3

Transportation of Fluids

The transportation is involved in handling of the raw materials, materials in manufacture and finished products. Transportation is also important in mixing, conveying them for filtration, filling into the containers, sealing etc. Transportation of fluids is more convenient and economical than transportation of solids. The importance of transportation of fluids is highlighted in the following areas.

1. **Bulk drugs :** Specified quantities of reactants are transported to the reactor. For example, gases such as chlorine and hydrogen are passed (in chlorination and hydrogenation) into the reaction system. Similarly, large quantities of water are transported to heat or cool the reaction vessels.
2. **Fermentation products :** Medium constituents are transported to the fermenter. For example, sterile air, nutrient broth etc., are passed into the fermenter.
3. **Liquid oral pharmaceuticals :** Production of dosage forms, such as solutions and elixirs, employ fluid flow. In the production of liquid orals, production operations are conducted in the first floor. The bottling and packing are carried out in the ground floor. Therefore, fluid flow in this case involves gravity.
4. **Suspension dosage forms :** In the production of suspensions, fluid flow is obtained with the help of a pump. Normally, it is a mixing process. When suspended solids settle at the bottom of the tank, these are pumped to the top of the vessel continuously.

5. **Semisolid pharmaceuticals :** In case of semisolid preparations (ointments, pastes etc.), fluid flow is obtained by passing them through a hot jacketed pipes. because it is easy to handle them in *fluidised* state under molten conditions.
6. **Injection dosage forms :** In the production of injections, sterile air and sterile water are transported from the place of production to the site of manufacturing operations.

In this modern age, wherein automation is the order of the day, pharmaceutical industry has evolved a number of innovative handling techniques.

VALVES

Valves are used to control the rate of flow of fluids in a pipeline.

Valves are placed between pipes. During maintenance of pipes, valves can be removed and repaired without disturbing the other connected units. Valves are designed in such a manner that they should withstand the following effects:

- Pressure of flow.
- Temperature changes.
- Strain from connected pipes.
- Distortion from the sealing surfaces.

Normally, valves are made of materials such as brass, iron, bronze, and cast iron, depending on the nature of materials that may come in contact. A number of valves have been designed. Some of them are:

(1) Plug cock valve
(2) Globe valve
(3) Gate valve
(4) Diaphragm valve
(5) QO (quick opening) valve
(6) Check valve

These are discussed in the following sections.

Plug Cocks

The construction of a plug cock valve is shown in Figure 3-1. Essentially plug cock consists of a body casting in which a conical plug is fitted. The plug has an opening (cylindrical bore) through which the liquid passes. Some packing materials are included around the stem to close it. The sides of the plug should not be parallel or tapered too much. These valves are used when either complete opening or complete closing is desirable.

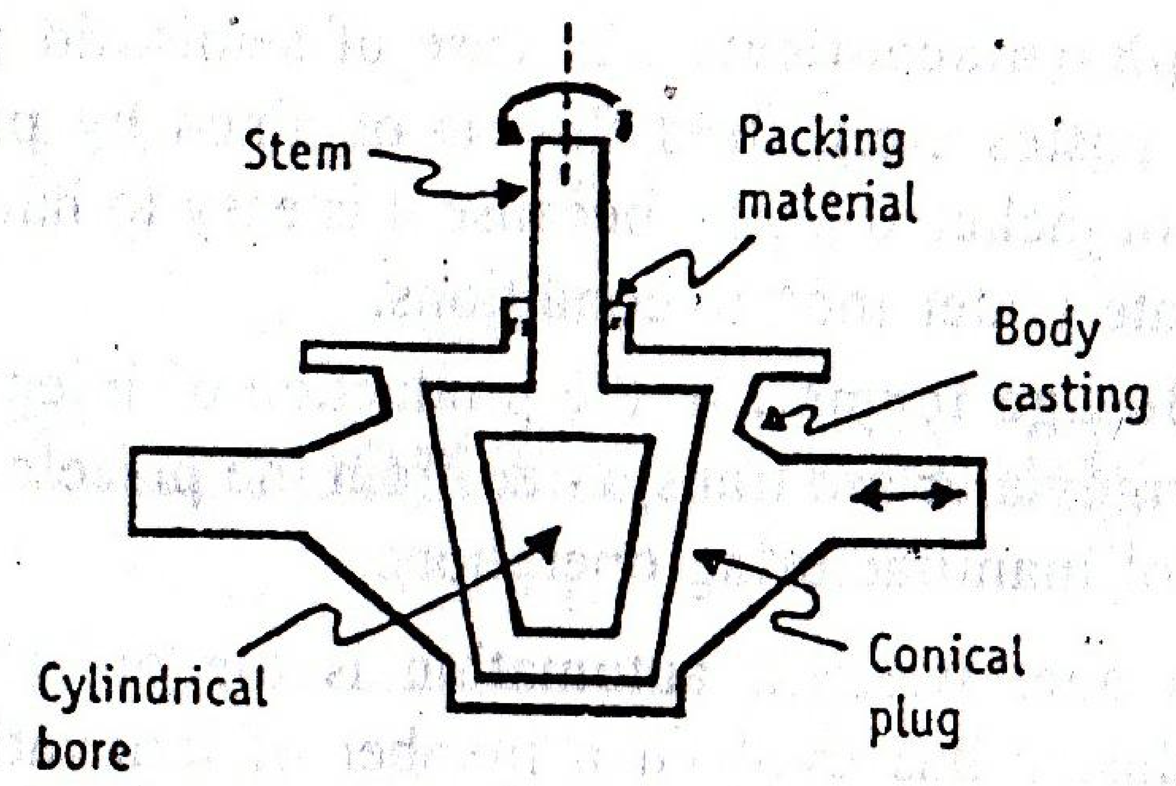


Figure 3-1. Construction of plug valve.

Cocks of wider designs are available with specially shaped openings, where the opening is nearly proportional to the angle through which the plug is turned.

Special design valves include lubricants at the stem of the cock. This lubricant is transmitted to the working faces through small holes drilled through the body of the plug.

Uses : (1) Plug cock valves are used for handling compressed air.

(2) These are used for the purpose of wide opening or complete closing conditions.

Disadvantages : Though it is simple, it has several disadvantages. These are:

(1) Plug cock valves are not suitable for steam or water, because of the cock material.

(2) It is difficult to turn the valves when the plug gets easily wedged in the body firmly. This problem is observed when the sides of the plug are too nearly parallel.

(3) Sometimes the plug comes out of its seat, if the plug sides are tapered too much.

(4) It is difficult to regulate the flow. In normal designs, the area of opening changes rapidly even with slight rotation of the stem. Similarly, flow does not change appreciably when the valve is opened fully.

Globe Valves

The construction of a globe valve is shown in Figure 3-2. A globe valve consists of a globular body with a horizontal internal partition.

The passage of fluid is through a circular opening, which can be opened or closed by inserting a disc in the opening.

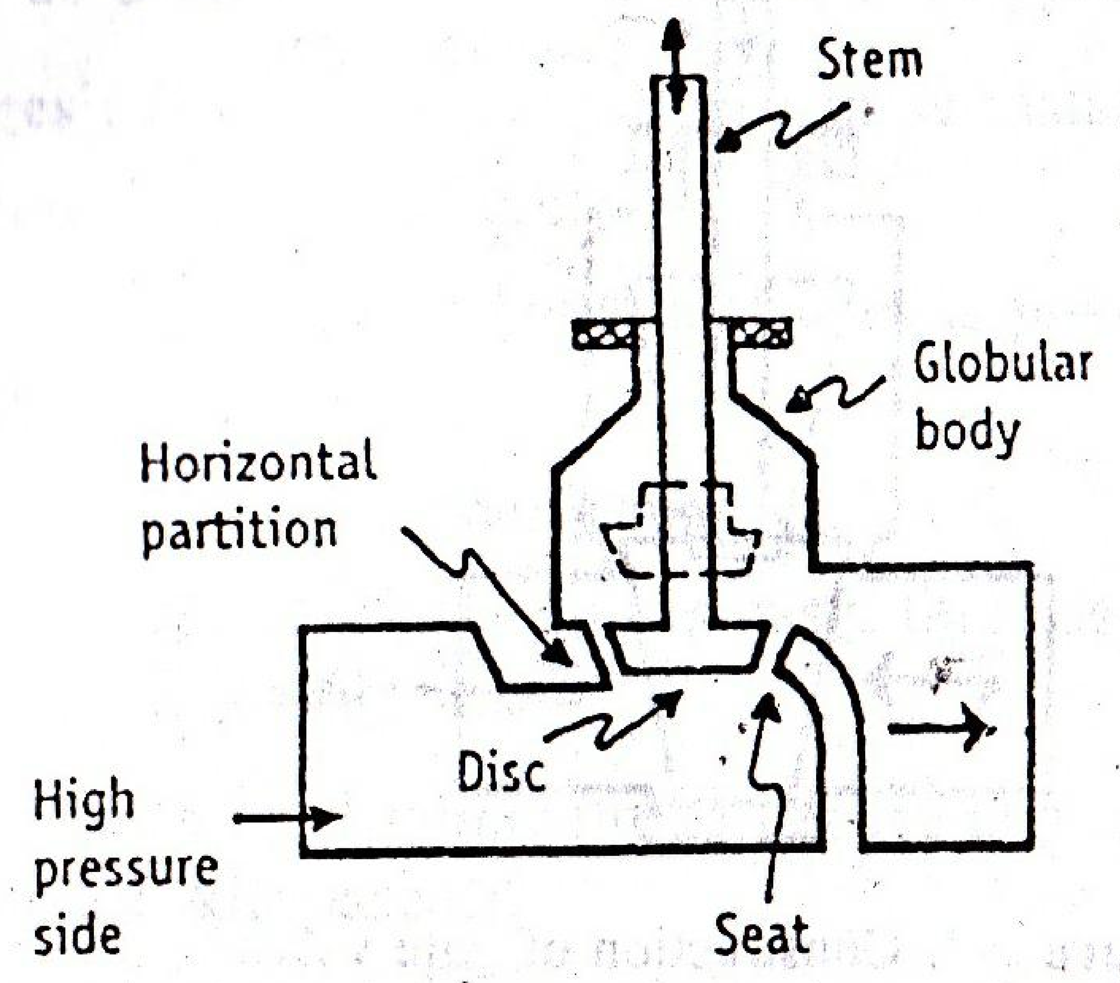


Figure 3-2: Construction of globe valve.

The disc is positioned on the ring, which is known as *seat ring.* The disc can be rotated freely on the stem. Globe valve is installed in the high-pressure side connecting the narrow portion of the disc. Globe valves can be connected in horizontal lines as well as in vertical lines.

The main difference in the variety of globe valves is the construction of the valve, namely disc and valve seat. Normally, cheaper valves have no separate seat ring. Good valves have the seat ring, which permits the ease of renewal. Angular valve is a modification in which an elbow fitting and a globe valve are combined in one compartment.

Uses : Globe valves are mainly used in pipes with sizes not larger than 50 millimetres. In horizontal lines, these valves prevent complete drainage.

Disadvantages : Rust, scales or sludge prevent the opening of the valve.

Gate Valves

The construction of a gate valve is shown in Figure 3-3. A wedge-shaped, inclined-seat type of gate is most commonly used. The pressure on the gates is controlling factor in large valves.

Two types of gate valves are available. In non-rising stem valve, the thread of the valve stem engages the gate. The gate can be raised and lowered without the movement of stem through the stuffing box. The advantage is that the overall length of the stem required is less. In the rising stem valve, the length of the stem is more, since the stem and gate are a single piece.

