New York.

Jha S. N. (2004). Dairy and Food Processing Plant Maintenance: Theory and Practice. International Book Distribution (Publication Division) Company, Lucknow.

19.16 ANSWERS TO CHECK YOUR PROGRESS

Your answer should include the following points:

Check Your Progress 1

1) i. The wastewater in septic condition for more time. Thus the wastewater is black with foul smell.

2) i. The rates of biochemical changes and the amount of dissolved gases depend on temperature. At high temperature, the dissolved oxygen will be less so aeration should be more.

3) i. BOD is the milligrams of oxygen required by bacteria in 5 days at $20^{o}C$ to aerobically degrade the organic matter present in a wastewater sample.

4) i. Design and operation of wastewater treatment processes and checking the suitability of final treated wastewater for reuse and disposal.

Check Your Progress 2

1) i. Minimize spillage of raw material and products, conversion of collected waste material from spills and other streams into low grade products, draining of milk residues from cans into troughs.

2) i. Physical, chemical and biological processes. Biological processes are more important.

3) i. To reduce the variations in flow rates and variations in concentration of organic matter or BOD.

4) i. By addition of chemicals, the physical state of dissolved and suspended solids is changed to bring about flocculation and settling.

Check Your Progress 3

1) i. Aerobic – presence of oxygen; anaerobic – absence of oxygen in the process.

2) i. Cylindrical tank – filled with packing for providing support to biological film. Under drains at the bottom to collect treated wastewater.

3) i. Draw as shown in text.

4) i. Dark brown colour and easy settling characteristics.

5) i. No packing material in reactor. No aerator or mixer, which reduces power consumption. The biogas produced can be used as fuel.

Check Your Progress 4

1) i. Reclamation- treating wastewater and reusing it in any application including the same application from where the wastewater is generated

2) i. Recycling- treating wastewater and reusing it only in the same application from where wastewater is generated.

3) i. Agricultural and landscaping irrigation, reuse of industrial activities and recharge of groundwater

4) i. Fouling, corrosion, biological growth.

5) i. Discharge and dilution into natural water bodies and land application to recharge groundwater.

UNIT 20 WATER CONSERVATION AND RAIN WATER HARVESTING

Structure

20.0 OBJECTIVES

After reading this unit, we should be able to:

- understand the basic concepts of water conservation such as hydrologic cycle and watershed
- discuss the importance of water conservation and rain water harvesting
- describe the construction of rain water harvesting system and its working
- enumerate various steps to save water in a dairy processing plant

20.1 INTRODUCTION

Water is a precious resource for growth and prosperity. We can note its importance from the fact that all the great civilizations prospered in the vicinity of water resources. Major sources of fresh water are surface water and ground water. Surface water depends on rainfall and groundwater can't be drawn beyond its recharge rate. Making the most efficient use of our limited and precious resources is essential. Thus there is growing awareness to conserve water. Agriculture is a major user of water and there is greater emphasis in water conservation in agriculture. Now-a-days quantity of available freshwater including groundwater is becoming short in supply even for domestic and drinking purposes. High standards of living in urban areas demand greater water supply. With rapid increase in industrial growth, the requirement of freshwater for industries is also increasing. Industries can play a major role by conserving water and recycling the treated wastewater to reduce the demand of freshwater. Water conservation not only helps in reducing the expenditure on procuring water but also reduces wastewater volume. This wastewater needs to be treated before it leaves the industry premises.

Every citizen as well as institutions and industries should use water judiciously. They can also help in augmenting the freshwater resources. Rainwater harvesting is one such movement where involvement of all the people is needed. With the surfaces around houses and buildings being cemented, particularly in cities and towns, rainwater, which runs off from terraces and roofs drains into low lying areas or drained into sewers without percolating into the soil. Thereby, precious rainwater is squandered. Therefore, roof water harvesting in residential and industrial areas can be used to augment the freshwater resources.

In this unit, we will appreciate the basic concepts such as hydrologic cycle and watershed, which are useful in water conservation. Then we will discuss different components of a rainwater harvesting system, their functions and material of construction. We will also learn some tips on conservation of water in a dairy plant. This unit is intended to sensitize about water conservation aspects in general on watershed basis and water conservation in a dairy processing plant in particular.

