PIPE FITTINGS AND VALVES

8.1 PIPE, TUBING AND THEIR COMPARISON

Piping systems in chemical plants consist of pipes (various sizes and materials), pipe fittings such as socket, elbow, etc. and valves for transferring materials from one equipment to another equipment within a processing area or for transferring materials from tank farm to processing area and vice versa. So in this chapter, we will discuss pipes, tubes, alongwith their sizes and materials of construction, pipe fittings and valves.

In the chemical industry, fluids are usually transferred from one point to another through pipe or tubing. Pipe or tubing is circular in cross-section and may be made in different diameters and in different wall thickness, from any available material of construction depending upon the service conditions. The materials of construction include iron, steel, brass, copper, glass, plastics, etc.

- Pipe is heavy walled, whereas tubing is thin walled. Metal pipe is available in standard lengths of about 6 m, whereas tubing is available in coils several meters long.
- Tubes from 6 to 50 mm are frequently made from non-ferrous metals, such as brass, copper or aluminium and are widely used in heat exchangers. Pipe is relatively larger in diameter than tubing and are made of cast iron steel, etc.
- Pipe surface is slightly rough, whereas the tube surface is very smooth.
- Pipe sections may be joined by screwing, flanging or welding, whereas tube pieces may often be joined by brazing, soldering or by flared fittings.
- In case of pipes, the schedule number specifies the thickness while in case of tubing, BWG specifies the wall thickness.
- The size of a pipe is specified in terms of nominal pipe size, whereas the size of a tube is specified by its outside diameter.

8.2.1 Safe Working

- It is a practice of performing a task with minimum risk to people, equipments, materials, environment and processes.

8.2.2 Pressure and Allowable Stress

- Pressure is defined as the force per unit area (F/A). That is, the force applied/acting perpendicular to the surface of an object per unit area over which the force is distributed. SI units : N/m^2, Pascal (Pa).
- **Maximum Allowable Working Pressure (MAWP) :** It is the maximum or highest pressure at which the vessel or equipment may be operated at its design pressure.
- **Operating pressure (Working pressure) :** It is the pressure at which the equipment operates during its life.
- **Design pressure :** It is the pressure in excess of the operating pressure for the sake of safety.
  Design pressure is 10 to 25% more than the operating pressure.
  $$\text{Design pressure} = 1.1 \text{ to } 1.25 \text{ (operating pressure)}$$
- **Allowable stress :** It is the maximum stress (tensile, compressive or bending) which is allowed to be applied on an object. OR It is the maximum stress that an object is expected to support. The allowable stress is calculated using the following relation :
  $$\text{Allowable stress} = \frac{\text{Yield strength}}{\text{Factor of safety}}$$

For example, for A36 steel, yield strength is 36000 psi and factor of safety is 4. With this, the allowable stress of A36 steel is (= 36000/4) 9000 psi.

[Yield strength or stress : It is the stress at which an object will be permanently damaged.]

8.2.3 Standard Sizes of Pipes

Nominal Pipe Size (NPS) :

Nominal pipe size is a North American set of standards used to designate diameter and thickness of a pipe.. Pipe size is specified in terms of a nominal pipe size for diameter based on inches and a schedule/schedule number for wall thickness. The term NB (nominal bore) is frequently used interchangeably with NPS. Based on the NPS and schedule of a pipe, the outside diameter and wall thickness of the pipe can be obtained from reference tables. The nominal pipe size of steel pipe ranges from 1/8 to 30 inches. For NPS 1/8 to 12 inches, the NPS and OD values are different (the nominal pipe size is slightly less than the outside diameter). For example, the OD of an NPS 12 pipe is actually 12.75 inches. For NPS 14 inches and larger, the NPS and OD values are equal (the nominal pipe size is the outside diameter). For example, the OD of an NPS 14 pipe is 14 inches. For a given NPS, the OD remains fixed and the wall thickness increases with schedule/schedule number. For a given schedule number, the OD increases with NPS whose wall thickness remains constant or increases. Pipes of other materials are also made with the same outside diameter as steel pipes for the same NPS.

8.2.4 Schedule Number / Pipe Schedule Number

Pipe schedule is the term used to indicate the thickness of a pipe. Schedule number is a dimensionless number that specifies the thickness of a pipe. The Schedule number is given by the expression

$$\text{Schedule number} = 1000\left(\frac{P}{S}\right)$$

where P is the internal working pressure in the pipe in psig and S is the allowable stress (ultimate tensile strength) for the pipe material at the conditions of use in psi.

The higher the schedule number is, the thicker the pipe is (in other words, the schedule number increases with the thickness of the pipe). Normally for pipes, the outer diameter is fixed for each nominal pipe size. Thus a particular nominal pipe size will have different inside pipe diameter (i.e., different wall thickness) depending on the schedule number specified.

There are eleven schedule numbers that are commonly used : 5, 20, 30, 40, 60, 80, 100, 120, 140 and 160. The most commonly used schedule numbers today are 40, 80 and 160. The most popular schedule number is 40.

8.2.5 Birmingham Wire Gauge [BWG]

Birmingham Wire Gauge (BWG) is a dimensionless number that specifies the thickness of a tube. BWG number increases with increase in thickness of the tube.

The tube wall thickness specified by the BWG number which range from 24 (very light) to 7 (very heavy).

8.2.6 Materials of Construction for Pipes and Tubes

Different materials that are used for construction of pipes and tubes include ferrous materials, non-ferrous materials, plastics, glass and lined metal.

Ferrous materials account for a large part of all the piping in process industries. In this category we have carbon steel, iron and stainless steel. Carbon steel pipe is strong, ductile and cheaper than the pipe made from other materials. Carbon steel pipe is natural choice, if it meets the requirements of pressure, temperature, corrosion resistance and hygiene. Iron pipe is made from cast iron and ductile iron and are used for underground water, gas and sewage lines. Galvanised iron pipes (GI pipes) are used for conveying raw water and distribution of treated water. Various stainless steels (SS-304, SS-316, etc.) are used for pipes and tubes because of their particular corrosion resistance to process chemicals.

Non-ferrous pipes and tubes are made from copper and copper alloys-brass, bronze and cupronickel, nickel and nickel alloys – monel and inconel, lead and aluminium. These materials (including stainless steels) are relatively expensive but are selected for pipes and tubes because of their particular resistance to process chemicals, good heat transfer and tensile strength at higher temperatures.

Non-metallic pipes and tubes are made of materials such as plastics, glass, rubber and ceramics. Plastic pipes are used for transporting corrosive fluids and especially useful for handling corrosive or hazardous gases and dilute mineral acids. They are used as all plastic pipe, as filled plastic materials (glass-fibre reinforced) and as lining or coating materials. Commonly used plastics are polypropylene, rigid polyvinyl chloride, acrylonitrile butadiene styrene and polyvinylidene chloride (Saran).

Lining carbon steel pipe with a material able to withstand chemical attack permits its use to carry corrosive fluids. Lining materials include rubber, plastics, glass and metals and thus we have rubber lined pipe, lead lined pipe, etc.

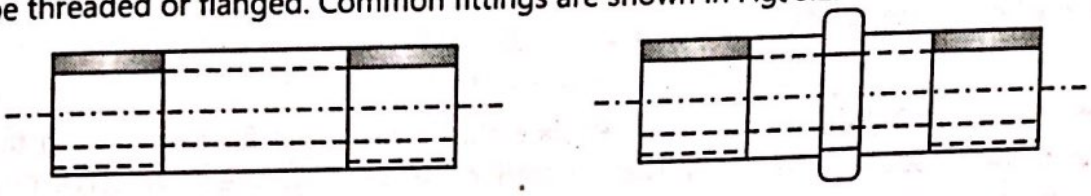
8.3 VARIOUS TYPES OF FITTINGS AND APPLICATIONS

Fittings :

Fittings refer to the pieces that can be employed in pipelines for one of the following purposes :

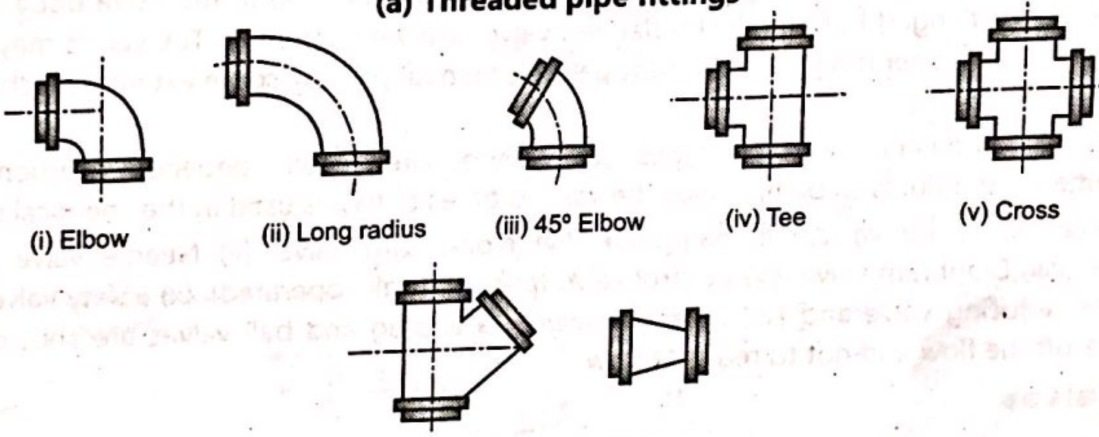
(a) Joining two pipe pieces., e.g., coupling/socket, union, nipple, hex nipple and barrel nipple.
(b) Changing the pipeline diameter, e.g., reducer.
(c) Termination of the pipeline, e.g., plug.
(d) Changing the direction of flow, e.g., elbow, bend.
(e) Branching of the pipeline, e.g., tee, cross.
(f) Controlling the flow through a pipeline, e.g., valves.

Fittings may be threaded or flanged. Common fittings are shown in Fig. 8.1.



(i) Barrel nipple (ii) Hex nipple

(a) Threaded pipe fittings



(i) Elbow (ii) Long radius (iii) 45° Elbow (iv) Tee (v) Cross

(vi) 45° Lateral (vii) Reducer

(b) Flange pipe fitting (two lines that are very close to each other indicate threading)

Fig. 8.1

For using screwed fittings, the ends of the pipe are threaded externally with a threading tool. Polytetrafluoroethylene tape is wrapped around the threaded end to ensure a good seal before making a threaded joint. Screwed fittings are used with pipe smaller than 3 in. Lengths of pipe larger than 2 in are usually connected by flanges or by welding. Flanges are metallic circular discs bolted together and compressing a gasket interposed between their faces. The flanges are attached to the pipe by screwing or by welding or brazing. Fittings are available in the same materials as piping.

BEND :

Bends are used to change the direction of fluid flow. They are having external threads. The frictional losses in bends are small compared to those in elbows due to smooth change in the direction of flow.

ELBOW

Elbows are used to change the direction of fluid flow. There is sudden change in the direction of flow and therefore, pressure drop is more in elbows than in bends.

TEE

Pipes are branched off at right angles by means of fittings such as tees. Tees are having internal threads.

NIPPLE

It is a small piece of pipe with external threads throughout (i.e., threaded on the outside). It is screwed into the internally threaded ends of the pipes to be connected. It is used to join two pieces of pipe. In case of bare nipple there are threads only at the ends of small pipe piece (a bare nipple is a piece of pipe of length 75 mm, 100 mm, 150 mm, etc. having threads at the ends).

SOCKET

A socket also called as a coupler is used to join two pieces of pipe with their axes in alignment. It is a small piece of pipe with internal threads throughout. The socket is screwed on half way on the threaded end of one pipe and then the end of the other pipe is screwed into the socket in the remaining half.

REDUCING SOCKET (REDUCER)

To change the size of the pipe in a straight run (i.e., for changing the diameter of the pipe line), a reducer is used. Reducers are having internal threads.

PLUG

These are used to close a pipe line at the end (for the termination of a pipe line). These are having external threads and provided with square heads.

8.4 VALVES

A valve is a mechanical device used either to regulate the flow/control flow or to stop the flow of a fluid through a pipe line or in or out of a vessel. Valves, in addition to regulate the flow, serve to isolate piping or equipment for maintenance without interrupting other connected equipments. Valves in common have a flow regulating element called a plug (valve plug) and it rests on a seat (valve seat) in the valve body. The ends of the valves may be threaded or flanged but in industry flanged valves are very common. The valves may be operated by the pressure of the fluid (self operating) or by hand (operated manually) or by some external mechanism (operated by means of air pressure).