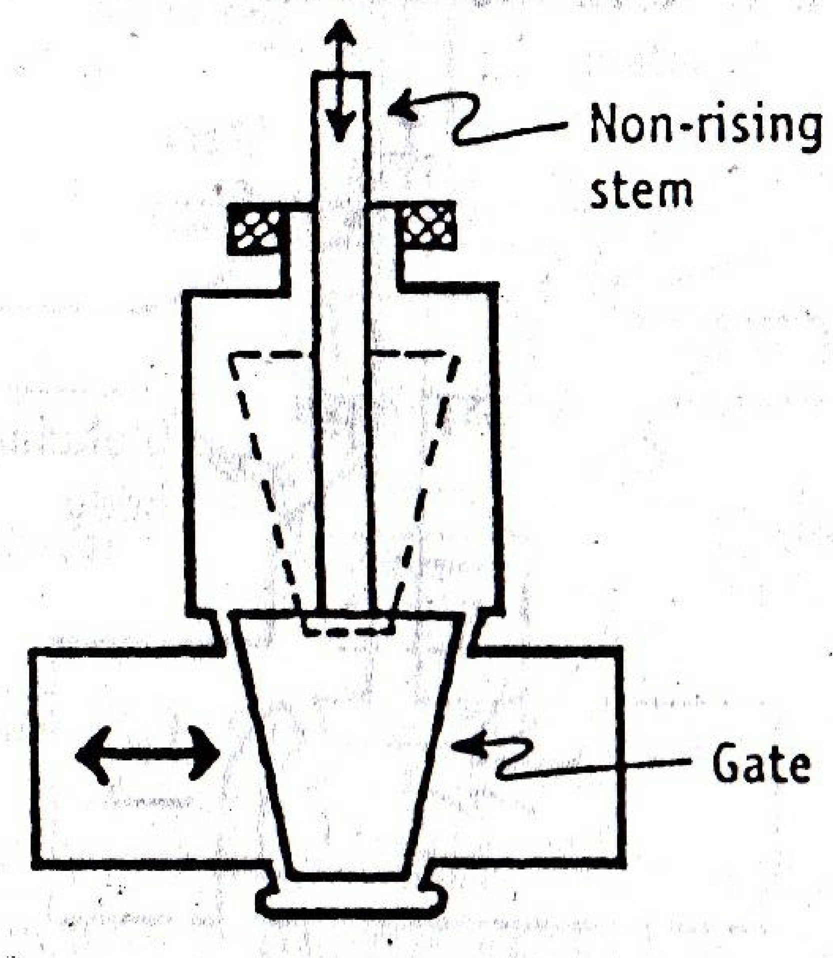


Figure 3-3. Construction of gate valve.

Advantages : (1). Gate valves are available in large sizes.

(2) These are available in a variety of designs to suit the conditions.

(3) Gate valves minimise the differential pressure during opening and stopping the flow.

Diaphragm Valves

The construction of a diaphragm valve is shown in Figure 3-4. Diaphragm is a flexible physical barrier. These valves are made of fabric reinforced, natural rubber and/or synthetic rubber faced with Teflon, a flurocarbon resin.

Special grades of rubber diaphragms coated with PTFE (polytetrafluoroethylene or teflon) are resistant to repeated steam sterilisation.

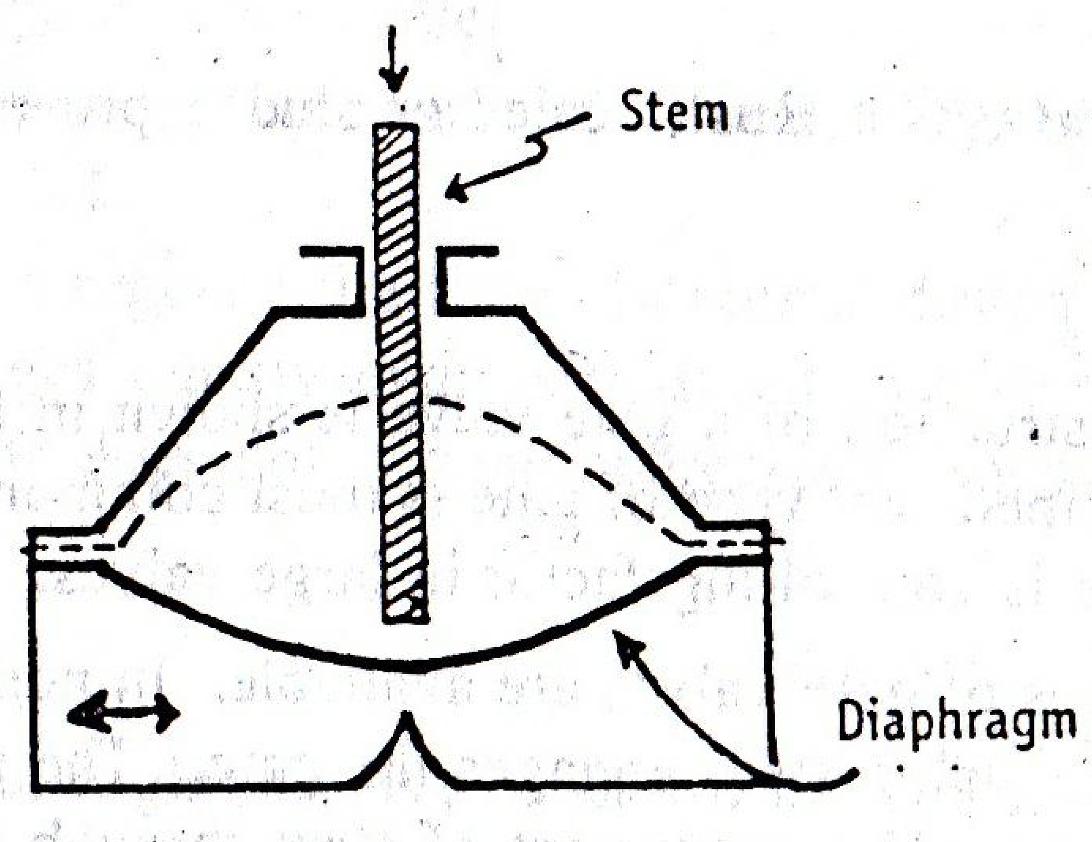


Figure 3-4. Construction of a diaphragm valve.

Uses : Diaphragm valves are more suitable for fluids containing suspended solids. Special types of diaphragms can be easily sterilised so that they can be used in the production of sterile products.

Advantages : (1) Diaphragm valves can be installed in any position.

(2) Pressure drop is negligible.

(3) Complete draining in horizontal lines is possible.

(4) Simple.

(5) Excellent operation (performance).

(6) Replacement of diaphragm is easy, there is no need to remove the valve from the line.

Disadvantages : (1) Diaphragm valves are applicable to pressures of approximately 340 kilopascals.

(2) Maintenance cost increases because of replacement of faulty diaphragms.

(3) These valves are expensive.

Quick Opening Valves (QO Valves)

In the gate valve, stem is threaded. Therefore, a number of turns are necessary to close the valve completely. QO valves have smooth stems and are opened or closed by lever handle in a simple operation. These are convenient, but involve the danger of water hammer.

Water hammer : When a liquid is flowing in a pipe, it is associated with considerable kinetic energy due to its mass and velocity. When such a flow is suddenly stopped, the velocity is suddenly destroyed. Since liquids are incompressible, the energy appears as an intense shock. Sometimes, this shock can be about 60 times the velocity of the fluid. Hence, QO valves are used only in short lines. On large lines, the valve should be closed slowly.

Check Valves

These valves are used when unidirectional flow is desirable. Protective mechanism is included to prevent the reversal of flow. These are automatically opened, when the flow of fluid builds up the pressure.

(a) Swing check
(b) Ball check
(c) Lift check, vertical.

The construction of check valves is given in Figure 3-5.

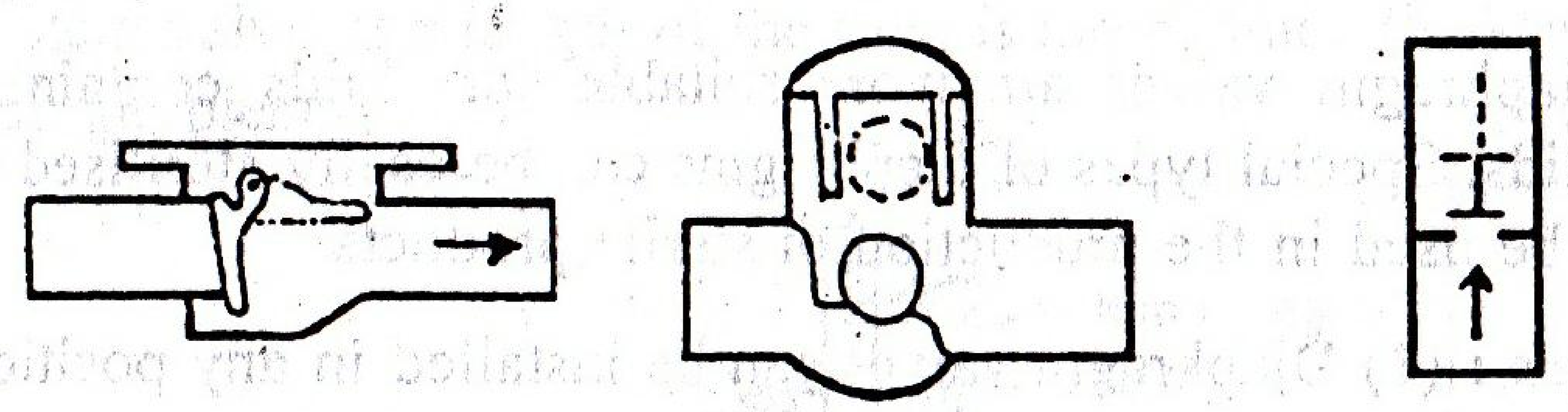


Figure 3-5. Construction of check valves.

Valves are classified depending on their functions. These are:

Reducing valves : These valves are used in order to maintain uniform pressure in one part of a system lower than the pressure in another part of the system. These valves are merely a special case of regulating valves.

These valves are installed in a high pressure steam line to give a constant, but lower pressure of steam in a steam coil.

Regulating valves : These valves are used to control the flow so as to maintain some other variables such as temperature and concentration at constant values.

PUMPS

Pump is a mechanical device to increase the pressure energy of a liquid. In most of the cases, pump is used for raising fluids from a lower level to a higher level. A number of pumps have been developed to meet a variety of operating conditions. Their principles of working and construction are widely different. The classification of pumps are:

Reciprocating pumps, examples are piston pump, plunger pump and diaphragm pump.

Rotary pumps, examples are centrifugal pumps and gear pumps.

Miscellaneous pumps, example is peristaltic pump.

Some of them are discussed in the following sections.

RECIPROCATING PUMPS

In *reciprocating pumps*, the pumping element moves in forward and backward directions in a cylinder. This cylinder is known as *water cylinder*, since it is usually used for pumping of water. In a simple

reciprocating pump, the pumping element moves forward (down stroke or delivery stroke) to push the liquid out as a discharge (output), later it recedes (suction strike) to draw the liquid in as an input. Normally, the pumping element is either a piston or a plunger.

The reciprocating pump is a positive acting type, i.e., a displacement pump. The pump creates pressure and lifts the liquid by the displacement of a moving member.

Uses : These are used for injection of small quantities of inhibitors in polymerisation units and corrosion inhibitors to high pressure systems. These are also used for boiler feed water applications.

Any form of power may be utilised to drive the piston rod. The movements may be applied through a piston rod or a crankshaft using either steam (*steam pumps*) or power (*power pumps*).

Steam reciprocating pumps : In these pumps, the steam cylinder contains a piston, which is directly connected to a piston rod of the water cylinder. This is the most common in reciprocating pumps. Steam pumps can have one steam cylinder with piston (simplex pump at steam-end) or two cylinders each having separate piston (duplex pump at steam-end). Normally, these two cylinders are mounted side by side in the same casing.

Power reciprocating pumps : The power pumps include all forms of reciprocating pumps, in which the piston is actuated by some form of energy other than steam. An example is an electric motor. The movement of the crankshaft is usually through gears by a belt from a line shaft using an electric motor. The common form of such a pump is the vertical, single-acting triplex power pump.

In general, the reciprocating pumps are classified based on the construction of water cylinders. These are two types.

(a) Piston Pumps
(b) Plunger Pumps

These are discussed in the following sections.

Piston Pumps

In *piston pumps*, the piston reciprocates in the enclosed space of the water cylinder. The piston carries the packing material along with it. As the piston moves, the packing material also moves along with it. The general classification of piston pumps is given in Figure 3-6.