20.2 THE HYDROLOGIC CYCLE

The hydrologic cycle describes the perpetual processes of motion, loss and recharge of the earth's water. The never-ending exchange of water from the atmosphere to the oceans and back again is known as the hydrologic cycle. The processes can be visualized as shown in Figure 20.1. This cycle is the source of all forms of precipitation (hail, rain, and snow), and thus of all water.

The water from rivers, ponds, ocean and soil evaporates while water stored in plants transpires to form clouds which store the water in the atmosphere. The vapour in the clouds condenses to result in precipitation. Like all other phenomena in nature, this cycle also derives its energy from the sun. Explanations of various terms used in the figure are given below.

i. Evaporation

Solar energy falling on earth heats up the surface water molecules. These energized water molecules break free from water surface to evaporate and rise as invisible vapour in the atmosphere.

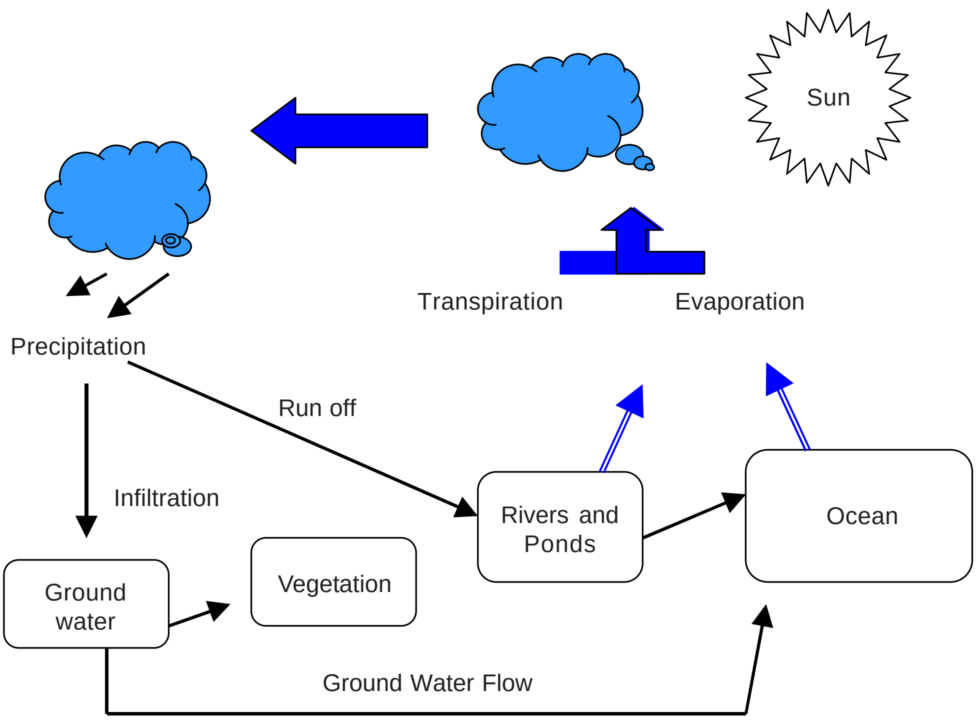

Fig. 20.1 Hydrologic Cycle

ii. Transpiration

All the plants emit water vapour through leaves. This process is named as transpiration. Actively growing plants transpire more vigorously. It could be as high as 5 to 10 times the water it can hold. It is physiological requirement of the plant.

iii. Condensation

The water vapours from evaporation and condensation rise. As temperature falls at higher levels, the water vapour cools and eventually ***condenses*** with tiny dust particles present in atmosphere as nuclei. These nuclei grow and agglomerate into clouds. These clouds are mobile and are driven by air currents in the atmosphere.

iv. Precipitation

If these clouds further rise in atmosphere, they get supersaturated with water and that water falls down as rain. If the temperature of surrounding is too low, then hail or snow fall results. All these forms of water getting condensed and falling on earth is called precipitation. The rainfall is more near the mountain ranges because they cause the clouds to rise in air.

v. Run off

Excessive precipitation or snowmelt during summer result in flow of water in streams to rivers or ponds. This visible flow of water on land surface depends on topography of watershed and is called run off. We will discuss watershed in next section.

vi. Infiltration

As the land surface is permeable, part of the precipitation or run off will infiltrate through the surface downwards. This infiltration water reaches the groundwater.

vii. Groundwater

Depending on geology of soil below the surface, the infiltration water is stored as ground water. This groundwater is brought to surface by digging wells for our use. Sometimes, the groundwater can flow into streams or into ocean. Groundwater hydrology is the science that studies the storage and dynamic movement of groundwater.