In the chemical industry, various types of valves are used depending upon the process conditions/requirements and fluids to be handled. The various types of valves used in the chemical industry are:

(i) Gave valve, (ii) Globe valve, (iii) Ball valve, (iv) Non-return valve, (v) Needle valve, (vi) Plug valve, (vii) Butterfly valve, (viii) Diaphram valve, (ix) Control valve (pneumatically operated), (x) Safety valve (pressure relief valve), (xi) Pressure reducing valve and (xii) Solenoid valve. Gate, plug and ball valves are shut-off valves whose purpose is to close-off the flow and not to regulate flow.

8.4.1 Gate Valves

Gate valves are used for minimising the pressure drop in open position. These valves are used primarily for on-off applications. Gate valves are suited for high pressure and high temperature use with wide variety of fluids. They are not suited for slurries and viscous fluids.

A gate valve is a valve that provides a straight through passage for the flow of a fluid. A gate is moved up and down within a body by a stem whose axis is at right angles to that of the body ends. In gate valves, the diameter of the opening through which the fluid passes is nearly the same as that of the pipe. In these valves, the direction of flow does not change and as a result the pressure drop through them is very low in fully open condition. Therefore, gate valves are used to minimise pressure drop in the open position and to stop the flow instead of to regulate the flow of fluid.

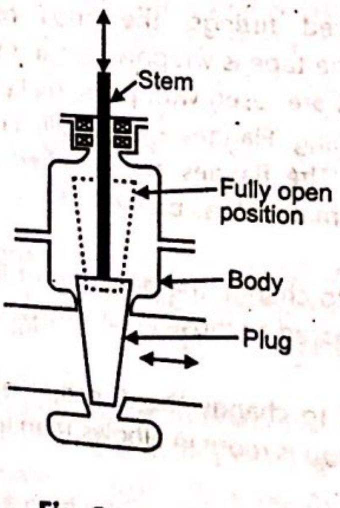


Fig. 8.2 : Gate valve

8.4.2 Globe Valves

A globe valve is used to control/regulate the flow of fluid. It is the most commonly used valve for efficient regulation of a critical service. Used extensively for automatic process control and for high temperature applications. These valves are not normally used for on-off service.

A globe valve is a valve having generally a spherical body in which the axis of a stem is at right angles to that of the body ends. Pressure drop through globe valves is much greater than that for gate valves due to change in the direction of fluid flow.

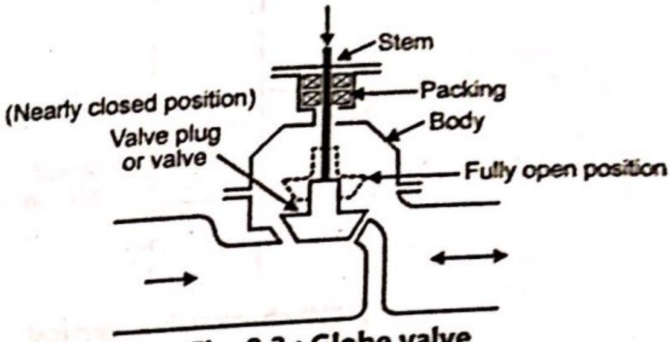


Fig. 8.3 : Globe valve

8.4.3 Ball Valves

It is used for flow control and on-off service. Widely used in industry where conditions of corrosion plus temperature/pressure exist. These valves are simple, compact and quick opening and they are operated through 90°. They are good for conditions which require to be fire safe. They are constructed in a very wide size and temperature – pressure ranges. These valves are used for corrosive liquids, cryogenic liquids and gases.

It is a valve in which a spherical closure element (ball) having a port through it (passage) is turned substantially through 90° from close to open position.

Easy to maintain, tight shut-off, quarter turn operation, quick operating and low pressure drop.

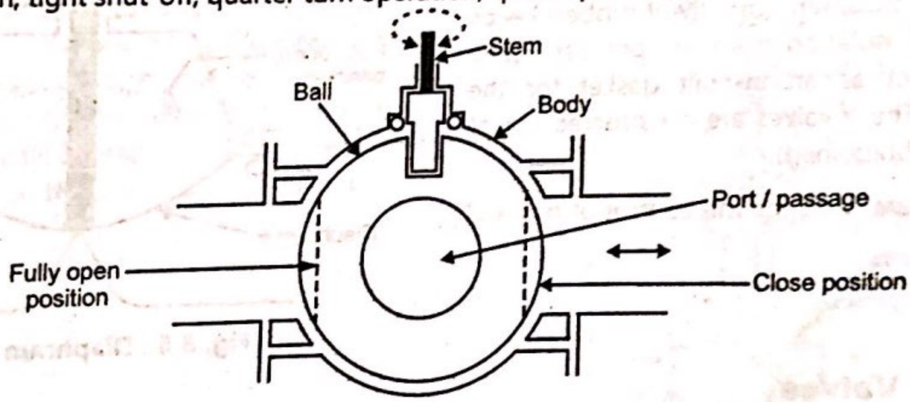
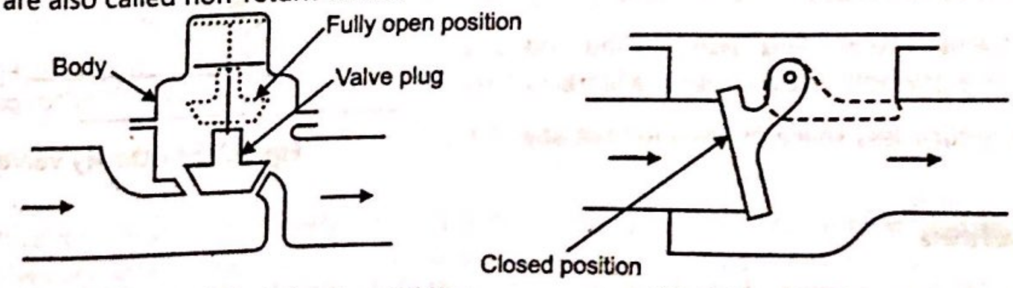


Fig. 8.4 : Ball valve (free ball)

8.4.4 Check Valves

These valves are used when unidirectional flow is desired. Automatically prevents reversal of flow/automatically prevents the flow of the fluid in the reverse direction (i.e., backflow) in lines. Available in wide sizes and temperature/pressure ranges. It can be mounted in a horizontal or vertical line.

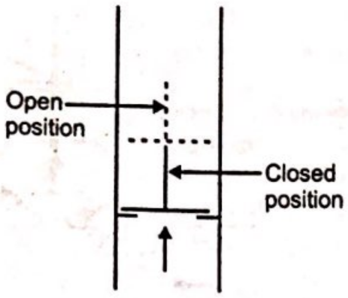
It is a valve that prevents reversal of flow by means of a check mechanism, the valve being opened by the pressure of the flowing fluid and closed by weight of the check mechanism when the flow ceases or by back pressure. These are also called non-return valves.



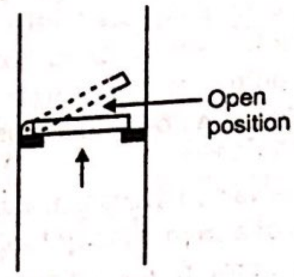
(a) Lift check valve (globe), horizontal line (b) Swing check valve

Fig. 8.5 : Check valves

Vertical lift check valves are used in vertical lines where the flow is normally upward. Globe check valves are used in horizontal lines.



(c) Lift check valve, vertical



(d) Swing type (foot valve)

Fig. 8.5 : Check valves (simple)

8.4.5 Diaphram Valves

It is a glandless type of valve used for corrosive, volatile and toxic fluids particularly where leakage must be avoided. They are also suited for handling slurries. They are used for regulating the flow and also for on-off service. These valves may be installed in any position.

A diaphram valve is a valve that contains a flexible rubber (natural or synthetic) diaphram as a plug.

In this valve, the diaphram (usually of rubber) keeps the working parts in isolation from the process liquid. The lined bodies act as an in-built gasket for the connecting flanges. These valves are constructed out of plastics or metals (rubber lined).

Butterfly valves are used for the control of gas and vapour flows.

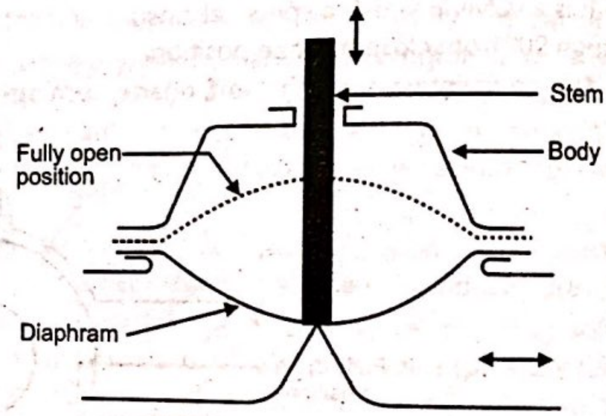


Fig. 8.6 : Diaphram valve

8.4.6 Butterfly Valves

These valves are specially suited for large flow of gases, liquids, and slurries at low pressures. Suited for throttling as well as on-off services and offer low pressure drop. It is extremely simple in construction, quick opening, low weight and low priced.

It has a disk-shaped closure element that rotates about a central shaft (stem).

It is a valve in which the disk is turned substantially through 90° from close to open position, on an axis right angles to that of the valve ports.

A butterfly valve is used in a large size pipeline and operates on the same principle as a damper in a store.

These valves occupy less space in the line than any other valves.

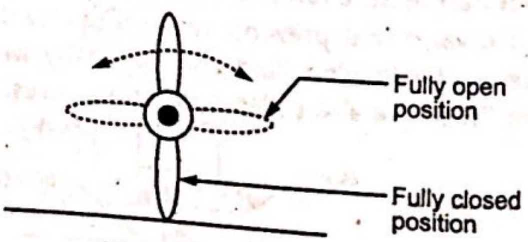


Fig. 8.7 : Butterfly valve

8.4.7 Plug Valves

Straight-through flow, positive shut-off, quarter turn operation-open to close, used for multiport operation (i.e., 2, 3, and 4 way), hence simplifying piping system. Used for general on-off service.

It is a form of shut-off device comprising a body with a parallel or taper cylindrical seating into which a plug is fitted which may be turned to move its port(s) relative to the body seat ports to control the flow of fluid. As it is operated through 90° with the help of a handle, it is easily opened and closed. Used for water lines (cooling tower water, chilled water).

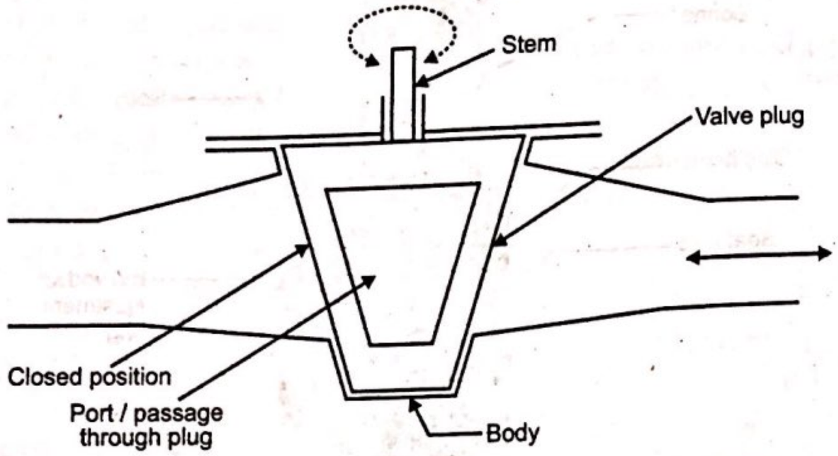


Fig. 8.8 : Plug valve

8.4.8 Control Valves

In automatic process control systems, the most commonly used final control element is a diaphram motor valve. It consists of a pneumatic diaphram motor actuator and a process fluid control valve. The actuator positions the valve plug in the orifice in response to a signal from the automatic controller. The valve operated pneumatically may be air to open or air to close type.

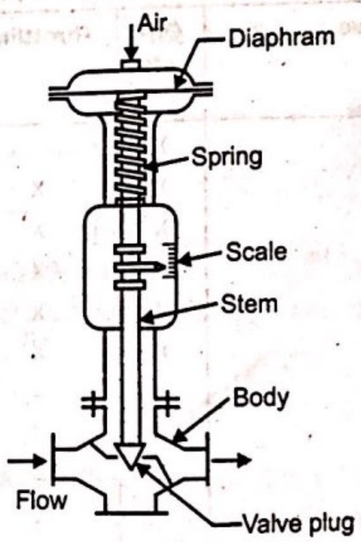


Fig. 8.9 : Control valve

8.4.9 Safety Valve

Chemical plants, boilers, pressure vessels or other system working under pressure may get damaged or destroyed if pressure rises are not controlled.