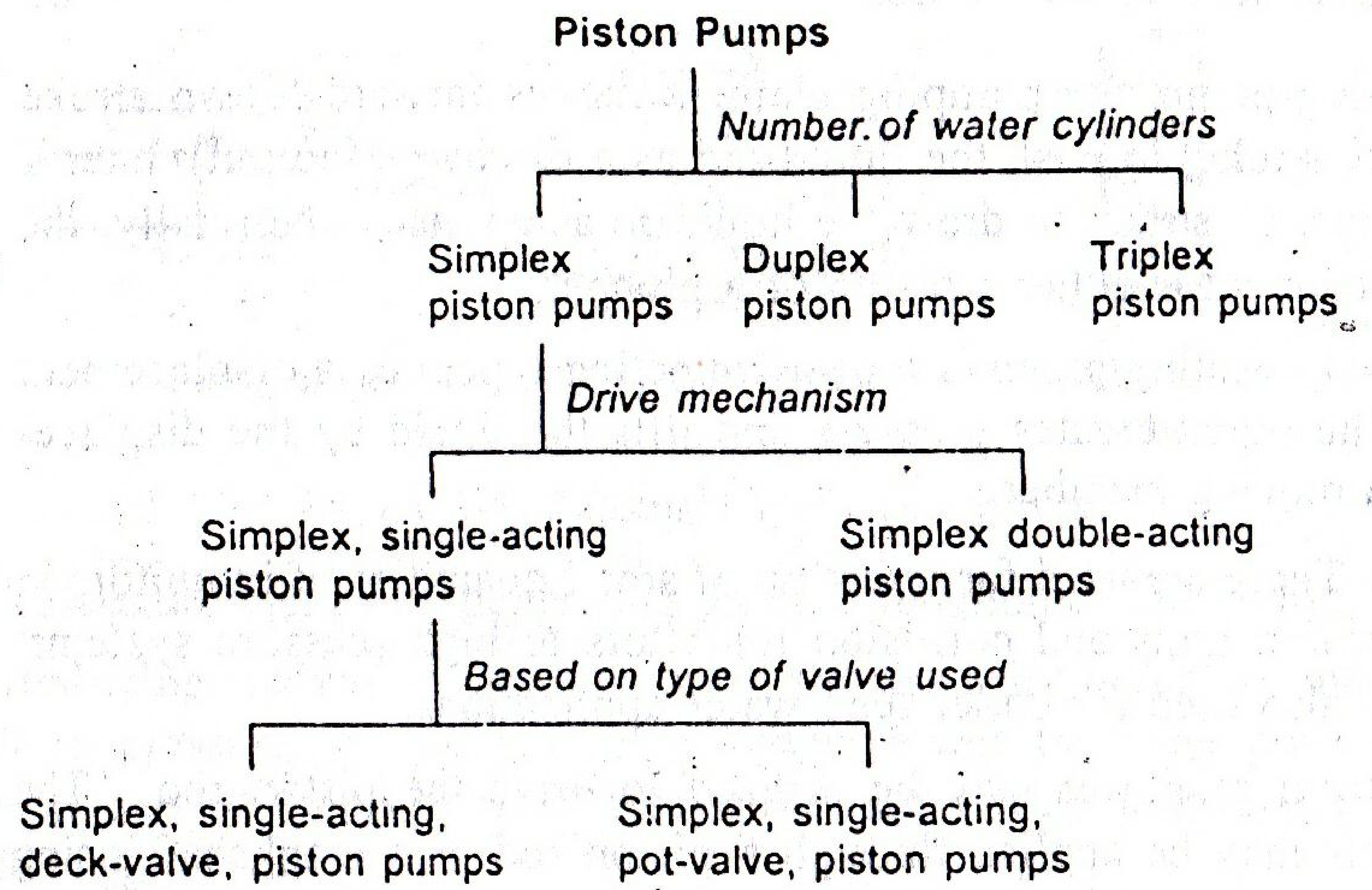


Figure 3-6. Classification of piston pumps. Further classification for duplex and triplex piston pumps follows the same sequence as that of simplex pump branching.

Piston pumps are classified based on the number of water cylinders.

Number of cylinders	*Name*	*Connecting system from steam end to water end*
One	**Simplex**	piston rod is joined
Two	**Duplex**	piston rods are joined separately
Three	**Triplex**	piston rods are joined separately

In a duplex pump, two water cylinders are arranged separately side by side in the same frame. Their piston rods are connected separately to two steam cylinders, which are also arranged side by side in the same frame in the steam end. Connecting several cylinders has an advantage of making the discharge more uniform and free from pulsation.

Each water cylinder may have different drive mechanisms and further classified as:

1. Single-acting piston pumps
2. Double-acting piston pumps

1. Single-acting piston pumps : These displace water on one half of the cycle of the piston movement, normally during the down-stroke. During the other half of the cycle (backward-stroke), the cylinder receives the fluid. Such a pump requires a minimum of two valves: one for receiving the liquid into the cylinder and the other for pumping the liquid out of the cylinder. Single-acting pumps have limited capacity in handling liquid and the discharge is pulsated.

2. Double-acting piston pumps : These displace water on both halves of the cycle. Such a pump requires a minimum of four valves. Two valves are used for suction (to receive fluid) and two valves are meant for pumping the liquid out. Several valves are used in order to pump the discharge at high velocity and more volume of water, during one-half of the stroke. The mechanisms of action of these valves are illustrated in the simplex, double-action, steam-driven, deck-valve, piston pump, which is given in the later section.

Since valves are employed in the pumping, the construction of valves is important for its effective functioning. These are classified as follows.

- Deck valve
- Pot valve

Deck valve : In this valve, springs are attached to the stem, which hold the valve disc against the valve seat. The valve is a non-returnable-one way, so that the flow is unidirectional. For high pressures deck valve is not suitable. Some times, bigger sizes of deck valves are necessary to give a high-pressure discharge.

Pot valve : Pot valves usually have metal discs, which are often provided with guide vanes to keep them in right alignment. The valve is a non-returnable-one way, so that the flow is unidirectional. These are required, when fluids are handled at high pressures. In case of viscous liquids and liquids with very high pressures, loose metal balls are used in place of the valve disc, since these are not strong enough to withstand.

The general principles described above are combined and illustrated using a model piston pump given below.

Simplex, Double-Acting, Steam-Driven, Deck-Valve, Piston Pump

Construction : The construction of a simplex, double-acting, steam-driven deck- valve, piston pump is shown in Figure 3-7. In the water cylinder, a piston consists of two discs with rings of packing between them. These are arranged such that outer packing can be drawn up to compress it. The piston may operate in a cylinder bored directly in the pump casting. In some pumps, the piston operates in a removable bronze liner.

This pump has four valves, i.e., double-acting. The lower row valves, E_1 and E_2, are suction valves and the upper row valves, F_1 and F_2 are discharge valves. For this purpose deck valves are used. The valve disc is made of hard rubber or metal. The valve is a non-returnable-one way so that the flow is unidirectional.

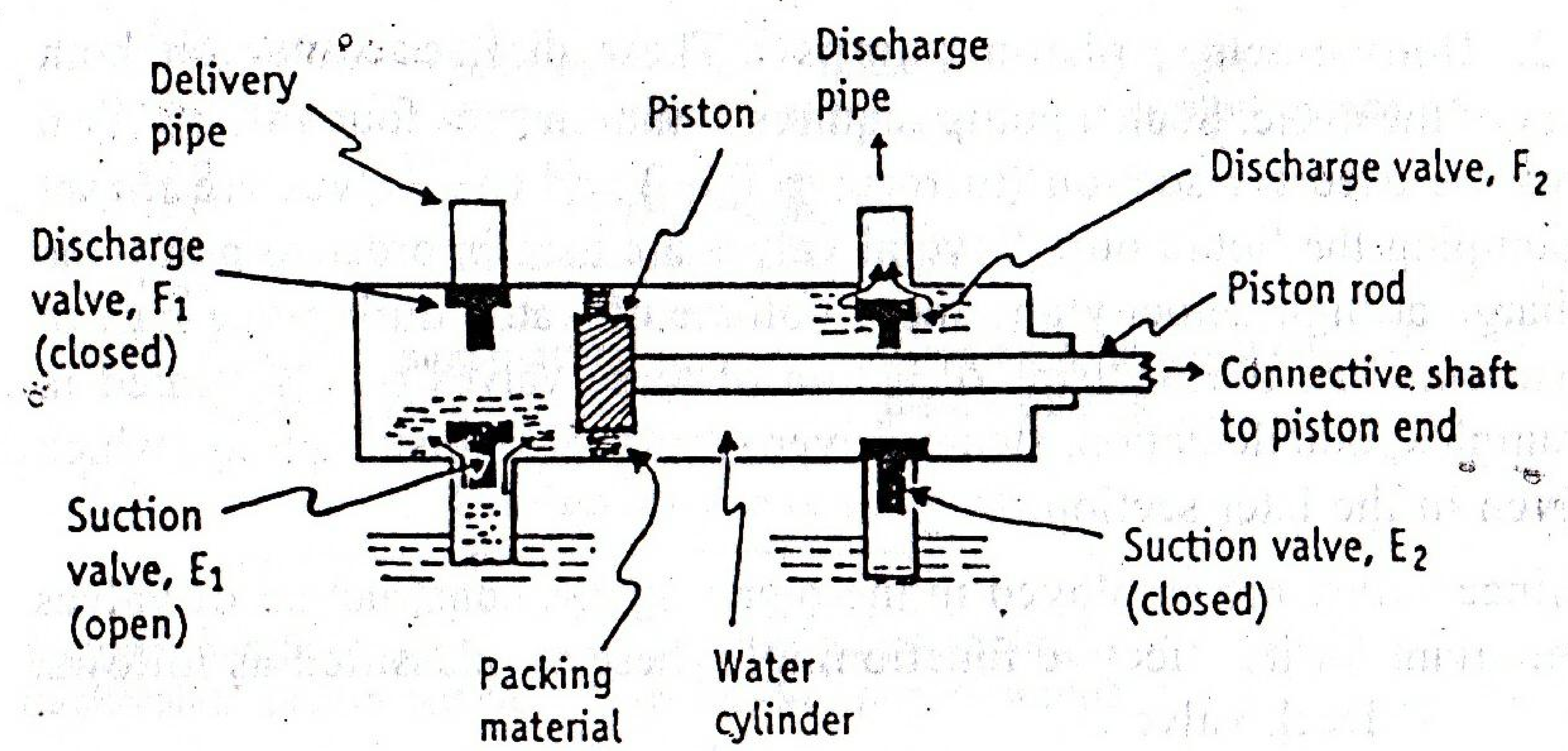


Figure 3-7. Construction of simplex, double-acting, steam-driven, deck-valve piston pump. Working principle is illustrated.

Working : Steam is used at full pressure for the entire stroke in order to maintain a constant pressure on the water end. This enables the pump to produce uniform discharge (output). The steam pressure sets the piston in motion at steam end. This makes piston to reciprocate in the water cylinder.

The valves are unidirectional. The movement of the piston creates vacuum and atmospheric pressure forces the water up through the suction pipe into the cylinder. The liquid pressure in the water cylinder allows the discharge valves (or delivery valves) to open.

When the piston is moving from left to right, the events occur in the following sequence.

Left side cycle	*Right side cycle*
E_1 (suction) valve opens : Water enters the cylinder from left side.	**E_2 (suction) valve closes :** Water does not enter the cylinder due to pressure.
F_1 (discharge) valve closes : Water will not be discharged from this left side.	**F_2 (discharge) valve opens :** Water (that is already present in the water cylinder) goes out through the discharge end.

Therefore, when the piston moves from left to right, water discharges through the valve, F_2. When the piston moves in the reverse direction, i.e., from right to left, it provides discharge from valve, F_1. Thus, the pump is a double-action pump, since it displaces water on both halves of

the cycle. Large volumes of fluids and at high velocity can be transported, since four valves are used.

Uses : Piston pumps are used for heads up to 60 metres. These pumps can be used, if the liquids are not too viscous, corrosive or abrasive. Piston mechanisms are employed in peristaltic and HPLC pumps.

Applications : Piston pumps are extensively used for spray system in sugar coating and film coating operations.

Disadvantages : (1) Piston pumps are relatively expensive.

(2) These are not easy to clean.

(3) Piston pumps induce coagulation of latex coating systems under conditions of significant line pressure.

Plunger Pumps

In *plunger pumps*, a plunger reciprocates in enclosed space of the water cylinder. The term plunger refers to an element, which moves past the stationary packing. The general classification is given in Figure 3-8.