20.3 WATERSHED AND WATER CONSERVATION

All of the land, which eventually drains to a common lake or river, is considered to be in the same watershed. Watersheds are defined by topographic divides which separate surface flow between two water system. All the rain that falls in a watershed flows in small streams. These small streams merge into a big stream. All such big streams flow in to a pond or lake or river. Agricultural and industrial activities in a watershed can affect the water quality of both surface water and groundwater. The pollutants find their way to surface water by runoff and to groundwater by infiltration. The human activities combined with natural forces shape the watershed. This combined effect affects the watershed landscape and its water quality. These, in turn, will affect our health and livelihood. Take the example of industrial activity which affects the water quality. The treated wastewater from industries is disposed off into environment. It reaches the water system of watershed and thus the quality of treated wastewater should be of acceptable level (as discussed in Unit 3 of this block) as stipulated by local regulatory authorities.

A watershed can be very large (e.g. draining thousands of acres to a major river or lake or the ocean), or very small, such as a 20-acre watershed that drains to a pond. A small watershed that lies inside a larger watershed is sometimes referred to as a sub watershed. The water conservation measures such as construction of check dams (small structures), percolation ponds and recharge wells should be based on topography of watershed. It is the social responsibility of the industries to conserving water to reduce wastewater volume. The water conservation will be economically gainful as well. Industries can recycle the treated wastewater in some cases to reduce the demand of freshwater. In this way watershed forms an ideal unit for management and sustainable development of its natural resources like water, soil, land and vegetation.

20.4 RAIN WATER HARVESTING

Rainwater harvesting is very old technique of water conservation in many parts of the world. We can find examples of rainwater harvesting systems in the history of great civilizations. As the name itself suggests, it involves collecting the rainwater and storing it. The technology can be as simple or as complex as required. The collected rainwater can be stored in metal or plastic tanks, which can be used for domestic or industrial purposes or it can be used to recharge the ground water. Excessive tapping of ground water through numerous tube wells has led to a fall in water table in many parts of our country. To avoid the alarming fall of ground water table, the aquifer must be recharged by collecting every drop of rainwater, since that is the only source of ground water.

In India, traditionally we used to store the rainwater in ponds, which were used as surface water sources for drinking, irrigation and other purposes. However loss of water by evaporation is more in these. With increasing population, there is growing need of land for housing. These ponds are fast disappearing even in small towns due to this growing need of land for housing. This is leading to change in thinking. Now we have two options for better use of rainwater. In first option, the rainwater can be harvested and stored in a storage tank for latter use. The second option involves recharging the ground water with harvested rainwater. Various recharge structures are available to recharge the rainwater into ground. These are outlined here:

Pits : Recharge pits are constructed for recharging the shallow aquifer. These are constructed 1 to 2 m, wide and to 3 m. deep which are back filled with boulders, gravels and coarse sand.

Trenches: These are constructed when the permeable stream is available at shallow depth. Trench may be 0.5 to 1 m. wide, 1 to 1.5m. deep and 10 to 20 m. long depending up availability of water. These are back filled with filter materials.

Dug wells: Existing dug wells may be utilized as recharge structure and water should pass through a graded filter or other filter media before putting into dug well.

Hand pumps: The existing hand pumps may be used for recharging the shallow/ deep aquifers, if the availability of water is limited. Water should pass through filter media before diverting it into hand pumps.

Recharge wells: Recharge wells of 10 to 30 cm diameter are generally constructed for recharging the deeper aquifers and water is passed through filter media to avoid choking of recharge wells.

Recharge Shafts: For recharging the shallow aquifer which is located below clayey surface, recharge shafts are used. The size of recharge shaft is 0.5 to 3 m diameter and 10 to 15 m deep. After digging, these are back filled with boulders, gravels and coarse sand.

Spreading techniques: When permeable strata starts from top then this technique is used. Spread the water in streams/canals by making check dams and bunds. A percolation pond may be constructed in low-lying areas.

Check Your Progress 1

1. What is hydrologic cycle?

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2. How the water vapour reaches the clouds?

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3. What is the role of industry in water conservation?

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4. What is the importance of watershed concept in water conservation ?

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5. How the rainwater harvested can be used?