A safety valve is a valve mechanism which automatically releases a substance (compressible fluid – gas or vapour) from a boiler, pressure vessels or other system, when the pressure exceeds preset limits.

A safety valve is designed to open and relieve excess pressure (or venting fluid – gas or vapour) from vessels or equipments and to reclose and prevent the further release of fluid after normal conditions are restored.

It is a safety device and operates for the purpose of overpressure protection – for protection against excessive pressure only.

It is a mechanical device, mounted vertically on pressure vessels, it closes again when overpressure/excessive pressure ceases, gives protection from overpressure and requires periodic check of calibration.

Two main types of safety valves are : spring loaded safety valves and pilot operated safety valves.

LIQUID PUMPING DEVICES [Transportation of Liquids]

9.1 PUMPING OF FLUIDS : IMPORTANCE OF PUMPS

- In the chemical process industries for the transportation of fluids from one process equipment to another, or through long pipes or ducts, we have to use some form of a mechanical pumping device. Such a mechanical device may be a *pump, fan, blower or compressor, which increases the fluid energy*. For the transportation (handling) of liquids, pumps are used, whereas for the transportation of gases, fans, blowers or compressors are used.
- The power required by a pump, depends on the height through which the liquid is raised, flow rate, length and diameter of the pipe and the density and viscosity of the liquid.
- Pumps are used to keep materials (liquids) moving through the production processes. Pumps are of different types and sizes. Almost all industries need pumps.
- The pumping of crude oil over a long distance, feeding water to a boiler, transfer of raw materials say for example, sulphuric acid, benzene, etc. from a bulk storage to a processing area, industrial cleaning, vehicle washing, spray drying, building services (agriculture), arigation, reverse osmosis, power generation, water supply (gardening), waste water treatment, sewage treatment, transfer of petrol from its underground storage tank to the fuel tank of a car are some examples of use of pumps.
- Pumps are used in almost all industries. The use varies from industry to industry but the common thing is to raise a liquid to a higher pressure. Pumps are used in industries such as chemical, petrochemical, pharmaceutical, food processing, dairy, alcohol, pulp and paper, refineries, oil and gas, etc.
- The liquid to be pumped may have clear or may contain suspended particles. It may be corrosive or non-corrosive and may have a low or high viscosity.

9.2.1 Classification of Pumps

A pump is a machine which converts mechanical energy supplied to it from some external source into pressure energy which is used to lift a liquid from a lower level to a higher level.

A pump is a machine used for moving liquids, solution or slurries by mechanical means.

Pumps are classified as :

(i) Dynamic pumps/kinetic pumps. (ii) Displacement pumps/positive displacement pumps.

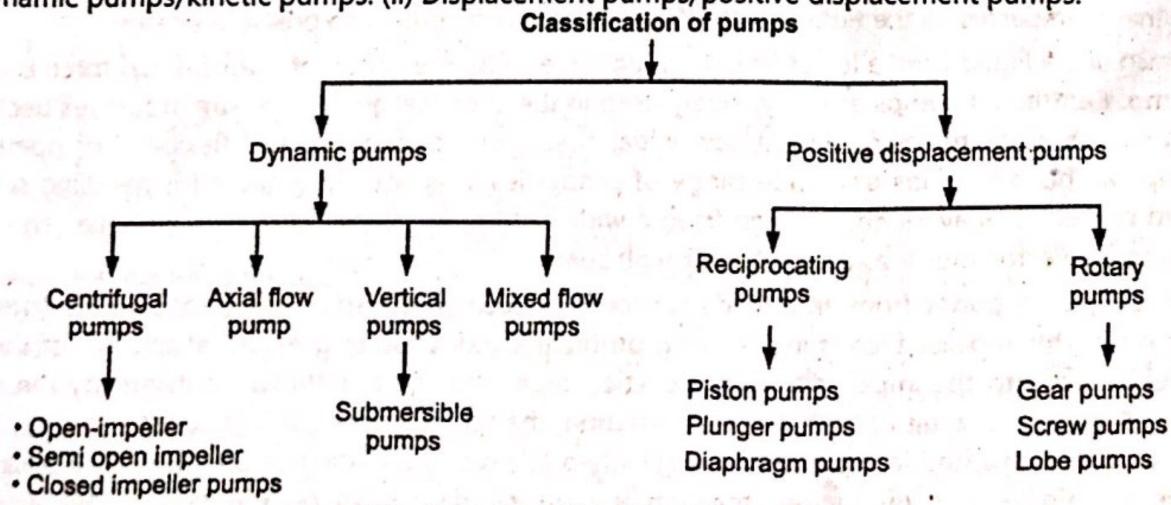


Fig. 9.1 : Classification of pumps

In centrifugal pumps, the kinetic energy of the liquid to be pumped is increased by the action of centrifugal force and is then converted into pressure energy that is needed to pump the liquid.

In positive displacement pumps, a definite or fixed quantity of liquid is pumped in every revolution.

A positive displacement pump is that pump which delivers/discharges a definite/fixed quantity of liquid during the displacement of its piston/plunger/gear/lobe (i.e., during each stroke or each revolution).

Since a fixed quantity of liquid is pumped after each revolution they can develop a very high pressure if the delivery valve or line is closed.

Positive displacement pumps are classified as :

1. Reciprocating pumps, e.g., piston pump, plunger pump, etc.
2. Rotary pumps, e.g., gear pump and mono pump.

In reciprocating pumps, the displacement is by reciprocation of a piston or plunger, while in rotary pumps, the displacement is by rotary action of a gear or vane.

9.2.2 Factors which Influence the Choice of Pump for a Particular Operation

While selecting a pump for a particular duty we have to consider the following factors :

(i) The quantity of liquid to be handled.
(ii) The head against which the liquid to be pumped/raised.
(iii) The nature of liquid to be handled (viscosity, clear liquids, suspensions, corrosiveness).
(iv) The nature of power supply.
(v) The method of operation – continuous or intermittent.
(vi) The flow rate required.
(vii) The pressure on delivery.
(viii) Cost and mechanical efficiency.

9.2.3 Pumps Measurement of Performance

(i) Capacity : It is the rate at which the fluid is pumped by a fluid moving device. It is expressed in various units – based on the type of pumping device. For liquids, it is expressed in litres per minute or gallons per minute and for gases, it is expressed in cubic feet per minute at inlet conditions of gases to the machine.

(ii) Overall efficiency : It is the *ratio of the useful hydraulic work performed to the actual work input, irrespective of the type of drive.*

9.3.1 Centrifugal Pumps

9.3.1.1 Principle

The kinetic energy imparted to the fluid by centrifugal force is converted into pressure energy.

A pump which lifts a liquid from a lower level to a higher level by the action of a centrifugal force is called as a **centrifugal pump**. Centrifugal pumps are very widely used in the chemical and petroleum industries because of its many advantages such as simplicity of design, low initial cost, low maintenance and flexibility of operation. The centrifugal pump can handle liquids of a wide range of properties. It is equally suitable for handling suspensions with a high solid content. It may be constructed from a wide range of corrosion resistant materials and it may be directly coupled to an electric motor as it operates at high speeds.

In a centrifugal pump, power from an outside source is applied to the shaft, the impeller then rotates within the stationary casing. The impeller blades in revolving produce a reduction in pressure at the eye of the impeller. Due to this, liquid flows into the impeller from the suction pipe. The liquid is thrown outward by the centrifugal action along the blades. As a result of high speed of rotation, the liquid acquires a high kinetic energy. The kinetic energy acquired is then converted into pressure energy when it leaves the blade tips and the liquid passes into the volute chamber and finally it is discharged through the outlet (discharge) on the pump. This action of the centrifugal pump is shown in Fig. 9.2.

9.3.1.2 Construction or Component Parts of a Centrifugal Pump

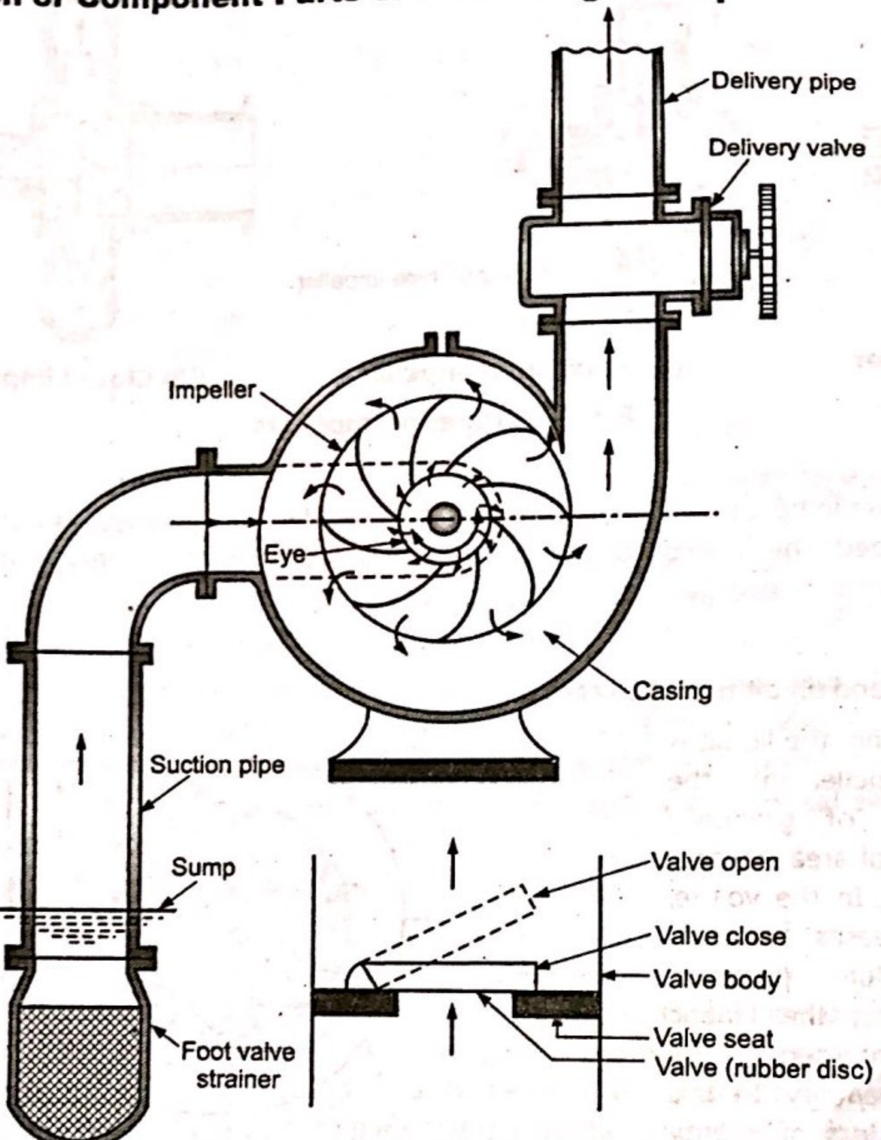


Fig. 9.2 : Component parts of a centrifugal pump

Impeller

It is a wheel or rotor that is provided with a series of curved blades or vanes. It is mounted on a shaft which is coupled to an electric motor (an external source of energy). The blades/vanes are shaped in such a way that the flow within the pump is as smooth as possible. The impeller is the heart of the centrifugal pump.

Impeller types :

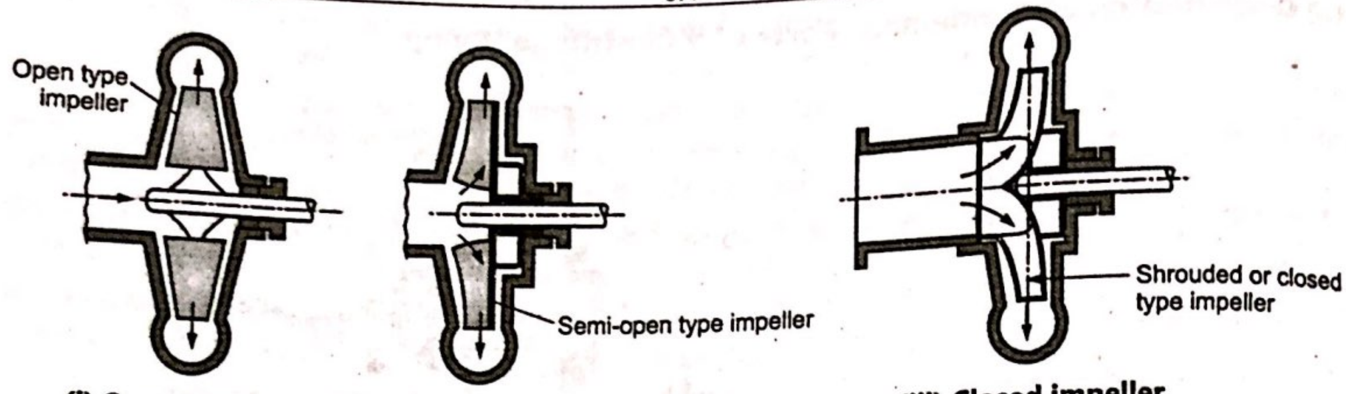
(i) Open impeller, (ii) Semi-open impeller, and (iii) Closed or shrouded impeller.