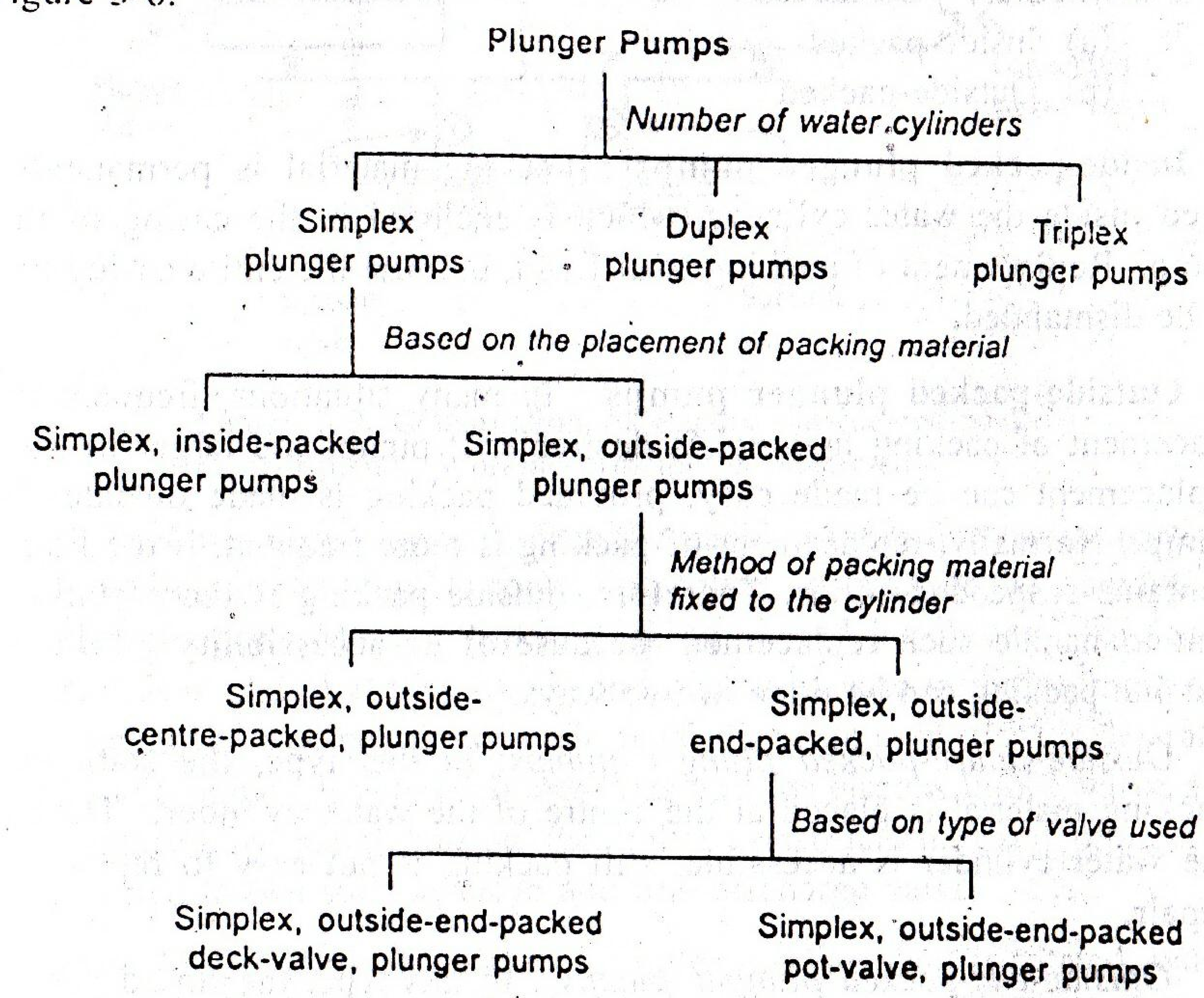


Figure 3-8. Classification of plunger pumps. Further classification for duplex and triplex plunger pumps follows the same sequence as that of simplex pump branching.

Plunger pumps are classified based on the number of water cylinders.

Number of cylinders	*Name*	*Connecting system from steam end to the water end*
One	**Simplex**	plunger rod via shaft
Two	**Duplex**	via crankshaft
Three	**Triplex**	via crankshaft

When the number of cylinders is more, these are connected in parallel to a crankshaft. For example, in a triplex pump, three plungers are connected to a crankshaft at points 120° apart.

Connecting several cylinders has an advantage of making the discharge more uniform and free from pulsation. It is better to use several cylinders each of small size, thereby it is easier to build up high pressure and maintain packing.

Since packing material is permanently fixed in the water cylinder, it can be placed in any position. Based on its placement, plunger pumps are classified as:

(a) Inside-packed
(b) Outside-packed

Inside-packed plunger pumps : Packing material is permanently fixed inside the water cylinder, which is enclosed in the casing of the pump. Replacement of packing is difficult, because the entire casing has to be dismantled.

Outside-packed plunger pumps : In many situations, frequent replacement of packing material is desirable. If pumps are larger in size, replacement can be made easy, provided packing is made outside the pump. Normally, replacement of packing is more frequent, if the liquid contains suspended solids. Therefore, outside packing is more convenient to handle such replacement because of its accessibility. Further, outside packing can be done in two ways.

Outside-centre-packed plunger pumps: In this type, the stationary packing material is placed at the centre of the water cylinder. Though the water cylinder is accessible, still packing is not easy to replace or repair.

Outside-end-packed plunger pumps : In this type, the liquid can be pumped at high pressures, because packing can be more easily maintained. Repairs and detection of leaks are easy, if the packing is outside and end-packed in a water cylinder.

The general principles described above are combined and illustrated using a model piston pump given below.

Duplex Outside-End-Packed, Power-Driven, Pot-Valve, Plunger Pump

Construction : The construction of the water end of a duplex outside-end-packed plunger pump is shown in Figure 3-9. In the plunger pump, a plunger moves past the stationary packing. Since the pump is duplex, the water cylinder is divided into two parts (A and B) by a partition. Two plungers are used. Both halves of the plungers A and B are connected to the same driving mechanism and power supply.

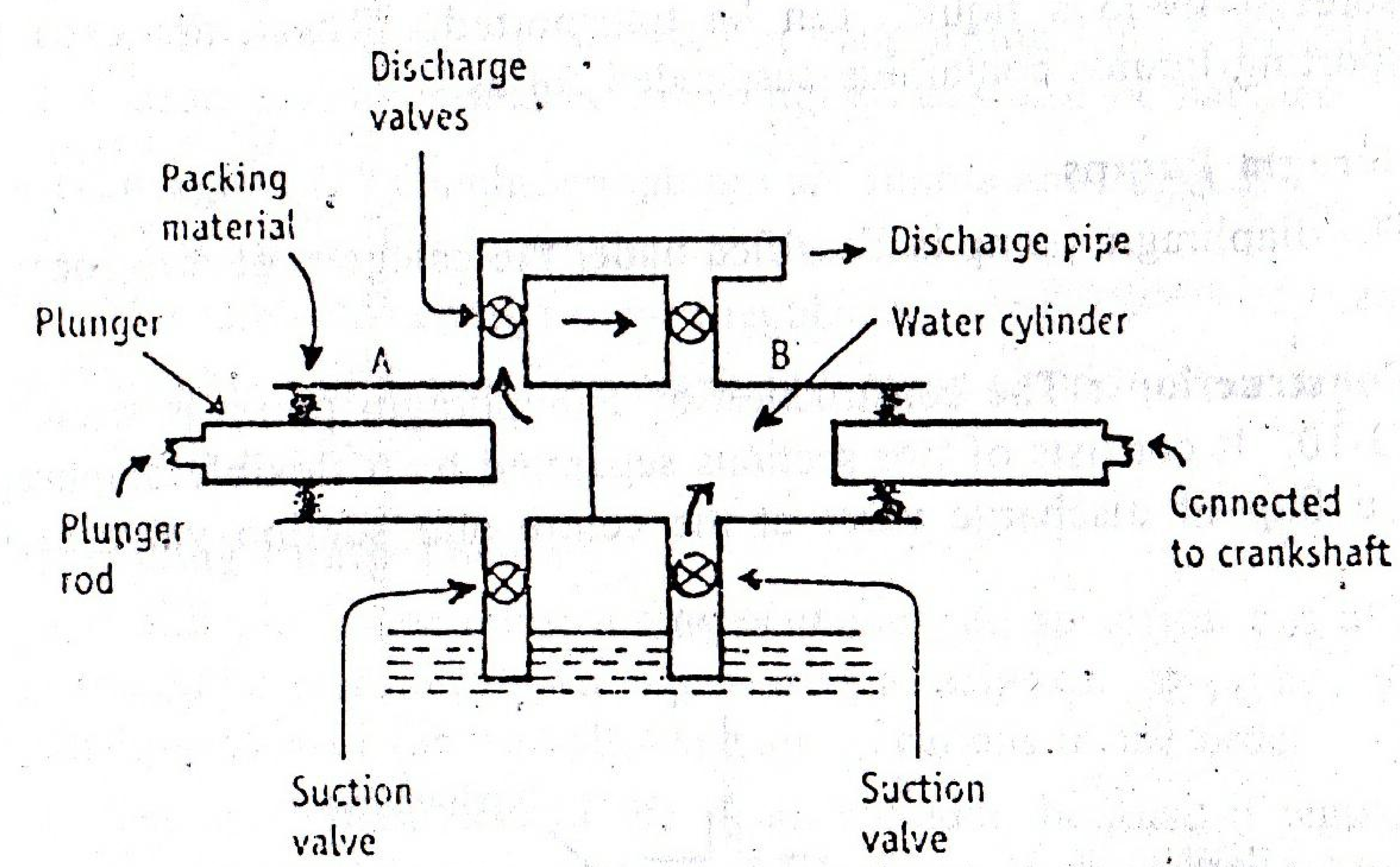


Figure 3-9. Construction of duplex outside-end-packed plunger pump. Working principle is illustrated.

It becomes necessary to replace the packing more frequently, particularly while pumping liquids containing solids. It involves the dismantling of the plunger. Many a times, packing should be checked for leaks. Hence, it is placed at the outside-end due to its ease in replacement and maintenance. The pot valves with metal discs are used. If it is desirable to handle liquids at very high pressures and for viscous liquid, valve disc is replaced by metal ball in the valve construction. Each plunger is connected to one suction valve and one discharge valve.

Working : Through an electric motor the line shaft is rotated, which further rotates the gears through a belt. The gears set the two plungers in motion in the two water cylinders (A and B). Each plunger is connected to one suction valve and one discharge valve.

The valves are one-way so that the flow is unidirectional. The movement of the plunger creates vacuum and atmospheric pressure forces the water up through the suction pipe into the cylinder. The liquid pressure in the water cylinder allows the discharge valves (or delivery valves) to open.

The two plungers are allowed to reciprocate in such a manner that at any moment, water enters into left-side cylinder, while water discharges through the right-side cylinder or vice versa. This ensures continuous pumping of water (non-pulsating). Large volumes of fluids at high velocity can be transported, since four valves are used in this case.

Uses : Plunger pumps are suitable for handling liquids at high pressures. Viscous liquids can be transported. These are used for transporting liquids containing suspended solids.

Diaphragm Pumps

The diaphragm pump is classified under the category of reciprocating pumps.