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20.5 ADVANTAGES OF RAIN WATER

Collecting rainwater is not only water conserving, it is also energy conserving since the energy input required to treat and pump water is avoided. It also prevents soil erosion and flooding caused by runoff. It increases the availability of water. The quality of rainwater is better than other sources such as surface water or groundwater. Salts and minerals are picked up by water from soil and rocks on its way to surface water bodies such as lakes/rivers. Groundwater is contaminated by many pollutants due to indiscriminate use of pesticides and incomplete treatment of effluents by industries. In this way rainwater is better than these two types of water sources.

However, rainwater harvesting is location specific. Thus, rainwater falling in non-industrialized areas can be more pure compared to the rainwater in industrial areas where pollutant emissions are prevalent, or in agricultural regions where intensive use of pesticides and insecticides is prevalent. Rainwater is generally soft and can significantly reduce the need of water softening treatment.

20.6 HOW DOES A RAIN WATER HARVESTING SYSTEM WORK?

Rainwater harvesting systems generally have the following main components. These components are listed here:

- Roof/catchment area
- Gutters and connecting pipes
- Leaf screens and first flush diverters and graded filter filled with coarse sand, gravel and pebbles
- Storage Tank
- Water Treatment system
- Water distribution system

Though in some domestic rainwater harvesting systems you may not find the graded filter. In some large-scale rainwater harvesting systems, it may be advantageous to have a sedimentation tank before graded filter to settle the dust particles. Main components of a domestic rainwater harvesting system shown in Figure 20.2.

i. The Roof / Catchment Area

Rainwater can be collected from any inert roofing, that is, it won't leach out any chemicals into rainwater. It is important that no lead is used as roof flashing or gutter solder, as the slightly acidic quality of rain can dissolve the lead and contaminate the water supply. Be aware that some composite asphalt, asbestos, concrete tiles and lead based paints can leach pollutants and affect the quality, colour and taste. Therefore we need to pay special attention to roofing, if we are going for rainwater harvesting. We may paint the roof with non-toxic paints to make the roof less porous and increase the collection efficiency.

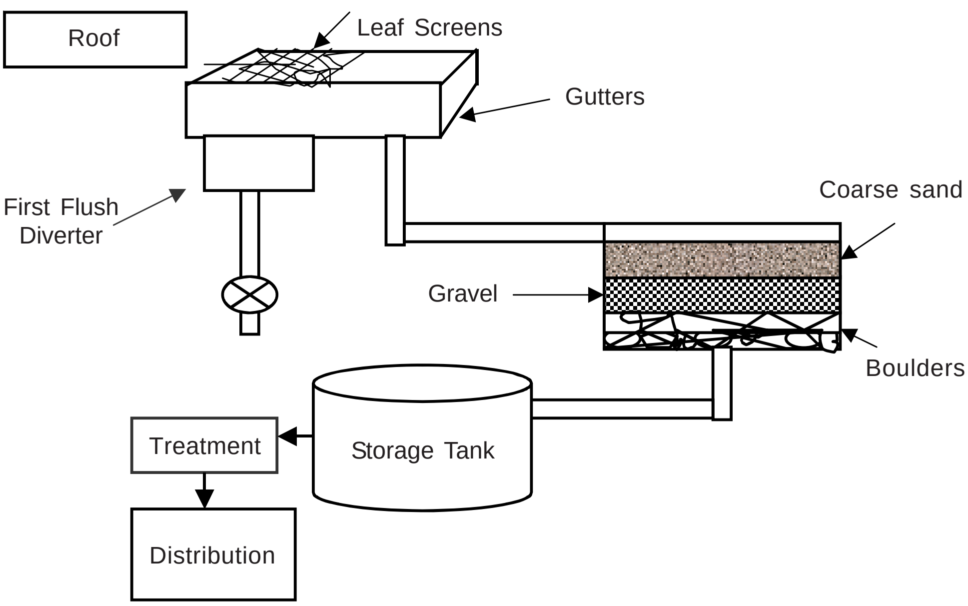

Fig. 20.2 Rainwater Harvesting System

ii. Gutters and Pipes

These are the conduits from the collection surface to storage tank. Size and slope of these will affect collection efficiency of the rainwater harvesting system. We need bigger size to avoid spillage and overflow during most intensive rainfall anticipated. But increasing size will increase the cost of installation, which is will give added advantage only during heavy rains. So we need to optimize the size. During off-season, rodents might make these pipes as their homes. So check gutters and pipes periodically for rodent infestation.

iii. Leaf Screens, First Flush Diverters And Graded Filters

The function of leaf screens is to prevent leaves and other debris from entering the rainwater collection system. Primary leaf screening devices may have a 6mm wire mesh in a metal or plastic frame installed on the top of gutter. The rainwater entering gutter will pass through the screen and leaves and rags etc. will be retained by the screens. If there are trees nearby and leaves pose a problem, a leaf screen may be installed along the entire length of the gutter.