The open impeller has the blades fixed to a central hub. Such impellers are suited for pumping liquids containing suspended solids, e.g., paper pulp, sewage, etc.

The closed impeller has the blades held between two supporting plates / shrouds (crown plate and base plate). This impeller provides better guidance for the liquid and is more efficient. This type of impeller is suited for pumping clear liquids (liquids containing no suspended particles, dirts, etc.).

The semi-open impeller has only one plate (base plate) and no crown plate (i.e., it has a plate on one side of the blades/vanes). Such impellers are suitable for liquids containing some solid particles or dirts.

For viscous liquids or liquids containing solids, open or semi-open type impellers are used. The most efficient impeller is the closed or shrouded type. The impeller may be a single suction type or double suction type. In the former type, the liquid enters the impeller from one side; while in the latter type, the liquid enters from both the sides.



(i) Open impeller **(ii) Semi-open impeller** **(iii) Closed impeller**

Fig. 9.3 : Types of impellers

Casing

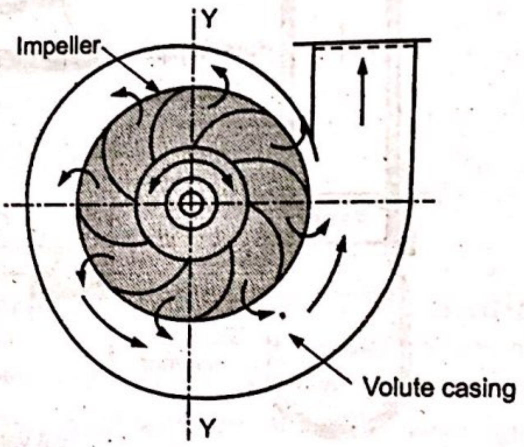
It is an airtight chamber in which the impeller rotates. It is provided with an inlet (suction) and outlet (discharge) for the liquid to be pumped. The function of the casing is to convert the kinetic energy imparted to the liquid by the impeller into useful pressure energy.

Types of casing :

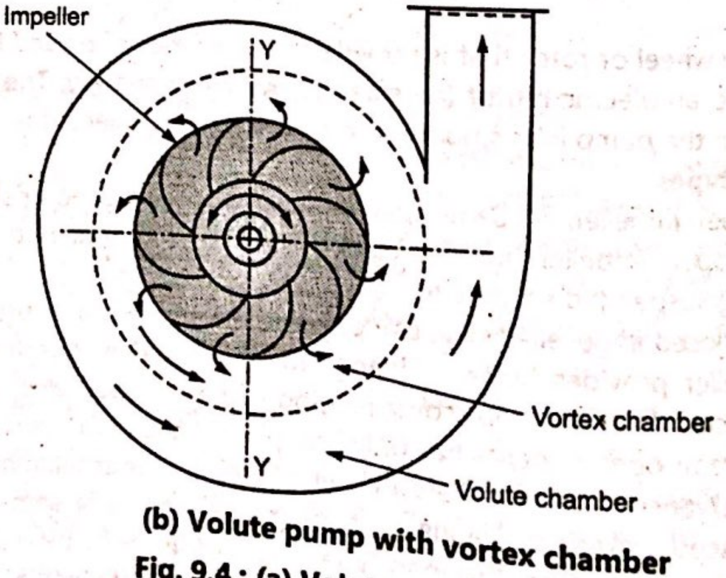
(i) volute type casing and (ii) diffuser type casing.

In a volute type casing, the liquid is discharged by the impeller into the volute - a chamber of gradually increasing cross-sectional area towards the outlet [Fig. 9.4 (a)]. In the volute, the fluid velocity decreases gradually thereby increasing fluid pressure, i.e., the volute converts the kinetic energy of the liquid imparted by the impeller into pressure energy. In this design, a considerable loss of energy takes place due to formation of eddies.

A vortex chamber is an improved version of the volute design. In this case, a circular chamber is provided between the impeller and the volute chamber [Fig. 9.4 (b)]. This design reduces eddies to a considerable extent with increase in efficiency.



(a) Volute pump



(b) Volute pump with vortex chamber

Fig. 9.4 : (a) Volute type casing

(b) Vortex type casing

In a diffuser type casing (turbine pump), guide vanes or diffusers are interposed between the chamber and the impeller. The impeller is surrounded by a series of guide vanes mounted on a ring called diffuser ring as shown in Fig. 9.5. The conversion of kinetic energy into pressure energy is more efficient with this type compared to the volute type. There is a gradual change in the direction of fluid so that the losses are kept minimum.

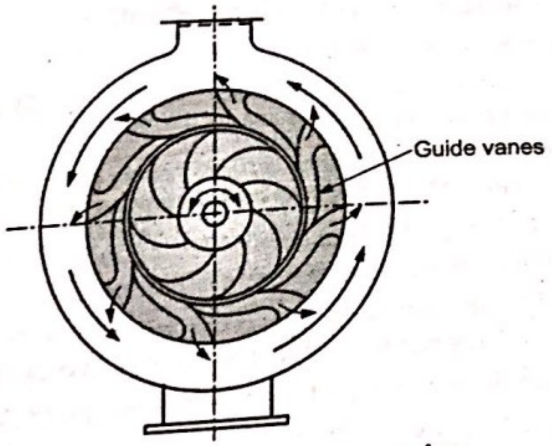


Fig. 9.5 : Diffuser type casing

Other component parts of the centrifugal pump are : shaft, bearing, stuffing box, or mechanical seal, etc. Shaft must be of a corrosion resistant material and must have good mechanical properties. The shaft transmits power from the drive unit to the impeller. Sometimes, a shaft sleeve of corrosion resistant material is provided over the corrosive shaft material from strength criteria.

Shaft is mounted on bearings which handle shaft load without excessive wear. Stuffing box is a means of reducing/avoiding leakage which would otherwise occur at the point of entry of the shaft into the casing. With this the maintenance costs are high. A considerable reduction in expenditure on maintenance can be effected at the price of a small increase in the initial cost by fitting the pump with a mechanical seal. For high pressures and corrosive fluids, mechanical seals are used.

9.3.1.3 Working of a Centrifugal Pump

In the operation of a centrifugal pump before the pump is started, priming of the pump is done. In the priming operation, the suction pipe, pump casing, and portion of the delivery pipe upto a delivery valve are completely filled with the liquid to be pumped so that all the air, gas or vapour from this portion of the pump is expelled out and no air pocket is left. In presence of even very small air pocket in any of these portions, pump will not discharge the liquid. The need to do priming of pump is due to the fact that the pressure generated by a centrifugal pump impeller is directly proportional to the density of fluid that is in contact with it. Therefore, if the impeller is rotated in the presence of air, only negligible pressure would be produced and thus no liquid will be lifted by the pump.

After the pump is primed properly, the delivery valve is kept close and power from an outside source (electric motor) is applied to the shaft. The delivery valve is kept close in order to reduce the starting torque for the motor. The impeller then rotates within the stationary casing. The rotation of the impeller produces a forced vortex which imparts a centrifugal head to the liquid and thus results in an increase of pressure throughout the liquid mass. As long as the delivery valve is closed and impeller is rotated, there will be just churning of the liquid within the casing. When the delivery valve is opened, the liquid is made to flow in an outward radial direction thereby leaving the vanes of the impeller at the outer circumference with high velocity and pressure. Due to centrifugal action, a partial vacuum is created at the eye of the impeller. This causes the liquid from the sump/reservoir (at atmospheric pressure) to flow through the suction pipe to the eye of the impeller thereby replacing the liquid which is being discharged from the entire circumference of the impeller. The high pressure of the liquid leaving the impeller is utilised in lifting the liquid to the required height through the delivery pipe.

During the operation, liquid receives energy from the vanes which results in an increase in both pressure and velocity energy. As such the liquid leaves the impeller with a high absolute velocity. In order that the kinetic energy corresponding to the high velocity of liquid leaving is not wasted in eddies and efficiency of the pump thereby lowered, it is essential that the high velocity of the leaving liquid is gradually reduced to the lower velocity in the delivery pipe, so that a large portion of the kinetic energy is converted into useful pressure energy. This is usually achieved by shaping the casing such that the leaving liquid flows through a passage of gradually expanded area. The gradual increase in the flow area of the casing also helps in maintaining uniform flow velocity throughout.

9.3.1.4 Advantages of Centrifugal Pumps

1. It is simple in construction.
2. Due to its simplicity of construction, it can be made in a wide range of materials.
3. Low initial cost and simplicity of design.
4. It operates at high speed and hence, can be coupled directly to an electric motor. In general, higher the speed, smaller the pump and motor required for a given duty.
5. It gives a steady delivery / discharge.
6. Lower maintenance (compared to other pumps) costs.
7. It does not get damaged even if the delivery line becomes blocked, or the delivery valve is closed, provided the pump does not run in this condition for a prolonged period.
8. It can handle readily liquids containing high proportions of suspended solids.
9. For equal capacity, the centrifugal pump is much smaller than any other type of pump. Therefore, it can be made into a sealed unit with the driving motor and immersed in the suction tank.

9.3.1.5 Disadvantages of Centrifugal Pumps

1. It is not usually self-priming.
2. It operates at low efficiencies (50 - 65%).
3. It cannot handle very viscous liquids efficiently.
4. It does not develop a high pressure. Multistage pumps will develop greater pressure heads but they are much more expensive and cannot be made into corrosion resistant materials because of their greater complex construction.
5. If a non-return valve is not provided in the delivery or suction line, the liquid will run back into the suction tank (reservoir) as soon as the pump stops.

9.3.1.6 Applications of Centrifugal Pumps

These pumps are used in water supply (domestic and industrial), waste water treatment, sewage treatment, irrigation (agriculture), building services (water in buildings), fire protection systems, power plants, fisheries and in industries such as chemical, petrochemical, pharmaceutical, dairy, food processing, oil refineries, etc.

9.3.2 Positive Displacement Pumps

Positive displacements are classified as :

1. Reciprocating pumps, e.g., piston pump, plunger pump and diaphragm pump.
2. Rotary pumps, e.g., gear pump, lobe pump and mono/screw pump.

A positive displacement pump is a pump which provides (discharges) a fixed flow rate irrespective of pressure changes within the system.

Principle of positive displacement pumps :

A positive displacement pump makes a liquid to move by trapping a fixed amount of the liquid and forcing (displacing) that trapped volume into the discharged pipe.

9.3.2.1 Reciprocating Pumps

Construction / Components of a Reciprocating Pump :

A reciprocating pump essentially consists of a piston or plunger which moves to and fro i.e., reciprocates back and forth in a close fitting stationary cylinder. Fig. 9.6 shows a reciprocating pump.

The cylinder is connected to suction and delivery pipes. Each of these pipes are provided with a non-return valve called suction valve and delivery valve respectively. A non-return valve permits unidirectional flow. Thus, the suction valve allows the liquids only to enter the cylinder and the delivery valve allows only its discharge from the cylinder. A piston or plunger is connected to a crank by means of a connecting rod. The crank is rotated by a driving engine or electric motor. When the crank is rotated by the drive, the piston or plunger moves to and fro

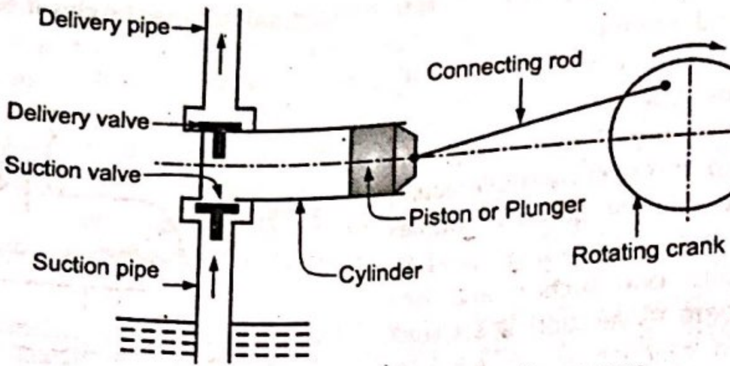


Fig. 9.6 : Single acting reciprocating pump

Working of a Reciprocating Pump :

Assume that the piston or plunger is initially at its extremely left position (i.e., completely inside the cylinder). If the crank rotates through 180°, then the piston or plunger moves to its extreme right position (i.e., moves outwardly from the cylinder). During the outward movement of the piston or plunger, a partial vacuum is created in the cylinder, which enables the atmospheric pressure acting on the liquid surface in the sump below to force the liquid up the suction pipe and fill the cylinder by forcingly opening the *suction valve*. As during this operation of the pump, the liquid is sucked from the sump, it is known as a suction stroke. Hence, at the end of the suction stroke, the piston or plunger is at its extreme right position, crank is at θ = 180°, the cylinder is full of liquid, the suction valve is closed and the delivery valve is just at the point of opening.