Construction : The construction of a diaphragm pump is shown in Fig. 3-10. It consists of two sections separated by a flexible diaphragm with a flap of discharge valve at the centre and suction valve at the

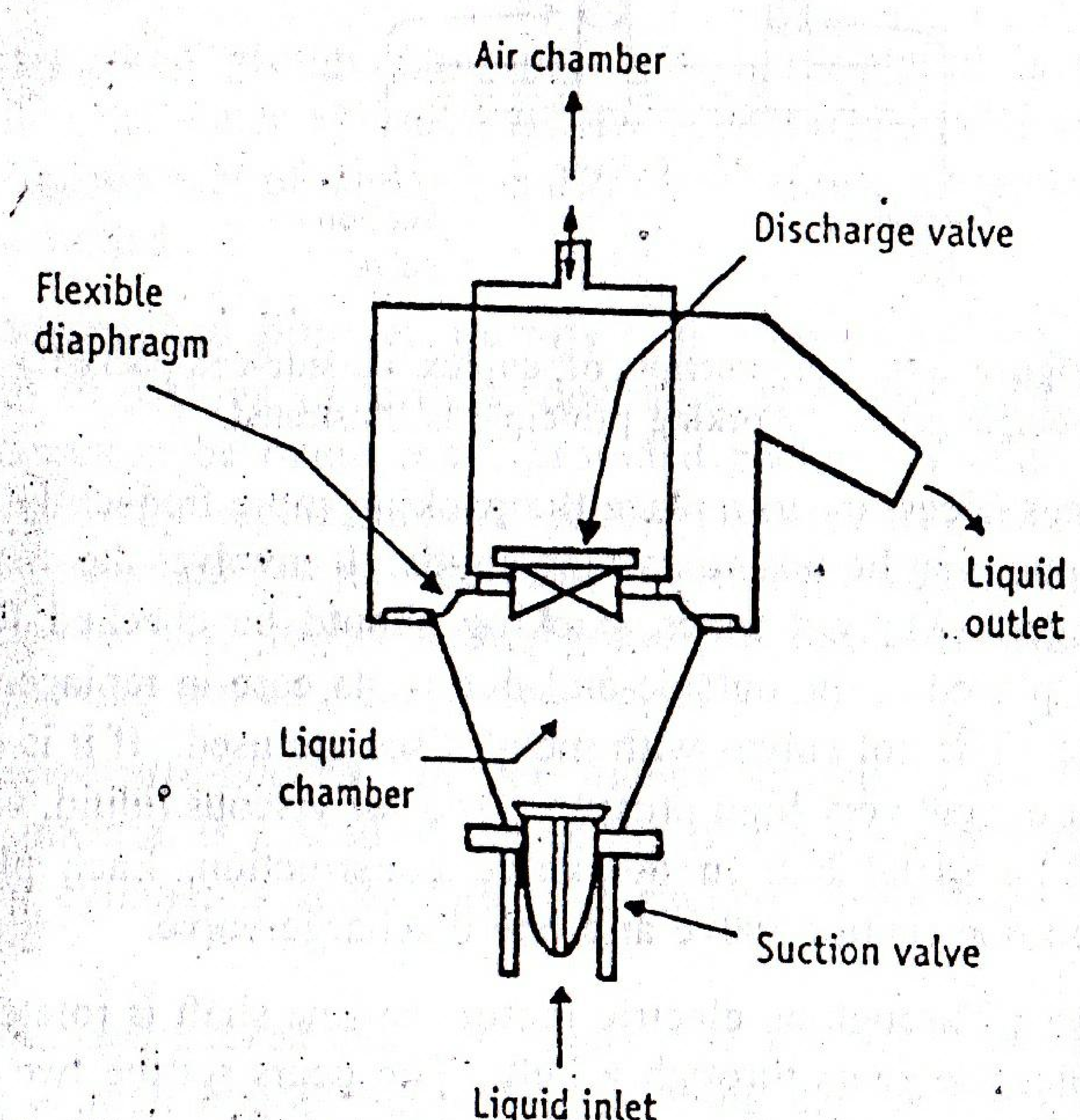


Figure 3-10. Construction of a diaphragm pump.

bottom. Diaphragm is fabricated with the materials such as metal, rubber and plastic.

Working : Through an air chamber, suction is applied so that the flexible diaphragm is pulled up (expanded). As a result, the suction valve is lifted up and the liquid enters the water chamber. When sufficient pressure is built up, the liquid lifts up the discharge valve. Then the liquid flows out. At this stage, both valves are opened so that suction and discharge operate simultaneously. Therefore, non-pulsating discharge is achieved. The stroke can be varied and discharge can be controlled within accurate limits.

Uses : Diaphragm pumps are used in transporting liquids containing solids. Hazardous, toxic and corrosive liquids can also be handled.

Advantages : (1) Diaphragm pumps are simple and rugged.

(2) They can be easily repaired.

(3) The rate of discharge can be regulated.

(4) Packing and seals of the diaphragm pump are not exposed to the fluids.

Reciprocating Pump Theory

As mentioned in the construction of pumps, all specifications of the pump should be mentioned, while procuring a reciprocating pump. Special attention is paid for the following specifications in the order.

1. The size (diameter) of the steam cylinder, because it regulates the pressure to be generated on the piston in the water cylinder.
2. The size (diameter) of the water cylinder, as it controls the desired discharge.
3. The length of travel of the piston.

Since piston displacement is essential for the discharge of fluid, it is necessary to evaluate the water cylinder in quantitative terms of efficiency. The displacement in the water cylinder may be theoretically expressed as:

$$\text{Theoretical displacement of double-acting pump } (m^3/min) = \text{piston speed } (m/min) \times \text{area of the piston } (m^2) \quad (1)$$

$$\text{Theoretical displacement of single-acting pump } (m^3/min) = (1/2) \text{ piston speed} \times \text{area of the piston} \quad (2)$$

When the discharge is equal to the theoretical displacement, then displacement is considered as 100%. It is not possible to achieve 100% theoretical displacement, as there are losses during the functioning of a pump. These losses are due to:

* slippage past the piston
* imperfect packing
* leaking of valves
* failure of a valve to close instantly

In practice, the actual discharge could be 50 to 90 % of theoretical displacement. The actual discharge is known as *volumetric or water-end efficiency*. Normally, low-speed pumps are more efficient, provided packing of the material and valves are in good condition. The lower figures of water-end efficiency represent poor packing of pumps and working at high speeds. Such conditions produce excessive wear and tear on:

* valves
* valve springs
* packing

Steam cylinder end : Since steam cylinder is responsible for driving the piston in the water cylinder, the force applied is evaluated as:

$$\textit{Force acting on the piston rod in steam cylinder} \text{ (N)} = \text{steam pressure (Pa)} \times \text{area of steam piston (m}^2\text{)} \quad (3)$$

Water cylinder end : In the absence of friction, the entire force would be transferred to the piston of the water cylinder. Under ideal conditions, it is expressed as:

$$\textit{Theoretical maximum water-end pressure} \text{ (Pa)} = \frac{\text{force acting on the piston rod (N)}}{\text{area of water piston (m}^2\text{)}} \quad (4)$$

Normally, it is expected that the piston remains stationary, if the total force on the steam piston is equal to the total force on the water piston. In order to do work on the liquid and to overcome pump friction, total force on the steam piston should be greater than the theoretical force

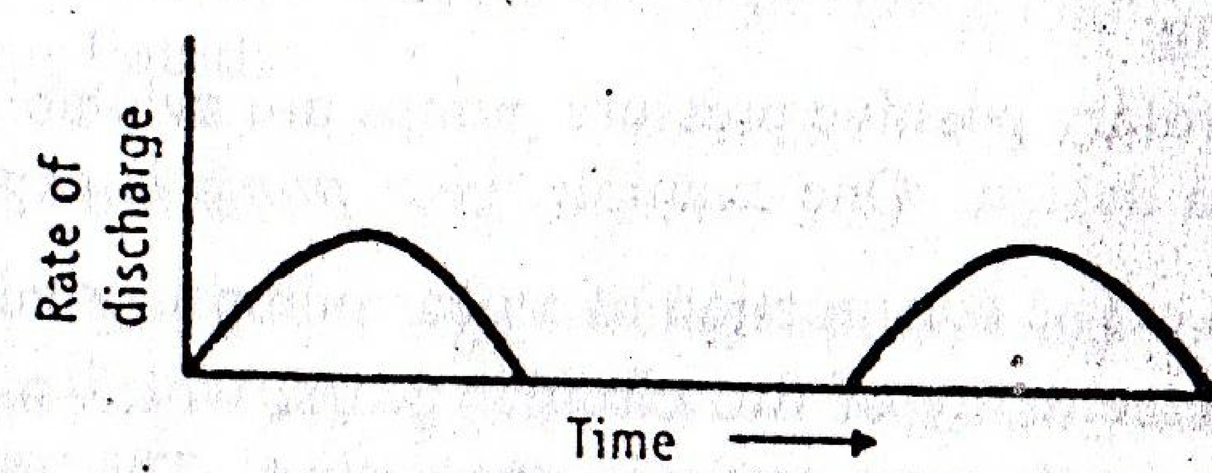
$$\textit{Steam-end or pressure efficiency} = \frac{\text{theoretical pressure on the steam piston (Pa)}}{\text{actual pressure needed (Pa)}} \times 100 \quad (5)$$

This efficiency varies from 60 to 80%.

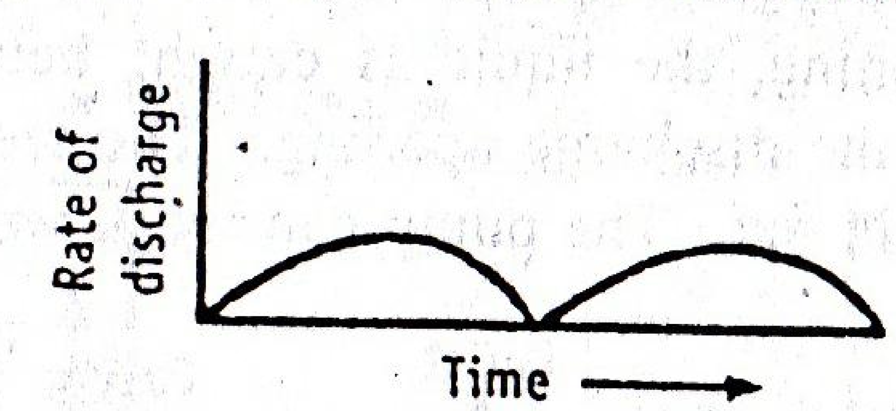
Nature of discharge : The liquid discharge in a single cylinder pump is shown in Figure 3-11. In a single cylinder pump, the discharge is zero at the beginning of the stroke. As the piston reaches full speed at the centre of the stroke, the discharge rises to a maximum. From this point, it decreases to zero at the end of the stroke. Thus the discharge is not uniform, but pulsating (Figure 3-11a).

Several measures may be followed in order to obtain desired nature of discharge as given below.

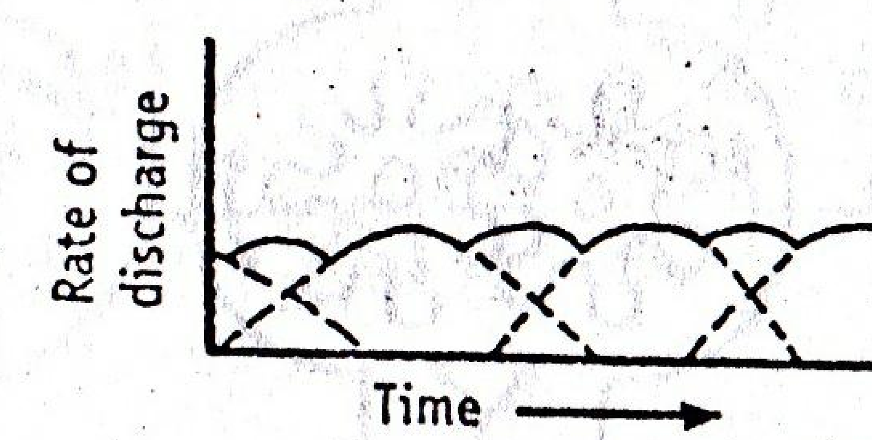
-- Pulsating discharge can be removed by using a duplex pump with a piston set half a stroke apart (Figure 3-11b).
-- For high pressures, a triplex pump is more suitable, since it avoids shocks and pulsations. The theoretical discharge from a triplex pump is shown in Figure 3-11c.
-- For very high pressures, pump with five cylinders on a single crankshaft is employed to make the discharge still more uniform.
-- A large air dome connected to the discharge side further reduces the fluctuations. The air in the cylinder will be compressed, when water piston is accelerating and will be expanded when it is decelerating.



(a) Discharge curve of a single acting simplex pump.



(b) Discharge curve of a single cylinder, double acting pump.



(c) Discharge curve of single acting triplex pump.

Figure 3-11. Discharge curves of different pumps.

ROTARY PUMPS

Rotary pump is the one by which the liquid can be transported based on the mechanism of rotation of one or more elements within a stationary casing.