The first part of the rainfall picks up most of the dirt, bird droppings and debris. This initial rainwater needs to be diverted. First flush diverters are the devices used for removal of this dirt and debris (shown in the Figure 20.2). The first flush diversion devices are nothing but a short pipe/ small chamber near the entrance of gutter where rainwater from roof is collected. As the rain fall starts, the initial water carrying dust and debris will fill this pipe or chamber. After that the rest of rain water find its way to graded filter and storage tank. The small chamber/pipe has a valve in the base that allows it to empty before the next rainfall. Typically 40 liters of water for every 100 square meters of roof area is diverted.

Graded filters are structures used for removal fine suspended particles. These are filled with coarse sand, gravel and pebbles sequentially to make a filter bed. The size of particles in each layer and depth of layer will influence the in efficiency of particle removal and head loss or pressure difference across the bed. Higher efficiencies can be achieved by use of small size of particles with increased depth. But this will lead to more head loss in the bed. These filters are prone to clogging. So you need to clean it or have provision for backwashing. In backwashing, pressurized water enters from bottom and leaves through top layer. This operation will remove particle adhered to pebble, gravel and sand.

iv. Storage Tanks

The characteristics of a good storage tank include durability, leak proof, opaque exterior and a clean, smooth interior. The tank should be located near a cool place where less light falls. This will inhibit the growth of algae. If tanks are not opaque and if lot of sunlight is there, the algae growth will be prevalent. We can construct the tank from many materials such as plastic, steel, concrete and fiberglass. Tank should be covered properly to prevent evaporation, mosquito breeding and to keep insects, rodents, birds, and children out of reach. Provide a manhole for tank cleaning and suitable overflow outlet for excess water removal. The elevation of tank can be above ground, below ground, or at the ground level. It could be wall mounted just under the gutter. It is best to locate the tank in a cool place, out of sunlight to inhibit the algae growth.

We need sufficient storage capacity of the tank to store the water. It depends on many factors. The quantity of water needed, the amount and pattern of rainfall and the surface area of catchment area are the criteria used in deciding the size of storage tank.

v. Water Treatment

The treatment operation depends upon the intended uses of rain water. Treatments for non-drinking purposes include simple filters, addition of chemical coagulants for flocculation and sedimentation. Fine filters and microbiological disinfection are only necessary for potable use, i.e. for drinking water. The disinfection can be achieved either by addition of chlorine or exposure of water to ultraviolet (UV) light. Chlorination is more commonly used. The fine filters need regular cleaning and maintenance.

In spite of installation of leaf screens and first flush diverters, dirt, rust, scale, bird and rodent droppings and airborne bacteria may still reach the storage tank. Therefore, even for non drinking purposes, it may be a good idea to have gravity settling of solids and filtration of dispersed solids. Optionally, fine filters may be installed prior to the end use.

Consult with experts before adopting different water treatment methods. Have water tested by an approved laboratory periodically to monitor the water quality.

vi. The Distribution System for the Treated Rainwater

The treated water needs to be conveyed to the point of use. Proper distribution system is needed for this. If the tank is installed at higher elevation than the taps, the water will flow by gravity. Otherwise, we need to install a pump in distribution system. Effective plumbing is important for efficient rainwater collection and distribution.

Check Your Progress 2

1. What are the advantages of rainwater compared to other sources of water?

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2. List the components of a rainwater harvesting system.

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3. Why initial part of rainwater should be diverted?

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4. What is the criterion used for sizing the storage tank?

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5. What treatment operations you need, if you want to use the rainwater for drinking purposes?

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20.7 HOW MUCH WATER CAN WE COLLECT?

The quantity of water we can collect depends on how much rain can we expect to collect in our location and how reliable is this rainfall. One centimeter of rainfall on one square meter of collection area equals to 10 liters. Once we have this rule of thumb, the next crucial parameters are collection efficiency and rainfall reliability.