When the crank rotates through further 180° (i.e., θ = 180° to 360°), the piston or plunger moves inwardly from its extreme right position towards left. The inward movement of the piston or plunger causes the pressure of the liquid in the cylinder to rise above atmospheric temperature, because of which the suction valve closes and delivery valve opens. The liquid is then forced up the delivery pipe and raised to the required height. As during this operation of the pump, the liquid is actually delivered to the required height, it is known as a *delivery stroke*. At the end of the delivery stroke, the piston or plunger is at the extreme position, crank has one complete revolution, and both the delivery and suction valves are closed. The same cycle is repeated as the crank rotates.

Types of Reciprocating Pumps

Based on the reciprocating member (pressure component) piston, plunger or diaphragm, there are three types of reciprocating pumps :

1. Piston pumps
2. Plunger pumps
3. Diaphragm pumps

According to the liquid being in contact with one side or both the sides of a piston or plunger, the reciprocating pumps may be classified as :

(i) Single acting pump and

(ii) Double acting pump.

(i) Single acting pump

It is the one in which the liquid is in contact with only one side of a piston or plunger (infront of piston or plunger). This pump has one suction pipe and one delivery pipe and in one complete revolution of the crank, there are two strokes - one suction stroke and one delivery stroke.

(ii) Double acting pump

It is the one in which the liquid is in contact with both the sides of a piston or plunger. This pump has two suction pipes and two delivery pipes. During each stroke, the suction takes place on one side of the piston and other side delivers the liquid. So in case of double acting pump in one complete revolution of the crank, there are two suction strokes and two delivery strokes.

Most piston pumps are double acting, while plunger pumps are single acting.

According to the number of cylinders provided, reciprocating pumps may be classified as :

1. Simplex – single cylinder pump.
2. Duplex – double cylinder pump
3. Triplex – triple cylinder pump.

A simplex pump is the one having only one cylinder. The single cylinder pump may be single acting or double acting. A double cylinder pump or duplex pump is the one which has two single acting cylinders, each may be equipped with one suction and one delivery pipe with appropriate valves and a separate piston or plunger for each cylinder. In an alternate arrangement, there may be only one suction pipe, one delivery pipe and one piston for both the cylinders. The working of a duplex pump is similar to that of a double acting single cylinder pump.

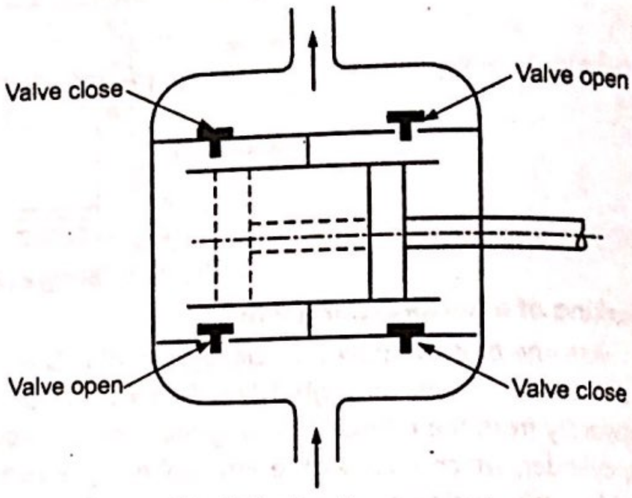


Fig. 9.7 : Duplex pump

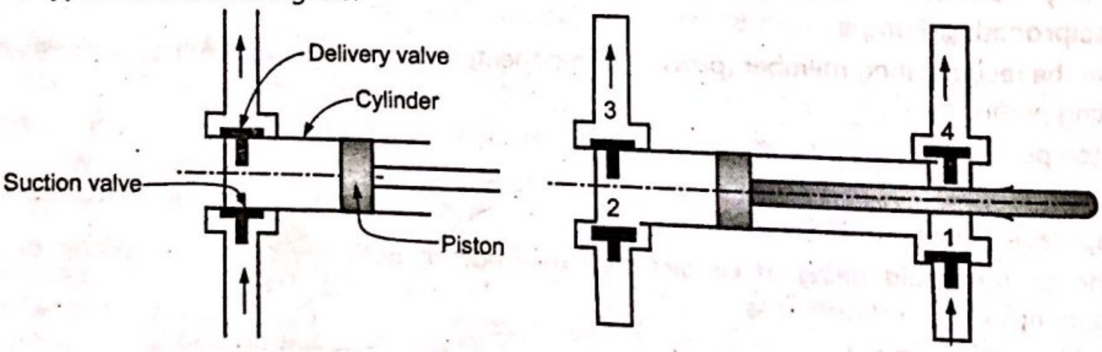
A triplex pump has three single acting cylinders, each equipped with one suction and one delivery pipe and separate piston or plunger.

1. Piston pump

It consists of a cylinder with a reciprocating piston. It is equipped with valves at inlet and discharge for the liquid being pumped. The liquid to be pumped enters from the suction line via a suction valve and is discharged at high pressure through a delivery valve. This type of pump may be single acting or double acting and may be direct acting, steam driven or power driven with a crank and a flywheel.

In case of single acting pumps, the liquid is admitted only on one side of the piston (infront of the piston) while in double acting pumps, the liquid is admitted on both sides of the piston.

Both these types are shown in Fig. 9.8.



(a) Single acting **(b) Double acting**

Fig. 9.8 : Piston pumps

In case of single acting pumps, as the piston moves backward from the suction port, the liquid is drawn into the chamber through a suction valve which allows the liquid only to flow into the chamber. As the piston moves forward, the liquid is pressed and liquid is pumped out via a delivery valve through the delivery port. In case of double acting pumps, the liquid is drawn into the pump and discharged from the pump during backward as well as forward strokes. In the backward stroke, the liquid is drawn into the pump through the suction port (1) and liquid is discharged through the delivery port (3) and in the forward stroke, the liquid is drawn into the pump through suction port (2) and liquid is discharged through delivery port (4). With single acting pumps, the delivery is zero during return stroke (backward stroke) and with double acting pumps, the delivery is same in the forward and return stroke.

The theoretical delivery of the piston pump is nothing but the total swept volume of the cylinder (number of ...okes per second × area of piston × length of stroke). Due to leakages past the piston, valves and inertia of the ...ves the actual delivery may be less than the theoretical delivery. The volumetric efficiency of piston pumps which ...the *ratio of the actual discharge to the swept volume* is normally greater than 90 per cent.

These type of pumps are provided with an air vessel at the pump discharge to make the flow in the delivery ...e continuous, i.e., to obtain uniform flow and to reduce energy requirement at the beginning of each stroke. ...ring the forward stroke commencement, the liquid is pumped into the air vessel and the air is compressed and at ...e end of stroke when discharge decreases, the pressure in the air vessel is sufficiently high to expel some of the ...uid in the delivery line.

The discharge of the liquid in the delivery line can be kept approximately constant by incorporation of a large ...r vessel close to the pump. The air vessel fitted on the delivery line also reduces the frictional losses.

This type of pump is comparatively simple in construction, operates at high mechanical efficiencies over a wide ...nge of operating conditions, does not require priming and can be used to develop pressure upto 6 MPa. The load ...n a driving mechanism with this type is uneven as the delivery is uneven.

The piston pumps are well suited for pumping small quantities of liquids to high pressures.

Fig. 9.9 shows discharge curves for reciprocating pumps.

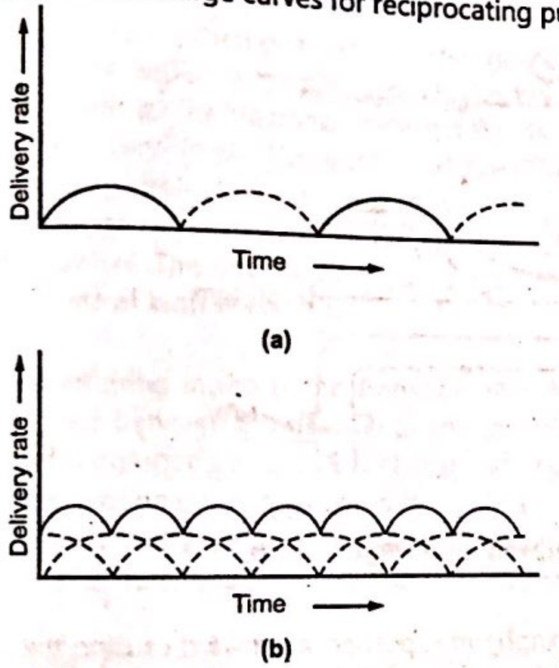


Fig. 9.9 : Delivery from (a) simplex and (b) duplex

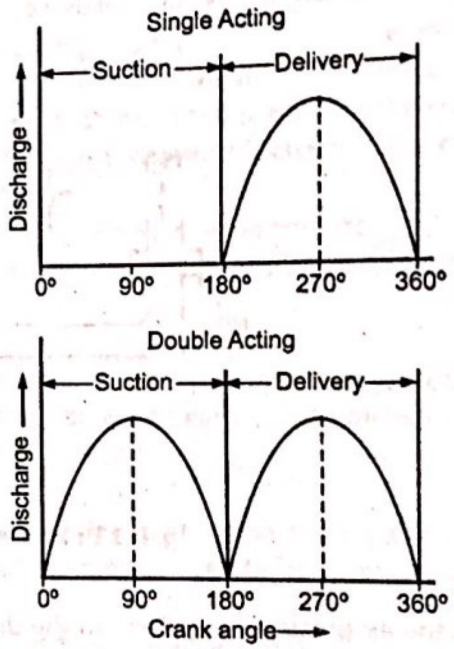


Fig. 9.10 : Delivery from single acting and double acting pump

2. **Plunger pumps**

The principle of operation of a plunger pump is the same as that of the piston pump. It consists of a heavy-walled cylinder of a small diameter that incorporates a close fitting reciprocating plunger, which is merely an extension of a piston rod. This type of pump is always single acting in the sense that only one end of the plunger is used to pump the liquid and usually are motor driven. These are used for high pressure applications and can discharge against a pressure of 150 MPa or more.

Applications : It may be used for injecting small quantities of inhibitors to high pressure systems and for feeding water to boilers.

3. **Metering pumps**

Metering pumps are driven by a constant speed electric motor and maintain constant delivery rates irrespective of changes in the pressure against which they operate. For low discharge and high pressure services, they are of the plunger type and for high discharge and low pressure services, they are of the piston type. During the pumping operation also, the delivery rate from the pump can be controlled by controlling the displacement (stroke) of the piston element by manually on the pump or remotely.

Applications Metering pumps are used for constant and accurately controlled delivery rates. They may be used for feeding of reactants and inhibitors to reactors at controlled rates and for the dosing of water supplies.

4. Diaphragm pumps

This pump is divided into two sections by a reciprocating driving member which is nothing but a flexible diaphragm. The diaphragm can be fabricated out of metal, rubber or plastic material (PTFE). In one section of the pump, there is a liquid to be pumped and in the other section there is a piston or plunger working in non-corrosive fluid (e.g., oil) which actuates the diaphragm to and fro. The fluid movement is transmitted by means of the diaphragm (flexible) to the liquid being pumped and hence with this arrangement packing and seals are not exposed to the liquid being pumped. Valves (non-return valves, ball type) at the suction and discharge are the only moving parts which are in contact with the liquid and these valves prevent reverse flow of the liquid.

Pneumatically actuated diaphragm pumps utilize compressed plant air for pumping. Such pumps must have a flooded suction. The pressure they develop is of course, is limited to the available compressed plant air pressure. Fig. 9.11 shows a schematic diagram of pneumatically actuated diaphragm pump.

Applications : Diaphragm pumps are used for handling corrosive liquids, toxic liquids as well as liquids containing suspensions of abrasive solids, i.e., slurries.