The pump consists of two circular discs with lobes, which are geared to each other or single circular impeller with vanes. In these pumps, the rotary mechanism throws the liquid away from it and pumping is achieved. In general, rotary pumps are classified based on the nature of force applied in pumping. These are:

I. Positive displacement pumps
II. Centrifugal pumps

These are discussed in the following sections.

I. Rotary Positive Displacement Pumps

In *rotary positive displacement pumps*, the liquid is mechanically displaced by the rotation (by pressure) of one or more elements within a stationary housing.

A variety of rotary positive pressure pumps are available with significant variations in design. One example, *gear pump* is explained below.

Gear pumps : The construction of a gear pump is given in Figure 3-12. It consists essentially of two circular gears, which mesh with each other. These run in close contact with the casing. The gears are rotated by some external agency. As spaces between the teeth of the impeller pass the suction opening, the liquid is caught between them, carried around the casing to the discharge opening. The teeth come into mesh, which forces the liquid out. The pump can work without valves also.

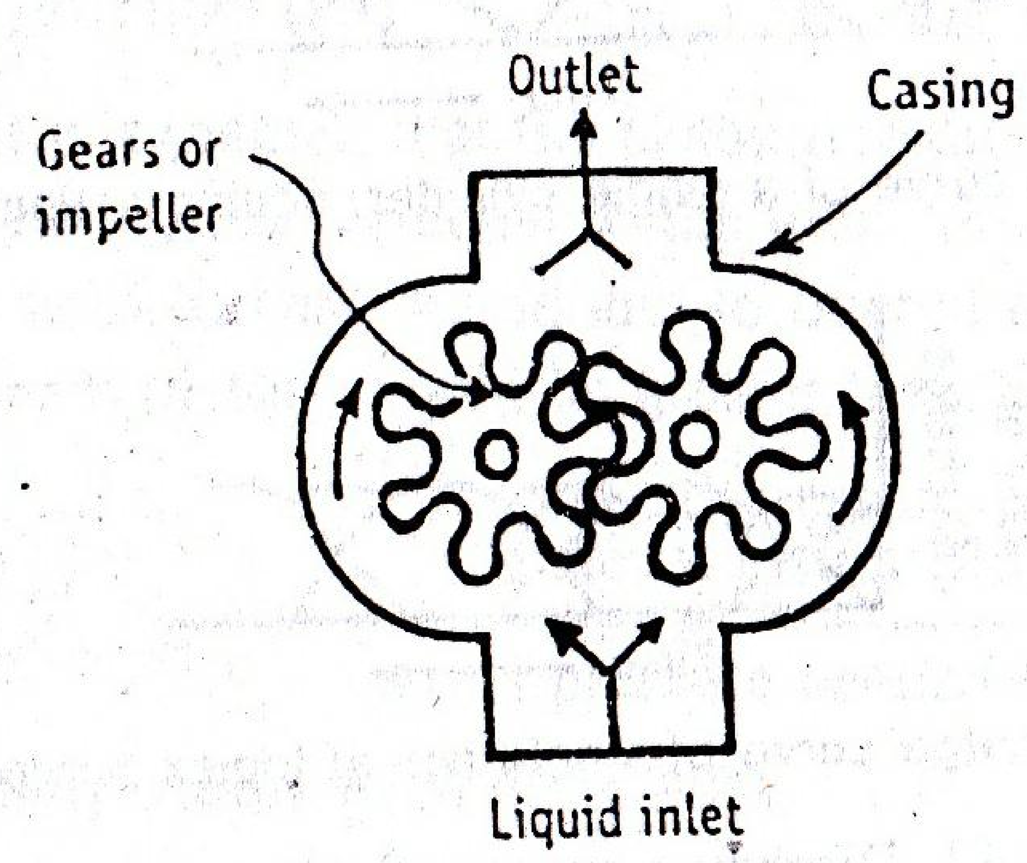


Figure 3-12. Construction of a gear pump.

The number of teeth on each impeller varies from 2, 3 or more. The two or three lobed pumps are generally known as *cycloidal pumps*. If the discharge valve of these pumps is closed while it is running, the pressure is built up inside the pump, which leads to either stopping the pump or breakage. In these pumps, the discharge rate is directly proportional to the speed.

Uses : A gear pump can handle viscous or heavy liquids such as vegetable oil, animal oil, greases, molasses, brine, semisolids and waxes. It is extensively used in aqueous film coating. It can transfer liquids of wide range of viscosities. It is useful when the speeds are not very high. Rotary positive-displacement (gear pump) pump is used to handle liquids that do not contain abrasive material.

Advantages : Gear pumps develop high pressure. It gives a discharge nearly free from fluctuations and independent of pressure.

Disadvantages : Gear pumps are not employed for transportation of solids in suspensions. It requires more complicated clean up procedures. It is likely that latex coating systems coagulate as a result of shear developed as liquid passes through pump head. It is also likely that excessive wear of element occurs while pumping highly pigmented, low viscosity coating liquids.

II. Centrifugal Pumps

The general construction of centrifugal pumps is shown in Figure 3-13. In centrifugal pumps, the blades of impeller rotate by which a reduction in pressure is produced at its centre (Figure 3-13a). This suction draws the liquid into the pump (Figure 3-13b). The basic

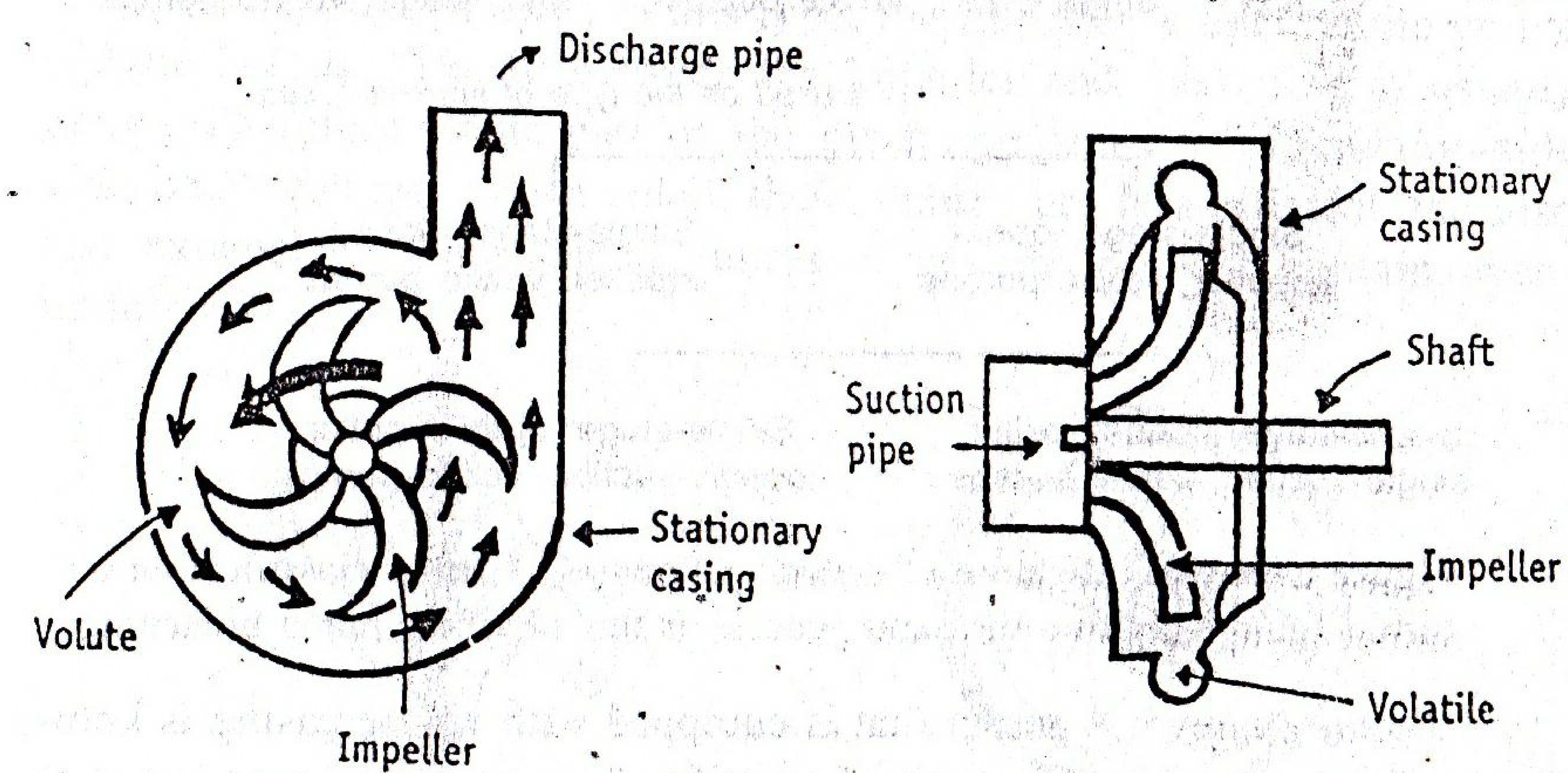


Figure 3-13. The general construction and parts of a centrifugal pump.

function of a centrifugal pump is to produce kinetic energy by the action of centrifugal force and then convert this energy partially to pressure by effectively reducing the velocity. Thus liquid is pumped out at high pressure and then transported.

In short, the centrifugal pump helps to rise liquids from a lower level to a higher level by creating a required pressure with the help of centrifugal action.

Centrifugal pumps have several advantages such as simplicity, low maintenance requirement, low initial costs, quiet operation and non-pulsating flow. These pumps occupy less floor space. Centrifugal pumps can be built with corrosion resistant materials. These have no limitation on the capacity of the pump. Therefore, centrifugal pumps are found practically in every service.

Classification of centrifugal pumps : Centrifugal pumps are classified based on the type of casing of the pump, volume or diffusion. Such a classification of centrifugal pumps is given Figure 3-14.

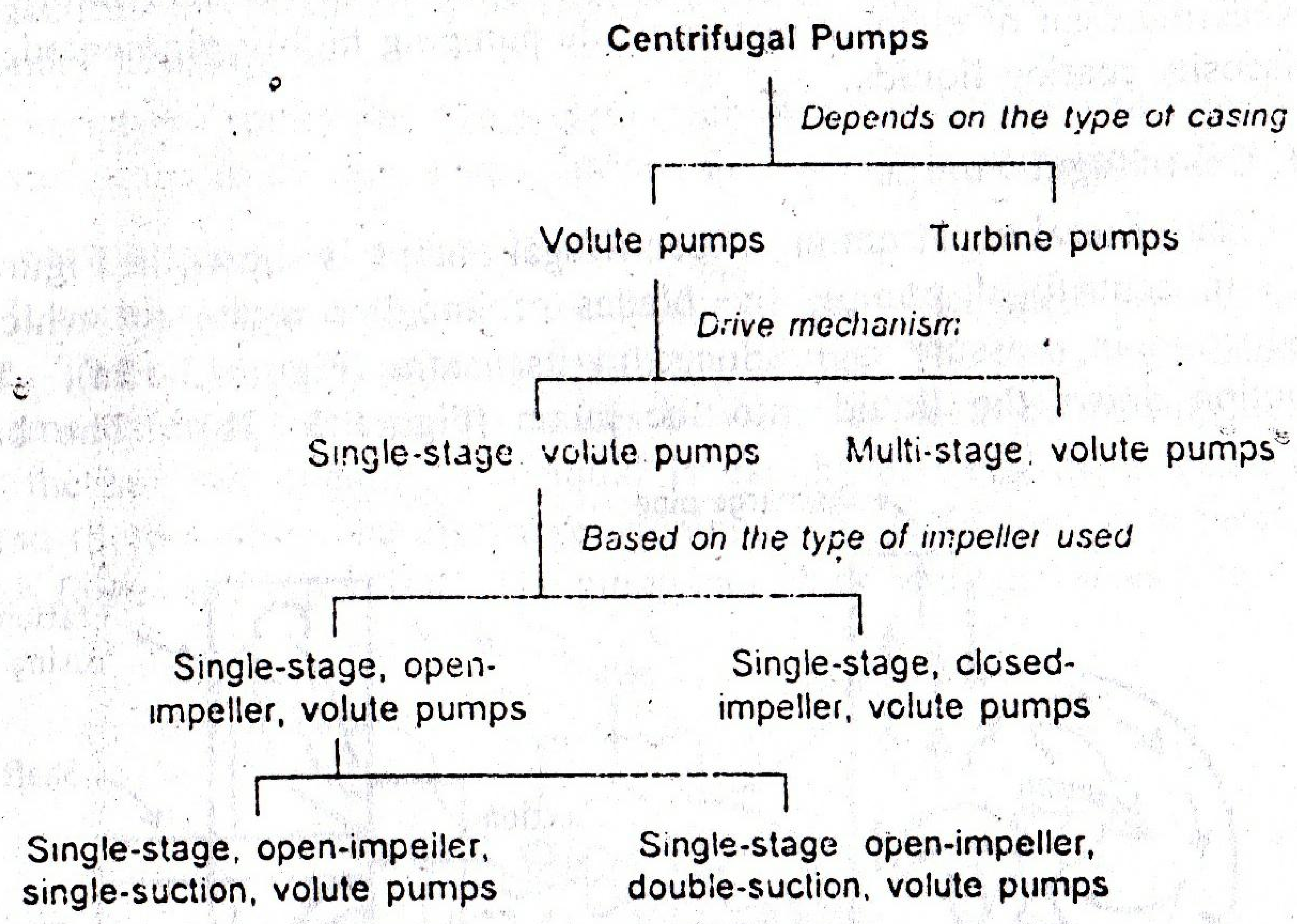


Figure 3-14. Classification of centrifugal pumps. Further classification on turbine pumps follows the same process as that of volute pump branching.