Collection Efficiency : It is practically not feasible to collect all of the rainwater. Depending on the type of roof, some rain water will be consumed to wet the roof surface. Then we have to divert and drain part of the rainwater initially. Naturally, the initial rainwater carries the dust, bird droppings etc. accumulated on the roof. This diversion of initial rainwater is called roof washing and depends on the type of roof. Usually, this will only be a small percentage of the rainfall. In addition to these, there will be spillage and overflow in gutters especially during intensive rainfall. Also we can't collect the excess rainfall after filling up of the storage tank. The collection efficiencies of different systems generally vary in the range of 50 per cent to 90 percent depending on the design.

Rainfall Reliability: In calculation of quantity of water that can be collected, we need the rainfall. One way is to use the local average rainfall. But averaging rainfall data over years is a crude method. The statistical analysis of previous rainfall data of the area will be required. This analysis will give us the probability of occurrence of rainfall.

Example calculation: Supposing we have 50 square maters of catchment surface and efficiency of rainwater collection system is 60%. If the analysis of rainfall data in our area yields 70 centimeters as most probable average annual rainfall, then rain water that can be harvested is calculated as below:

0.7 m x 50 sq. m. x 0.6 = 21 cubic meters or 21,000 liters. So you will need storage capacity of about 21 cubic meters for an area of 50 square meters.

20.8 MATERIALS OF CONSTRUCTION OF RAIN WATER HARVESTING SYSTEM

Various materials can be used for different components of a rainwater harvesting system. These are given below:

Roof: The Rainwater can be collected from the roof made of clay tiles or cement plastered surface. Metal roofing can also be used. We can paint the roof material to reduce its porosity. Avoid using lead based paint, as it will provide chance for leaching of lead into harvested rainwater. Other roofing materials such as composite asphalt, asbestos and concrete tiles which might leach chemicals that affect the quality of water harvested.

Gutters and connecting pipes: Gutters are generally made up of seamless extruded aluminum. The Galvanized iron or PVC are commonly used for connecting pipes.

Leaf Screens: Leaf screens are wire mesh of suitable thickness with metal or plastic frame.

Graded filter: The structure for filter could be masonry, concrete or plastic. This structure will be filled.

Tank or Storage structure: Masonry, concrete, plastic, steel and fiberglass are the generally recommended materials for storage structure. The material should be inert and durable. Depending on the intended use, like water for gardening, we can use open ponds lined with polythene sheets. Such innovations will greatly reduce the cost.

Water Treatment System: For non potable uses, simple cartridge filters are sufficient. If the rainwater is used for drinking purposes, a tank for chlorination or a zone of UV light for disinfection of water should installed.

Distribution System: The distribution piping is generally made of galvanized iron.

20.9 WATER CONSERVATION IN A DAIRY PLANT

Water has diverse uses in a dairy processing plant. It is used for heating, cooling, washing and cleaning. The consumption of water in these operations generally ranges from three to four liters for processing one liter of milk. However, there are examples where plants has reduced the consumption to one liter water for processing one liter of milk. Water conservation in a dairy processing plant gives dual benefits. It lowers the water and energy bill of the plant. It also helps to reduce the effluent treatment cost as all the water from the plant reaches the effluent treatment facility before its disposal. With growing awareness, there will be pressures on industries to conserve water. This is being thought as environment friendly and it will partly pave way to sustainable development.

For successful implementation of the water conservation measures, the commitment of management is required. Once the management decides to adopt water conservation, it should try to change the mind set of all the people involved. The management should evolve strategies to train and motivate plant personnel to achieve the goals of water conservation. The people involved in it should consider the water as a raw material with a cost and the management should encourage people to innovate.

Every plant should map water usage and decide where water can be moved from one process and used in another process. In some cases, water can be reused without any treatment. In other operations, water might require treatment before it can be used some where else. All water for reuse should be screened to reduce solid buildup. Chlorination is recommended for all reused water, and the residual chlorine level should be increased to 4 mg/l twice a month to make sure that organisms that could harbor in the organic rich environments are killed.

The following water conservation tips can be applied in dairy plant:

- Use automatic shut off devices on water hoses on steam and water mixing systems.
- High pressure jets for cleaning cans, tankers and silos will require less water.
- Install water meters and read them after each shift to identify people who are conserving water.
- Wherever possible, try to reuse water where possible. For example, hot water used for rinsing after cleaning in a cleaning in place (CIP) cycle could be used for prerinsing in next CIP cycle.