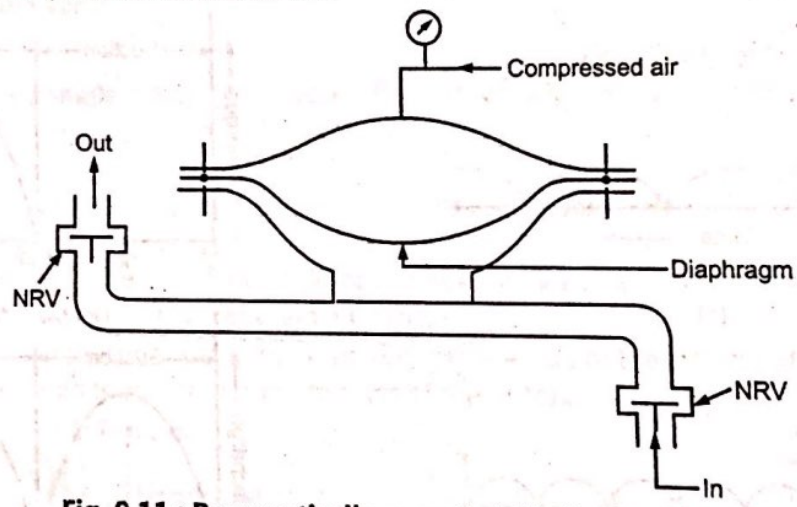


Fig. 9.11 : Pneumatically operated diaphragm pump

Working :

When the air pressure is applied on the diapharm, the diapharm is pushed downward causing the liquid in the pump casing to be pumped into the discharge line. During this discharge stroke, the NRV at the discharge line gets opened and that on the suction line gets closed. When the air pressure is released, the diapharm is returned to its position, pulled upward, and during this suction stroke, the liquid fills the pump casing. During this stroke, the NRV at the suction line gets opened and that at the discharge line gets closed. In this way, the air pressure on the diaphragm is alternately applied and released for the pumping of liquid.

9.3.2.2 Positive Displacement Rotary Pump

In rotary pump as the elements of the pump rotate in a casing, a reduced pressure is created on the inlet side, the liquid is thus forced into the pump, it is then trapped between the rotating elements and the casing and finally is forced out of the discharge side of the pump. The rotary pumps can handle liquids of any viscosity. The discharge rate from this pump is a function of its size and speed of rotation. Rotary pumps include gear pumps and mono pumps.

1. Mono pump/Screw pump

This pump consists of a rotor that rotates in a stator made of rubber or other similar material. The rotor is a true helical metal screw while the stator has a double helical thread pitched opposite to the spiral on the rotor. The liquid to be pumped moves continuously towards a discharge through the voids between the rotor and the stator. This pump is capable of handling highly viscous materials, gritty liquids, etc.

Applications : It is widely used in the chemical industry for feeding slurries containing higher proportion of solids to filtration equipments. Fig. 9.12 shows a schematic diagram of mono pump.

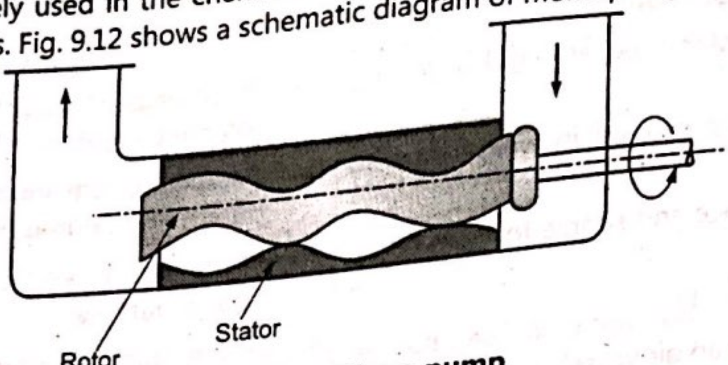


Fig. 9.12 : Mono pump

2. **Gear pump**

Principle : A gear pump uses the meshing of gears to pump liquid by displacement, i.e., it creates liquid displacement via the meshing of gears.

Construction :

It consists of two toothed gear wheels (spur gears) enclosed in a casing which is provided with inlet and outlet connections for the liquid to be pumped. Of the two gear wheels, one is driven by an electric drive and other rotates in mesh with it. The clearance between the gear wheels as well as between the surface of the gear wheels and the casing is very small. The pump has no valves. For this pump, the delivery/discharge rate of liquid is independent of pressure.

This pump does not need priming. The number of teeth on each gear wheel varies from three to four or to a considerable number. The gear and casing of a gear pump is rigid and this allows gear pumps to pump viscous liquids and operate at high pressures.

Working :

The liquid entering in the pump from the inlet due to creation of a reduced pressure at the inlet is carried round in the space between the gear teeth and the casing during the rotation of gears. Due to further rotation of gears the liquid is pumped out of the discharge as the gear teeth come nto mesh.

A neat sketch of gear pump is shown in Fig. 9.13.

Applications : These pumps are used for handling high viscosity liquids such as molasses, paints, crude oil, lube oils, fuel oils, pure bitumen vegetable fats, vegetable oils, cacao butter, chocolate black liquor resins and adhesives.

Advantages : High speed, high pressure, priming is not required, relatively quiet operation.

Disadvantages : They are not sufficient for liquids carrying suspended solids due to close clearance between gear wheels and teeth.

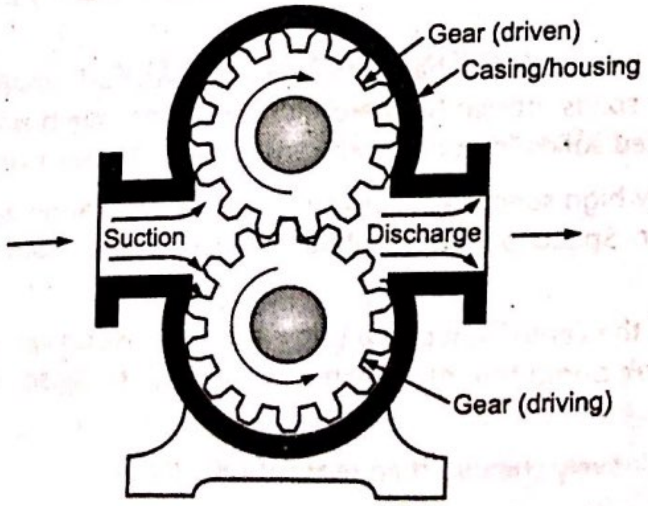


Fig. 9.13 : Gear pump

9.3.3 Comparison of Centrifugal Pump with Reciprocating Pump

Centrifugal Pump	Reciprocating Pump
1. The means of fluid transfer is a centrifugal force.	1. The means of fluid transfer is a displacement of volume by a piston element.
2. Simple in construction and light in weight due to less number of parts.	2. Complex in construction and heavy construction due to more number of parts.
3. It requires less floor space and simple foundation.	3. It requires more floor space and comparatively heavy foundation.
4. It needs priming.	4. It does not need priming.
5. It does not incorporate an air vessel.	5. It incorporates an air vessel.
6. Discharge is steady and even.	6. Discharge is not even, it is pulsating.
7. Used for large capacity and low heads.	7. Used for low capacity and high heads.
8. It is operated at high speeds.	8. It is operated at low speeds.
9. It can handle relatively viscous liquids and liquids containing suspended solids.	9. It cannot handle viscous liquids and liquids containing suspended solids. It can handle clear liquids.
10. They are coupled directly to an electric motor.	10. They are belt driven.
11. They are operated against a closed valve without danger.	11. They are never operated against a closed valve.
12. Efficiencies are low.	12. Efficiencies are high.
13. Maintenance cost is low.	13. Maintenance cost is high.
14. Costwise they are cheaper.	14. Cost of the reciprocating pump is higher than the centrifugal pump of the same power.
15. Designed for high discharge.	15. Designed for high heads.
16. Cannot develop high pressures.	16. Can develop high pressures.
17. Less wear and tear.	17. More wear and tear.

9.3.4 Advantages of Centrifugal Pump over Reciprocating Pump

1. Simple in construction, requires less floor space, relatively simple foundation.
2. Discharge capacity is very much greater than that of the reciprocating pump which can handle relatively small quantities of liquid.
3. Centrifugal pumps can be used for handling relatively viscous liquids and liquids containing large proportion of suspended solids efficiently whereas reciprocating pump is used for low viscosity liquids and liquids free from suspended solids/impurities otherwise its valves can cause frequent trouble.
4. It can be operated at very high speed without any danger of separation and cavitation and can be coupled directly to electric motor. Speed of reciprocating pump is limited from consideration of separation and cavitation.
5. The maintenance cost of the centrifugal pump is low and only periodical checkup is sufficient. On the other hand, for the reciprocating pump the maintenance cost is high because parts such as valves etc. may need frequent replacement.
6. Centrifugal pumps are relatively cheaper than reciprocating pumps.
7. For equal capacity, the centrifugal pump is much smaller than the reciprocating pump.

GAS PUMPING DEVICES
[Transportation of Gases]

10.1 DEVICES OF TRANSPORTATION OF GAS/AIR

Like liquids, gases must also be moved through pipelines and process equipments using proper fluid moving devices. **Fans, blowers, and compressors** are used for transportation of gases based upon the service conditions.

The pumping devices for gases can be operated at higher speeds as the density of gas is considerably less than the density of liquid. As the viscosity of a gas is low, there is a greater tendency for leakage to occur, thus, gas compressors are designed with small clearances between the moving parts.

In gas compression, a large proportion of energy of compression appears as heat in the gas, thereby the temperature of the gas increases significantly. The increased temperature of the gas may limit the operation of the compressor due to this we have to make a provision for cooling of the gas in order to maintain reasonable temperatures. Thus, gas compression is often carried out in a number of stages with interstage cooling in the compressors.

Fans : A fan is a machine that moves large amounts of a gas with low increase in pressure.

Blowers : A blower is a machine for moving volume of a gas with moderate increase of pressure.

Compressors : A compressor is a machine for raising a gas to a higher level of pressure.

The main objective in case of compressors is to increase the static pressure. Therefore, the mechanical energy held by the gas is in the form of pressure energy whereas the main objective of fans and blowers is a high flow of gas and hence the mechanical energy of rotor/impeller is utilised to increase the kinetic energy of the gas and consequently a rise in the static prèssure is less.

10.2.1 Induced Draft Fan and Forced Draft Fan

- In an induced draft system, the fan is at the exit/discharge end of flow path of the system and consequently the system is under negative pressure, i.e., at a pressure less than the atmospheric pressure as the air/gas is drawn out of the system by the fan.

  Examples : Cooling towers and boilers.
- In a forced draft system, the fan is located at the inlet of the flow path of the system and thus the system is under positive pressure, i.e., at a pressure more than the atmospheric pressure as the gas/air is forced into the system by the fan.

  Examples : Cooling towers and boilers.
- Draft fans are of two types :

  (i) Forced draft fan (FD fan) and (ii) Induced draft fan (ID fan).
- **Induced Draft Fan :** It is a fan that maintains a system under negative pressure (i.e. below atmospheric pressure) by pulling out air/gas through the system.

Examples :

(i) A fan used to remove/draw out flue gases from boiler into the atmosphere. It is located prior to the boiler chimney.

(ii) A fan is located at the top of a cooling tower to draw or pull air through the cooling tower. Axial fans are commonly used.

- **Forced Draft Fan (FD fan) :** It is a fan which maintains a positive pressure in a system by supplying pressurised air to the system.

  It produces a positive pressure inside a system.

Examples :

(i) A fan used to force outside air into a boiler to provide hot air for the combustion of a fuel thruogh a preheater. It maintains flue gases at a pressure more than the atmospheric pressure.

(ii) A fan placed at the base of a cooling tower which forces air into the cooling tower. Centrifugal fans are commonly used.

Fans :

Fans are used for moving gases when the pressure heads of less than 30 kPa are involved. They are either centrifugal type or axial flow type. The centrifugal type fans depend on the centrifugal force for moving the gas, while axial flow type fans impart energy to the gas as it flows parallel to the central axis of the fan. The inlet and outlet volumes of gases are essentially equal due to very low operating pressures and hence are simply movers of gas. Fans are employed industrially for ventilation works, supplying air to dryers, supplying draft to boilers, removal of fumes, etc.

10.2.2 Types of Fans

These fans are classified as :

(i) Axial flow fans/Axial fans.

(ii) Centrifugal fans.

An axial fan moves air or gas parallel to the axis of rotation.

A centrifugal fan moves air or gas perpendicular to the axis of rotation.

Axial fans are suited for low pressure, high flow applications.

Centrifugal fans are suited for high pressure, low flow applications.

1. **Axial fans :**

These fans use axial forces for the movement of air and increase its pressure.

An axial fan consists of a fan casing and impeller consisting of blades mounted on a hub. The hub is mounted on a shaft.

Blades rotating around an axis draw air in parallel to the axis and force air out in the same direction.

Axial fans are used in aircraft, helicopters, wind tunnels, cooling towers, general ventilation, paint spray booth exhaust, etc.