Volute pumps : A pump that is equipped with volute casing is known as *volute pump*. In this type of centrifugal pump, water entering at the suction point is thrown outwards into the volute by the rotation of the curved vanes. As a result, the liquid suddenly changes its direction in the volute, which decreases the velocity head and consequently increases the pressure head. These changes facilitate the pumping of the liquid. The step to change the direction of liquid flow is not smooth. Therefore, these pumps are least efficient. These are also less expensive.

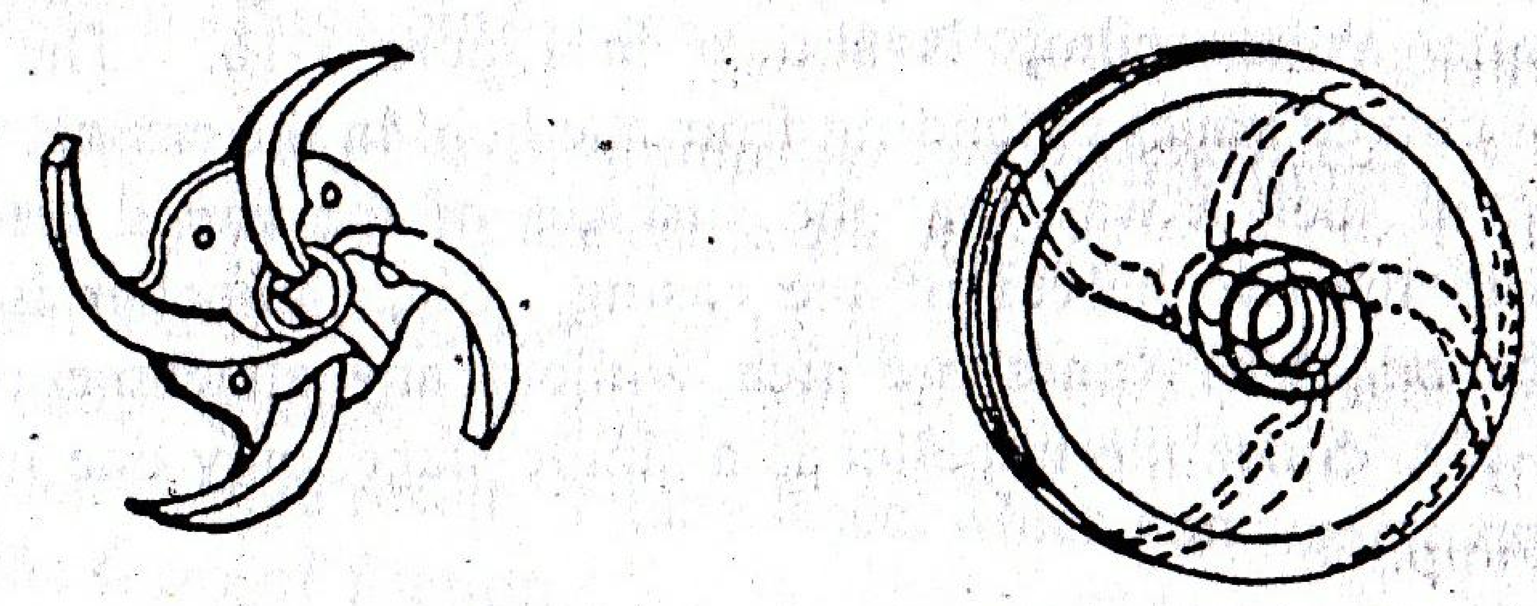
Turbine pumps : A pump in which a diffusion casing equipped with vanes is known as *turbine pump*. In this type of centrifugal pump, a stationary diffusion ring is interposed between the impeller and casing chamber. As a result, the change in the direction is smooth, without shocks during pumping. Therefore, it does not involve energy losses due to eddies as observed in volute pumps. Therefore, turbine pumps are more efficient. However, these are expensive.

Single-stage pumps : In this type, one impeller is employed. Single-stage volute pumps are common and the cheapest. However, their efficiency is the least. The single-stage, turbine pump can generate maximum head of about 90 metres.

Multi-stage pumps : In this type, two or more impellers are placed in series. The liquid from the tip of one impeller is delivered to the inlet of the next impeller with minimum loss. Multi-stage volute pumps are not common, since the losses in each stage would add up leading to a low overall efficiency. In turbine pump, multi-stage can be employed to increase the efficiency of a pump. Heads up to 300 metres may be generated. However, multi-stage turbine pumps are more expensive.

These pumps (volute and turbine) are further classified as follows.

Open-impeller pumps : In this type, the impeller is open to the volute (Figure 3-15a). The fit between the impeller and the casing is usually poor. Therefore, some part of the discharge leaks to the suction-side (i.e., back leakage). As a result, these pumps are less efficient and also less expensive. Many small pumps of general purpose contain open-impeller.



(a) Open impeller (b) Closed impeller

Figure 3-15. Pump impellers.

Closed-impeller pumps : In this type, the impeller vanes are enclosed between two metal sheets (Figure 3-15b). A close fit is maintained between the circumference of the impeller and the entrance of the volute (or between the hub of the impeller and the corresponding point on the casing). Therefore, back leakage of fluid is not observed. These pumps are more efficient and more expensive.

Single-suction pumps : In this type, the liquid enters the impeller from one side only. When such an impeller is allowed to rotate at high speeds, suction is created at its eye (centre), which pulls the impeller away from the shaft. The disadvantage of this pump is the unbalanced hydraulic pressure. As a result, end thrust is produced on the bearings.

Double suction pumps : In this pump, the liquid enters the impellers from both sides. The pump consists of two impellers placed back to back and united in one casing. Therefore, hydraulic pressure is well balanced.

The general principles described above are combined and illustrated using a volute pump given below.

Volute pumps : The space between the edges of impeller and the casing of the chamber is known as *volute*. A pump that is equipped with volute casing is known as *volute pump*.

In this type of centrifugal pump, water entering at the suction connection is thrown outwards by the rotation of the curved vanes into the volute (Figure 3-13). As a result, the liquid suddenly changes its direction in the volute, which decreases the velocity head and consequently increases the pressure head. These changes facilitate the pumping of the liquid. The step to change the direction of liquid flow is not smooth. Therefore, these pumps are least efficient. These are also less expensive.

Single-Stage, Single-Suction, Open-Impeller Volute Pump

Construction : The construction of a single-stage, single-suction, open-impeller volute pump is shown in Figure 3-16. The impeller consists of curved vanes extending from the hub. In the casing, impellers are placed in such a way that the surfaces of the vanes are in close contact with the two halves of the casing. Since impeller is an open runner, the edges of vanes are free without any attachment of rings (Figure 3-16). Since the impeller is a single-stage, only one impeller is used for pumping.

The impeller is attached to a shaft, which is rotated by the use of power from outside. Nearer to the centre (eye) of the impeller, provision is made in the casing to receive the fluid by suction. At the top of casing, an exit for discharge is provided to which volute is exposed.

Working : Power is applied on shaft to rotate. Along with it, the blades of the impeller are also revolved. This results in reduced

pressure at the eye of the impeller. Hence, the liquid flows into the impeller through the inlet suction pipe. This liquid is forced outward along the blades at increasing tangential velocity. The liquid leaves the blade tips and passes into the volute chamber. In this process, its velocity head decreases and consequently pressure head is increased. The liquid moves along the casing. Finally, the liquid leaves the discharge pipe.

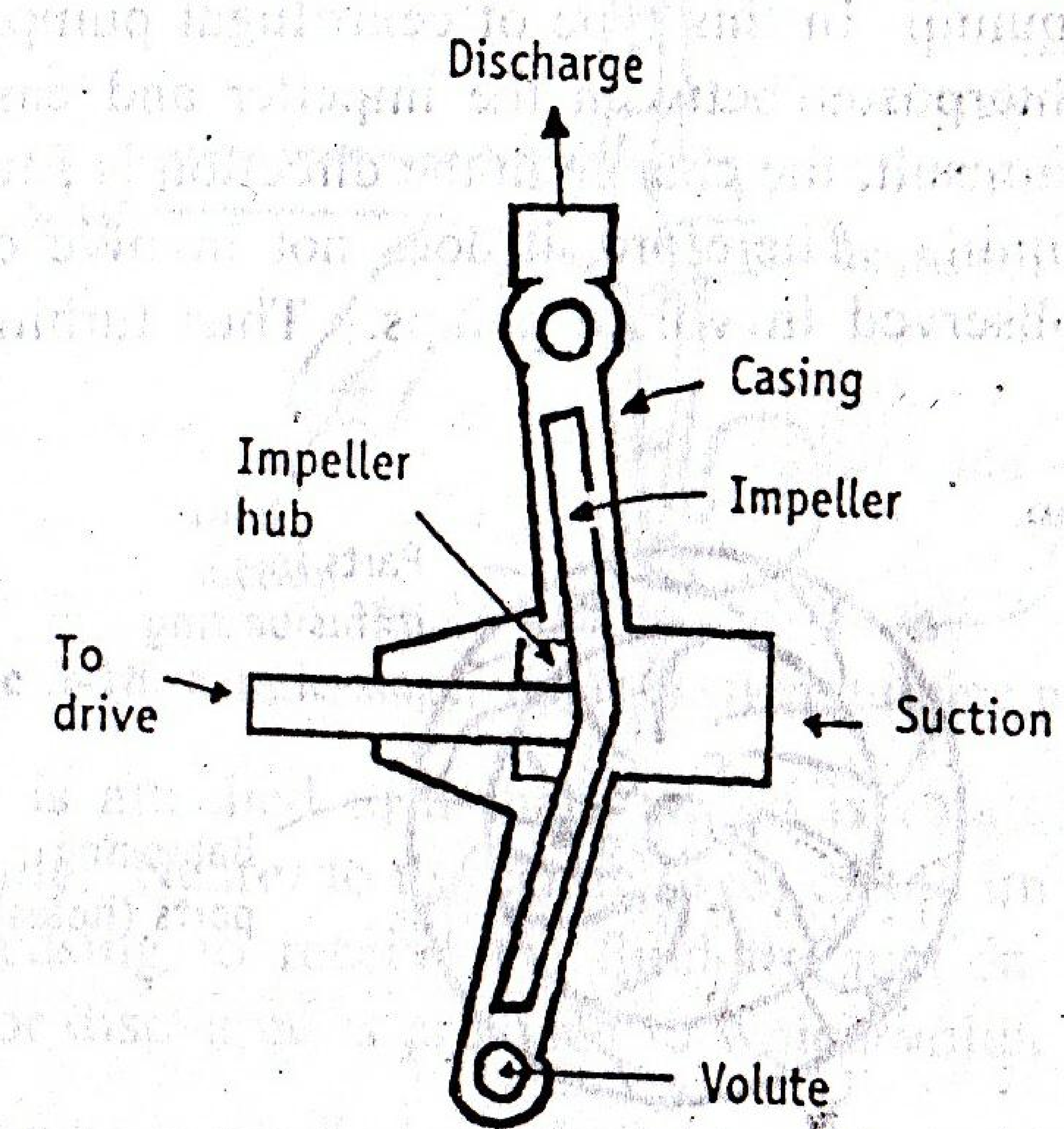


Figure 3-16. Construction of single-stage, single-suction, open-impeller volute pump.