- Use level controllers to control the pumps. This will avoid overflow from tanks.
- Frequency of cleaning can be reduced by adopting continuous processes in place of batch processes. Especially in dairy plants producing traditional Indian dairy products, the introduction of continuous machines will lead to greater hygiene and less frequent cleaning.
- Use optical sensors for automatic shut off valves in wash rooms and urinals.
- Avoid spillage of products and raw materials. Clean the spills before washing with water. Don't use water jets to sweep the spilled materials in to drain. This is the usual practice in many diary plants.
- Automation of operations leads to low water consumption. Hence, automate CIP cleaning and other processing operations.

Check Your Progress 3

1. What parameters you need to calculate the amount of water that can be harvested?

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2. List the materials that can be used for storage tank.

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3. What are the benefits of water conservation in a dairy processing plant?

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4. How will you clean up spillage in dairy plant?

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5. What is the effect of automation and continuous mechanization on water consumption of dairy?

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20.10 LET US SUM UP

Understanding of hydrologic cycle and watershed is important to water conservation measures. Hydrologic cycle is perpetual exchange of water between surface water on earth and water vapour in atmosphere in the form of clouds. All the water in a watershed drains into a single water body such as river or pond. In a watershed, all the activities involving water in agriculture, domestic usage and industrial production will ultimately affect the quality of water. One of the ways augmenting freshwater resources is rainwater harvesting. This has six basic components namely, roof/ catchment area, gutters and connecting pipes, leaf screens and first flush diverters and graded filter, storage tank, water treatment system and water distribution system. Correct selection of materials for these components and proper sizing of each component determine the cost and performance of the system. By adopting innovative technologies and change of attitude of people, lot of water can be saved in a dairy plant. With this background, we will not only save water in our home and work place but also can motivate others to adopt water conservation as a way of life.

20.11 KEY WORDS

Aquifer	:	Water bearing soil layer below the ground.
Automation	:	Use of instruments and microprocessors for control of processes.
Continuous Machines	:	Use of machines to operate a process continuously for relatively long periods compared to batch processes.
Cleaning in Place	:	Cleaning of different equipments without dismantling them using a network of pipes, pumps and tanks of cleaning agents integrated into the actual process.
Disinfection	:	Killing of all bacteria and other micro organisms in water.
Hydrologic cycle	:	The continuous exchange of water from the atmosphere to the land and oceans and back again.
Rainwater Harvesting	:	Collecting and using rainfall/precipitation from a catchment surface.
Sustainable	:	Development achieved without over exploitation of natural resources such as water, land, forests, coal, petroleum etc.
Topography	:	Slope of the land and vegetation on the land which will influence the flow of water.
Watershed	:	The land area that drains water to a particular stream, river, or lake. It

20.12 SOME USEFUL BOOKS

Texas Water Development Board in Cooperation with The Center For Maximum Potential Building Systems (1997). Texas Guide To Rainwater Harvesting. Second Edition. Austin, Texas, U.S.A.

20.13 ANSWERS TO CHECK YOUR PROGRESS

Your answer should include the following points:

Check Your Progress 1

1) i. Explain continuous exchange of water between land or water surfaces and clouds.

2) i. By evaporation from land and water surface and by transpiration from plant leaves.

3) i. Industry can adopt measures to reduce water consumption, augment fresh water resources by harvesting rainwater and recycle the treated wastewater.

4) i. Location of the water conservation structures is decided by topography of the watershed.

5) i. For recharging the ground water which can be tapped latter or to store in a tank for the purpose of use in domestic and industrial applications.

Check Your Progress 2

1) i. Explain superior quality rainwater compared to water from groundwater and surface water sources.

2) i. The list should include all six components given in the section.

3) i. Explain the contaminant of initial rainwater which need to be taken away.

4) i. The quantity of water needed, the amount and pattern of rainfall and the surface area of catchment area are the criteria used in deciding the size of storage tank.

5) i. Filtration of fine solids and microbial disinfection .

Check Your Progress 3

1) i. Collection efficiency of rainwater harvesting system and rain fall reliability.

2) i. Contain masonry, concrete, plastic, steel and fiberglass.

3) i. Contain reduction in water bill, energy saving and reduction in wastewater volume.

4) i. First scrape the spills and then wash it with water and commitment not to use water jets to move spilled material into drains.