2. **Centrifugal fans :**

Principle : Centrifugal fans use centrifugal force to impart movement to the air/gas and increase its pressure.

Construction and Working :

A centrifugal fan has a fan wheel/impeller which is composed of a number of blades, mounted on a hub. The hub is fixed on a drive shaft that passes through the casing/housing.

In the centrifugal fan, the air/gas enters the fan in an axial direction and leaves the fan in a radial direction.

When a impeller rotates, the air/gas near the impeller is thrown-off from the impeller at high velocity due to centrifugal force and then moves into the casing. In the casing the gas/air decelerated and static pressure increases. The gas/air is finally guided to the exit via outlet duct.

Applications : Centrifugal fans are used for high pressure applications. They are used in ventilation systems for buildings, heating, drying, air conditioning, air pollution, steam boilers, power plants, cooling towers, exhausting corrosive and hazardous gases from chemical plants, for cooling ovens in glass industry, chemical plants, etc.

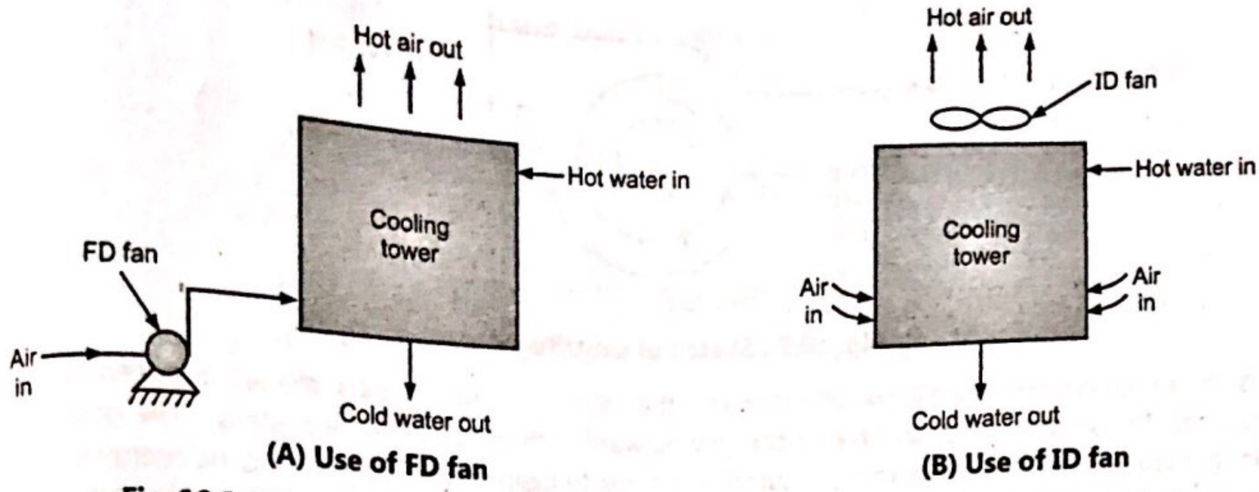


Fig. 10.1.(A) and (B) : ID and FD fans in cooling tower operation (Block diagram)

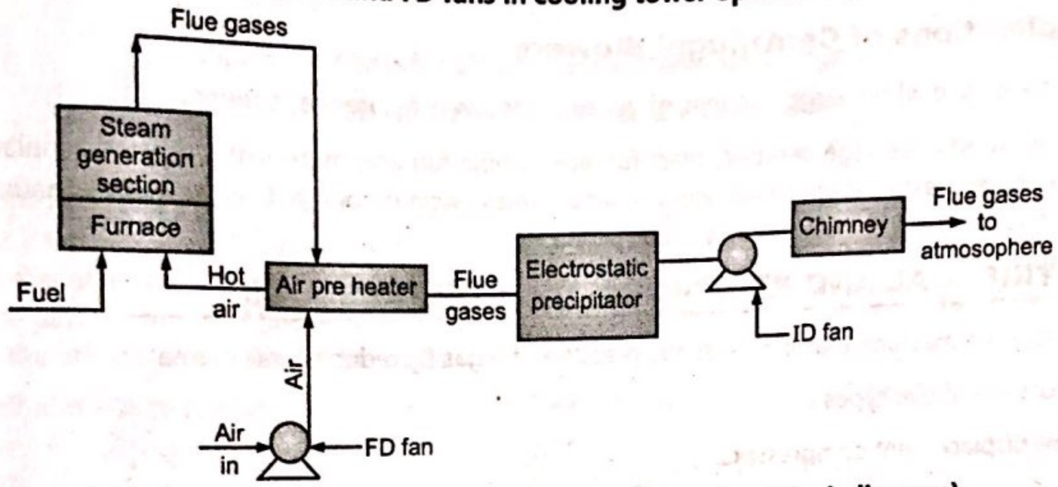


Fig. 10.2 : Use of ID and FD fans in boiler operation (Block diagram)

10.3.1 Centrifugal Blowers

A single-stage centrifugal blower bears a superfacial resemblance to a centrifugal pump. The centrifugal blower differs from a centrifugal pump in that the gas handled in it is compressible, whereas the liquid handled in the pump is incompressible. Also, centrifugal blowers require large diameter impellers and high speed of operations as compared to centrifugal pumps since very high heads of low density fluid (gas/air) is needed for generating pressure ratios.

Principle : The principle of a centrifugal blower is the same as that of the centrifugal pump.

A spinning impeller causes increase in kinetic energy of a gas/air by centrifugal force which then used to increase pressure of gas/air.

Construction :

A centrifugal blower consists of :

(i) Impeller (vaned/bladed).

(ii) Casing.

(ii) Inlet and outlet ducts.

An impeller is keyed to a shaft and enclosed in a volute casing. The shaft is connected to a drive (e.g. an electric motor). Inlet and outlet ducts (connections) are provided on the casing perpendicular to each other. The outlet duct is tangential to the rotation of the impeller. (Refer Fig. 10.3).

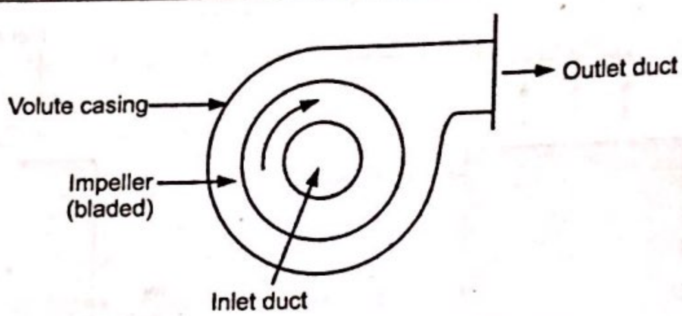


Fig. 10.3 : Sketch of centrifugal blower

Gas or air enters the impeller axially through the inlet duct and it gets divided between the impeller blades/vanes. The spinning impeller throws the gas outward with increased kinetic energy. The gas leaving the impeller at high velocity then flows into the surrounding volute casing which converts kinetic energy into pressure energy and thereby increase static pressure of the gas and is finally discharged through the outlet duct.

10.3.2 Applications of Centrifugal Blowers

- Blowers are used where large volumes of gas or air at low pressure are required.
- These are used in sewage aeration, blast furnace, cupola furnace, municipal gas plant, ventilation, pollution control, dryers, exhausting gases, vapours and fumes, incinerators, hot air blowers, exhausting corrosive hazardous chemicals, household machines, etc.

10.4 CENTRIFUGAL AND RECIPROCATING COMPRESSORS

A compressor is a machine that increases the pressure of a gas by reducing its volume.

Compressors are of two types :

(a) Positive displacement compressors :

(i) Reciprocating compressors and (ii) Rotary compressors.

(b) Dynamic compressors :

(i) Centrifugal compressors (radial flow compressors), (ii) Axial flow compressors.

- Positive displacement compressors work by mechanically changing the volume of the gas/air whereas dynamic compressors (e.g., centrifugal compressors) work by mechanically changing the velocity of the gas/air (the working fluid).
- Compressors can be single-stage or multistage machines depending on the maximum delivery pressure. For a compression ratio upto 5, single-stage compressors are used and for the compression ratio (the ratio of delivery pressure to suction pressure) greater than 5, multistage compressors are used.

10.4.1.1 Centrifugal Compressors

Principle : These compressors work on the principle of conversion of kinetic energy into pressure energy.

Construction : A centrifugal compressor is a dynamic compressor/turbo compressor which consists of

(i) Stationary casing/volute.

(ii) Rotating impeller.

(iii) Diffuser.

The casing houses a rotating impeller. The impeller is mounted on a shaft which is directly connected to a prime mover. The impeller consists of a set of blades. The diffuser may be vaned or vaneless.

Fig. 10.4 shows a schematic diagram of a centrifugal compressor.

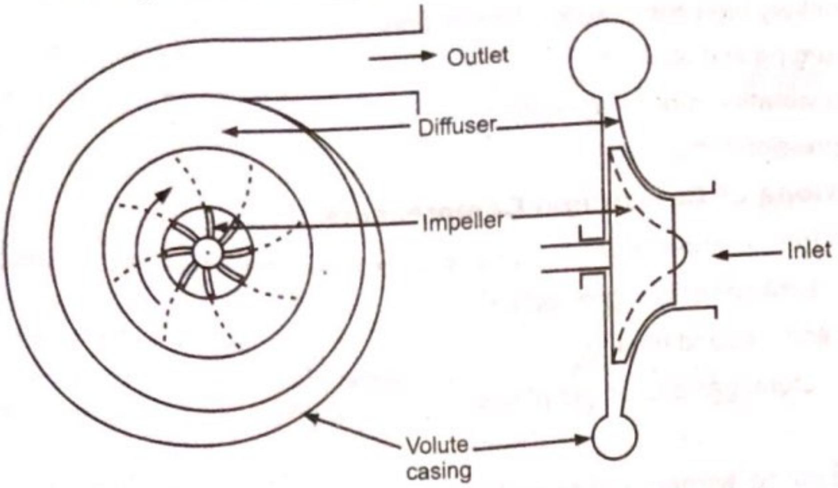


Fig. 10.4 : Centrifugal compressor (Schematic diagram)

(Note : You can draw any view in the examination)

Working :

As the impeller starts rotating, the vanes draw low pressure gas/air from the centre of the impeller and push outward to its periphery i.e., to open end of the impeller by centrifugal force. The radial movement of gas/air results in a pressure rise and the generation of kinetic energy. The gas exits the impeller vanes at very high velocity and enters into the diffuser where kinetic energy of the gas is converted into pressure energy. The volute casing collects the gas from the diffuser and directs to the outlet.

Nearly half of the total pressure is achieved in the impeller and the remaining in the diffuser.

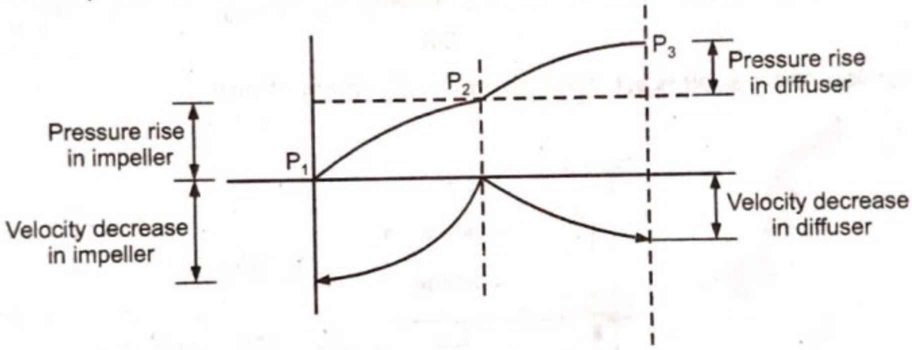


Fig. 10.5 : Velocity - pressure variation in a compressor

10.4.1.2 Advantages of Centrifugal Compressor

Wide operating range :

(i) Low weight and easy to manufacture.

(ii) Suitable for continuous compressed air supply.

(iii) Oil free in nature.

(iv) Relatively energy efficient.

(v) Does not require special foundation.

(vi) High flow rate than the positive displacement compressor.

(vii) Reliable and low maintenance costs.

(viii) Low initial cost.

10.4.1.3 Disadvantages of Centrifugal Compressor

(i) Unsuitable for very high compression, limited pressure.
(ii) Problem of surging and choking.
(iii) Sophisticated vibration mounting needed.
(iv) Limited compression ratios.

10.4.1.4 Applications of Centrifugal Compressors

- To provide oil free compressed air in some sensitive applications such as food processing.
- To meet high demands of compressed air.
- Refrigeration and air conditioning.
- Oil refineries, natural gas processing plants.
- Gas turbines.
- In automobile, turbochargers and superchargers.
- Off-shore platform applications.
- Petrochemicals (e.g., manufacture of ammonia, urea, ethylene oxide).
- Chemical industries.

10.4.2.1 Reciprocating Compressors

- A reciprocating compressor is a positive displacement compressor that uses a piston (driven by a crankshaft) to compress a gas and deliver it at high pressure.

Principle :

- Displacement of piston in cylinder causes rise in pressure.

OR

- The compression of a gas/air is achieved by the displacement of piston.

Construction :

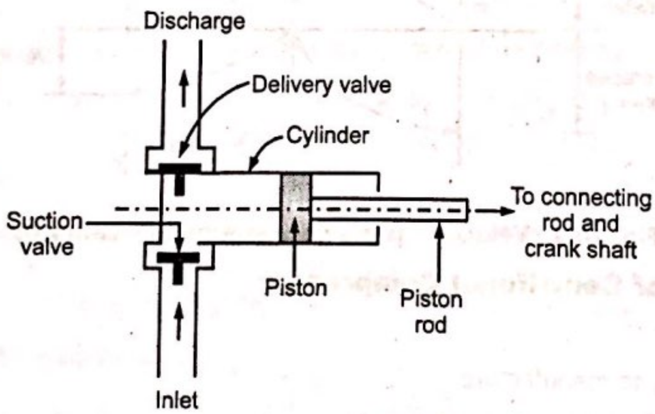


Fig. 10.6 : Reciprocating compressor

A reciprocating compressor mainly consist of :

(i) Cylinder.
(ii) Piston and connecting rod.
(iii) Crankshaft with a drive.
(iv) Suction/inlet valve (check valve).
(v) Discharge/outlet valve (check valve).

Reciprocating compressors may be **single acting** (where compression is only on one side of the piston, i.e., the gas/air is compressed only on one side of the piston) or **double acting** (where compression is on both sides of the piston i.e., the gas/air is compressed alternately on both sides of the piston).

In these compressors, a piston is the compressing and displacing element. The piston has a reciprocating motion within a cylinder.

The cylinder is equipped with suction and delivery valves.

A connecting rod transforms the rotary motion of the crankshaft into the reciprocating motion of the piston in the cylinder.

The compressor cylinder is usually water jacketed in order for removing heat of compression. These compressors are usually belt driven from an electric motor.

Reciprocating compressors are available as a single-stage or multistage units. Multistage units are used to achieve the required compression ratio. In multistage compressors, the gas is cooled between the stages as this interstage cooling reduces the temperature of the gas approximately to the suction temperature. The interstage cooling is necessary for safe operation as it keeps the temperature within the safe operating limits and it also results in reduction in the power required for compression.

Working :

During the suction stroke, the motion of the piston reduces the pressure inside the cylinder than that in the suction line. Due to this, the suction valve opens and the gas flows into the cylinder. During this stroke, the discharge valve remains closed. During the discharge stroke, the piston moves forward in the cylinder, compressing the gas. In this stroke the suction valve remains closed. As the piston is moving forward, the gas is getting compressed, pressure is increasing and when the pressure in the cylinder exceeds the pressure in the discharge, the valve opens. The compressed gas is then delivered through the discharge line during the remaining discharge stroke.

10.4.2.2 Applications of Reciprocating Compressors

Refrigeration plants.

Gas pipelines.

Natural gas processing plants.

Chemical industries.

Compressed air for automobiles.

Petrochemicals (e.g., manufacture of LDPE).

Petroleum refining (e.g., desulphurization and reforming).

Hydrogen stations.

Gas filling stations, compressed air to power pneumatic tools.

10.4.3.1 Comparison of Reciprocating and Centrifugal Compressors

Reciprocating Compressor	Centrifugal Compressor
1. Reciprocating compressors are slow speed machines.	1. Centrifugal compressors are high speed machines.
2. Reciprocating compressors cannot be directly connected to a prime mover.	2. Centrifugal compressors can be directly coupled to a prime mover.
3. Reciprocating compressors can develop pressures upto 1000 kg f/cm^2.	3. Centrifugal compressors can develop pressures upto 10 kg f/cm^2.
4. Reciprocating compressors are used when low rate of flow and high pressure are required.	4. Centrifugal compressors are used when high rate of flow and low pressure are required.

... Contd.

... compressors have the highest pressure ratio.

10.6.1 Vacuum Service / Vacuum Generating Devices

A vacuum is *any system pressure below the atmospheric pressure* [760 mm Hg (torr)]. A vacuum pump is *a device which takes the suction at a pressure below the atmospheric and discharges at the atmospheric pressure.* (Vacuum refers to a subatmospheric pressure). For carrying out an operation under vacuum, pumping device is required to create a vacuum, and to maintain the low pressure. The compression ratios in vacuum producing devices are very high as compared to those in compressors. The operations under vacuum are very common in chemical industry, especially in performing operations such as distillation, evaporation, etc.

Every vacuum producing device takes in gas at low pressure where the volume is very large and discharges at atmospheric pressure. Commonly used vacuum producing devices are :

1. Rotary vacuum pumps (liquid ring type) and
2. Steam jet ejectors.

10.6.2.1 Steam Jet Ejectors

- An ejector is a device used to pump gases and vapours from a system in order to create a vacuum in the system.
- The purpose of an ejector is same as that of vacuum pump.
- An ejector is a device in which the kinetic energy of primary/motive fluid (it is a high pressure fluid, e.g., steam) is used to pump or suck secondary fluid (e.g., gases and vapours) from a process equipment with a subsequent creation of vacuum in the process equipment.

Principle : They work on the nozzle-venturi principle.

An ejector is a device that produces vacuum in a system using a motive fluid. If steam is used as a motive fluid then the ejector is called as a steam jet ejector. A dry saturated high pressure stream is the normal requirement.

The kinetic energy of steam is used to pump process gases and vapours.

Construction :

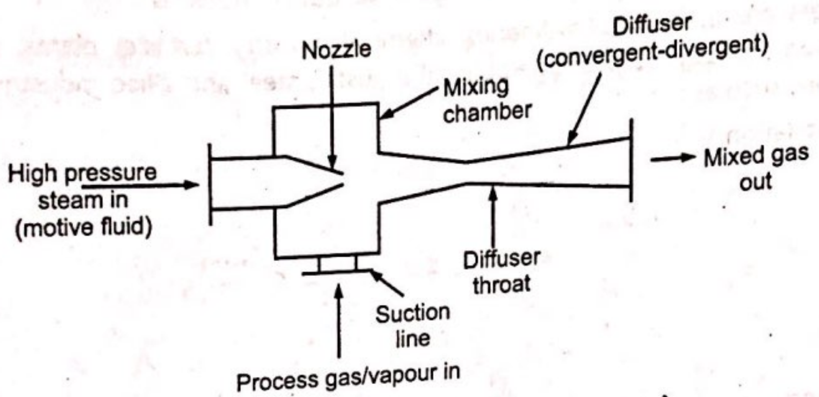


Fig. 10.7 : Steam jet ejector (single-stage)

A steam jet ejector consists of :

(i) Nozzle.

(ii) Mixing chamber.

(iii) Diffuser.

(iv) Suction fluid (gas or vapour from process) inlet.

(v) Motive fluid (steam) inlet.

(vi) Mixed fluid outlet.

Working :

- The suction line of the ejector is connected to the process equipment which is to be kept under low pressure, i.e., which is to be operated under vacuum.
- A high pressure steam (motive fluid) is accelerated from its initial velocity to a high velocity as it passes through the nozzle (i.e., in the nozzle, steam velocity increases) with a subsequent decrease in its pressure. Thus, a low pressure, high velocity flow prevails in the mixing chamber (i.e., a vacuum is created in the mixing chamber) and because of this, the process gas/vapour from a process equipment gets sucked into the mixing chamber and gets mixed with the steam. During the mixing fluid, the steam gets retarded and the vapours/gas gets accelerated.
- The mixed fluid/mixture from the mixing chamber enters the diffuser (convergent-divergent diffuser) where its pressure is increased by rapid deceleration of the mixed fluid (i.e., where its velocity is converted into pressure energy). It means that the mixed fluid is compressed to a high pressure in the diffuser. The high pressure mixed fluid is then released to the atmosphere or some closed system.

10.6.2.2 Advantages of Steam Jet Ejectors (Compared to Vacuum Pumps)

Relatively low initial cost.

High efficiency.

Less maintenance requirements.

Reliability.

Rugged and simple construction.

Simple operation.

No moving parts.

Easy to install and operate.

No source of power is required.

10.6.2.3 Applications of Steam Jet Ejector

- Steam jet ejectors are used to create a wide range of vacuum conditions.
- Steam jet ejectors are used in oil refineries, chemical industry, fertilizer plants, petrochemical industry, power plants, food industry, edible/vegetable oil industry, steel and allied industries, etc. for carrying out process operations such as :

  High vacuum distillation.

  Deodorisation.

  Drying.

  Crystallisation.

  Degassing.

  Filtration.

  Vacuum packaging.

  Deaeration and cooling.

10.6.3.1 Liquid Ring Vacuum Pumps

- Liquid ring vacuum pumps are mechanical devices that are used to create a vacuum in the system to which they are connected by making use of a suitable sealing liquid.
- In most of the applications, the sealing liquid is water and hence they are known as water ring vacuum pumps (or water ring water piston rotary vacuum pumps).

10.6.3.2 Water Ring Vacuum Pumps

Principle : Water ring vacuum pumps (or any liquid ring vacuum pump) operate according to the positive displacement principle.

Construction :

A water ring vacuum pump consists of impeller (vaned/bladed).

Casing :

Inlet/discharge ports.

Inlet connection – gas/vapour inlet.

Discharge connection – gas/vapour + water outlet.

Operating liquid inlet/water inlet.

It consists of a multiblade impeller fixed on a shaft and located eccentrically within a cylindrical casing. The casing is partially filled with water (a sealing liquid). Inlet/outlet connections and water inlet connections are located on the casing.

Working :

- Before starting the pump, it should be partially filled with water. During the pump operation, water should be continuously supplied through the water inlet. It circulates within the casing and leaves with the exit gases/vapours through the discharge connection.
- During operation the gases/vapours from a process equipment are sucked through the inlet connection into the pump and pushed out through the discharge connection along with water into the atmosphere.
- As the shaft turns, the rotating impeller throws off the water by centrifugal force towards the walls of the casing forming a ring of water. The water ring thus formed is concentric with the casing and eccentric with the impeller and also rotates within the casing.
- In the uppermost portion of the casing, the water ring is nearest to the impeller and completely fills the impeller cell (space between the two adjacent blades) with water (Refer Fig. 10.8) and in the lowermost portion, the impeller cells are free of water, i.e., the impeller blades are not dipped into the water.
- During the first half rotation, the water ring moves away from the impeller hub acting as a piston. The free/void space in the cells increases and thus the gases/vapours are sucked through the inlet port at the side of the impeller.

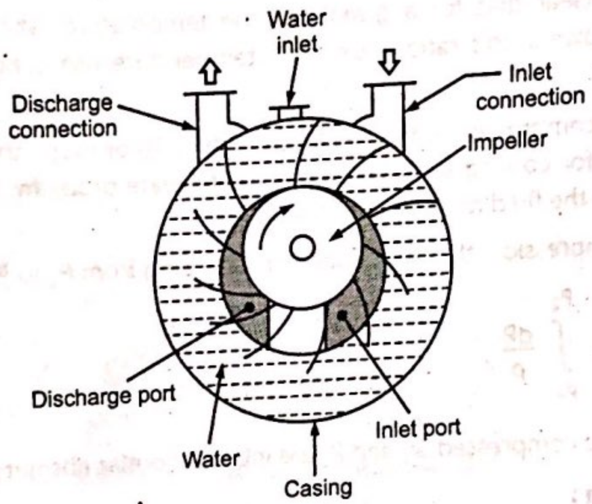


Fig. 10.8 : Water ring vacuum pump (OR Liquid ring vacuum pump)

- During the second half rotation, the water ring moves towards the impeller hub (water ring acting as a piston). Because of this the free space in the cells decreases and consequently the gases/vapours are compressed and pushed out through the discharge port along with some water. The gases/vapours along with water are discharged into the atmosphere through the discharge connection. The inlet port is joined by an internal passage to the inlet connection and the outlet port is joined by an internal passage to the outlet connection.

10.6.3.3 Applications of Water Ring Vacuum Pumps

Water ring vacuum pumps are used to carry plant operations such as distillation, filtration, evaporation, crystallisation, degassing and drying, under negative pressures in chemical, polymer, food, pharmaceutical, plastics and rubber industries [In plastic and rubber industries for degassing].

(Operations under vacuum are used to reduce the operating temperatures to reduce heat loads or to avoid thermal decomposition of heat sensitive materials.)