Uses : Volute pumps are used for viscous liquids and liquids containing solid materials. Open impellers are used for this purpose.

Advantages : Volute pumps are cheapest of all centrifugal pumps.

Disadvantages : (1) Volute pumps are the least efficient, because of power losses due to the following reasons.

(a) When water is thrown out by radially moving vanes, it must suddenly change the direction as it enters the volute. Such a sudden change results in turbulence, which consumes some power in the form of friction.

(b) These are cheap pumps, hence not accurately finished. The fit between the impeller and the casing is usually poor. A part of liquid discharge leaks to the suction side. To prevent this back leakage, a closed impeller is used.

(2) In these pumps, the suction side of impeller is under pressure, which is less than the atmospheric pressure. As a result, air may

be drawn into the pump through the stuffing box. This air greatly decreases the rate of discharge or even entirely stops the pump. Sealing the glands can prevent this. A small amount of liquid under the pressure of the discharge is directed through seal pipes to lantern rings in the packing.

Turbine pumps : The diffusion casing equipped with vanes is known as turbine pump. In this type of centrifugal pump, a stationary diffusion ring is interposed between the impeller and casing chamber (Figure 3-17). As a result, the change in the direction is smooth, without shocks during pumping. Therefore, it does not involve energy losses due to eddies as observed in volute pumps. Thus turbine pumps are more efficient.

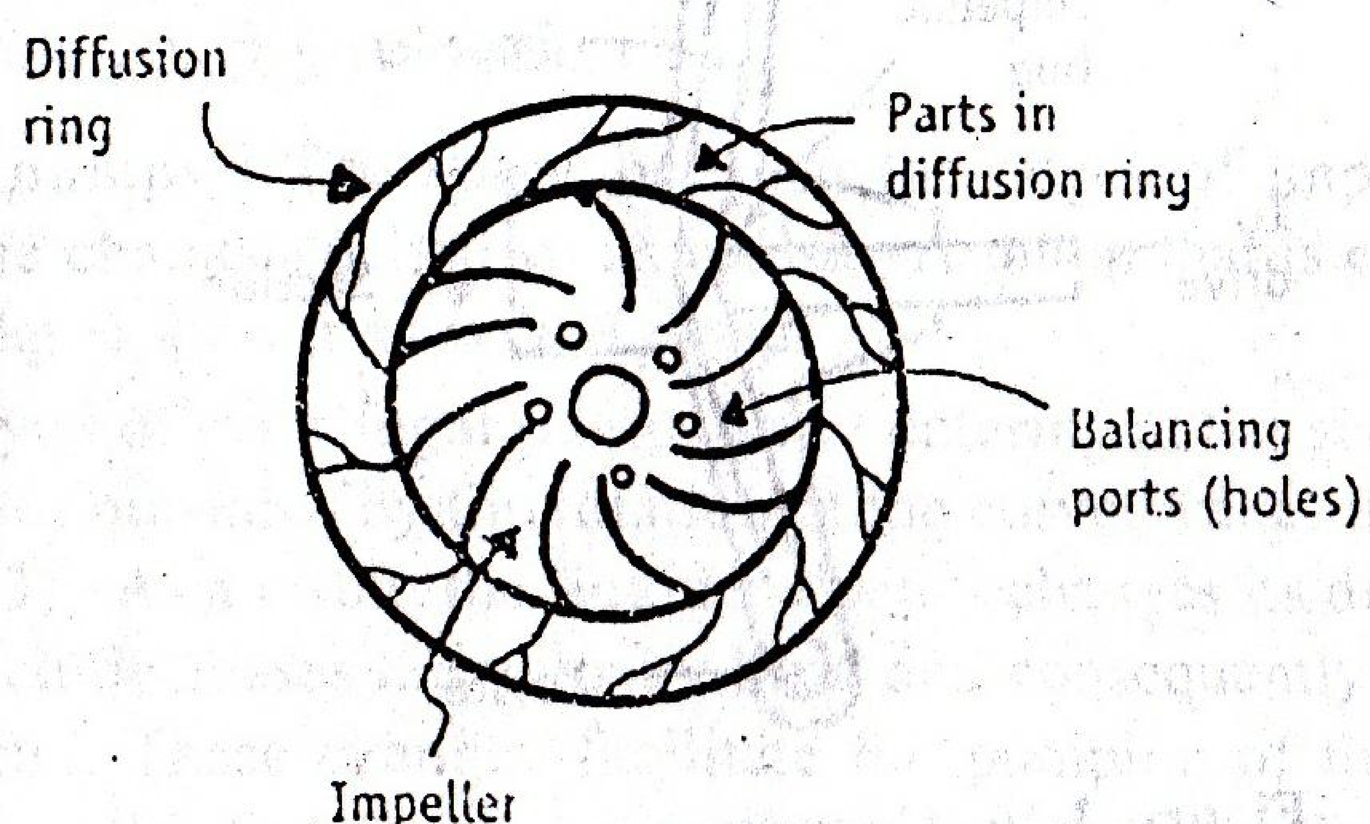


Figure 3-17. Design of impeller in a simple turbine pump.

The design of the impeller and the general construction of the turbine pump is similar to the volute pump. Connecting more number of impellers in series can generate the maximum head. The overall efficiency of such a pump is high, because the liquid from the tip of one impeller is delivered to the inlet of the next impeller with a minimum loss (multi-stage). Therefore, heads up to 300 metres may be generated.

The general principles described earlier are combined and illustrated using a model turbine pump given below.

Single-Stage, Single-Suction, Turbine Pump

Construction : The construction of a single-stage, single-suction, turbine pump is shown in Figure 3-18. The impeller is a pumping mechanism, which consists of curved vanes extending from the hub. In the casing, impeller is arranged in such a way that the two halves of the casing are closely in contact with the surface of the vanes. A diffusion ring contains passages, which change gradually in cross-section and direction. Since the impeller is single-stage, only one impeller is used in the pumping.

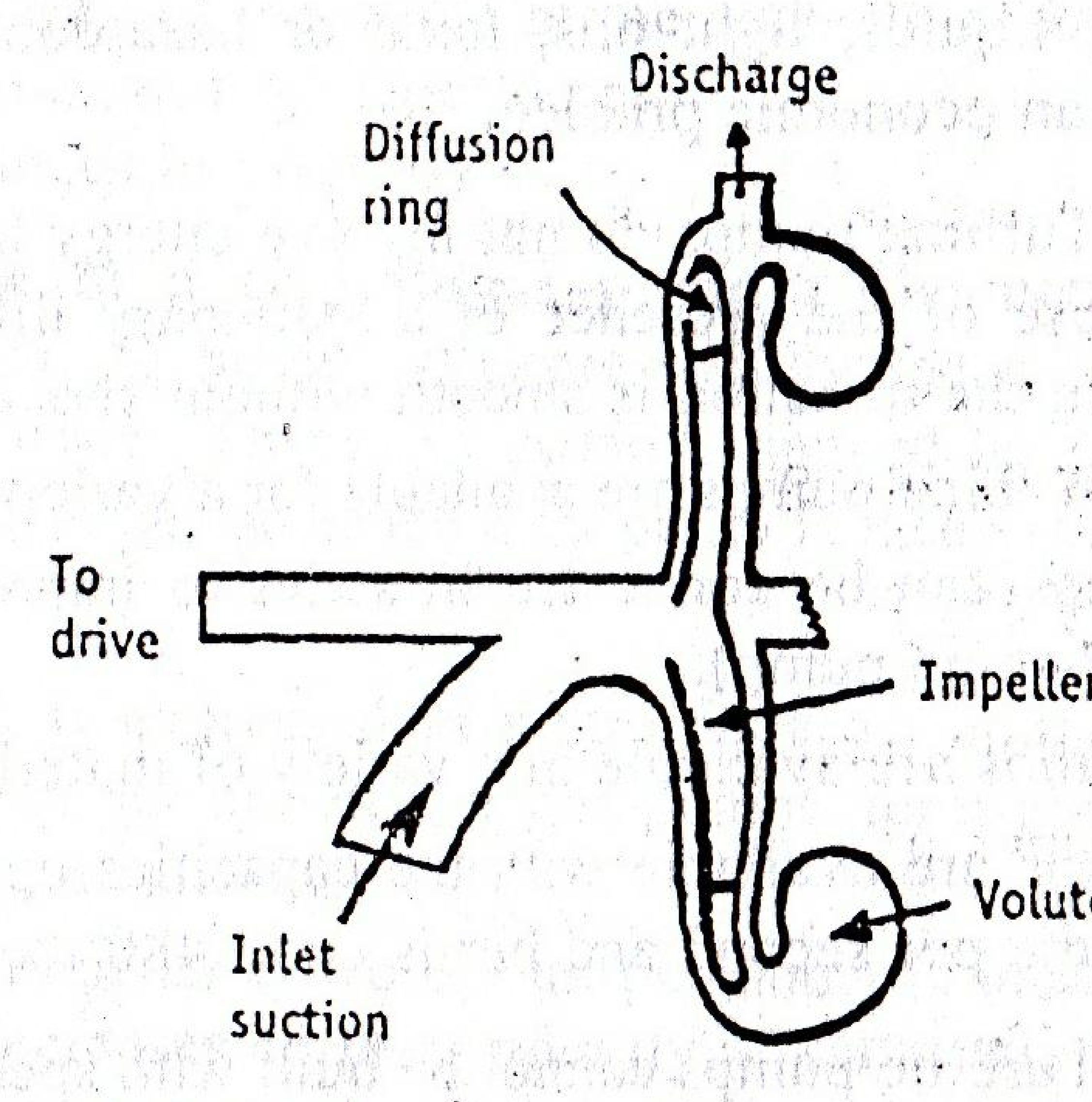


Figure 3-18. Single-stage, single-suction, turbine pump.

The impeller is attached to a shaft, which is rotated by the use of power from outside. Nearer to the centre (eye) of the impeller, provision is made in the casing to receive the fluid by suction. At the top of casing, an exit for discharge is provided to which volute is exposed.

Working : Power is applied on shaft to rotate. Along with it, the blades of the impeller are also revolved. This results in reduction in pressure at the eye of the impeller. Hence, the liquid flows into the impeller through the inlet suction pipe. This liquid is forced outward along the blades at increasing tangential velocity. The liquid released from the tip of the impeller is caught in these passages and turned gradually and smoothly into a discharge valve without shocks and eddies.

In a single suction turbine pump, the impeller produces the end thrust on the shaft, which is partly overcome by holes in the impeller. This partly equalizes the hydraulic pressure behind and front of the impeller. The rest of end thrust is taken up in a thrust bearing.

Uses : Turbine pumps are used in handling of clear, non-viscous and non-corrosive liquids. Vertical turbine pumps, which are particularly suited for pumping water from deep well, are often called *deep-well pumps*.

Double suction, single-stage pumps are used for general water supply and circulating services. Chemical pumps can be used when the liquids to be handled are non-corrosive to iron or bronze.

Turbine pumps are widely used for handling organic solvents, organic heat transfer liquids, light oils, toxic or hazardous liquids or where leakage poses an economic problem.

Advantages : (1) Turbine pumps do not involve energy losses due to eddies, because of the presence of a stationary diffusion ring. The change in the direction is smooth without shocks.

(2) Single-stage turbine pumps are available for a variety of services.

(3) Turbine pumps can be connected in series to improve the efficiency (multi-stage pump).

(4) Chemical pumps are available in a variety of materials.

(5) Turbine pumps are available with the capacities up to and over 400 metre cube per second and heads up to 480 metres.

Disadvantages : Turbine pumps cannot be built with special material. So corrosive liquids cannot be handled.

Air Binding And Self Priming Pumps

When a centrifugal pump is switched on, the fluid does not instantaneously develop pressure. During initial period, air enters the impeller and then fluid follows. The head generated (in metres) by air may be comparable to the head degenerated (in metres) by the liquid. However, the pressure produced by the same air is very small in terms of liquid head. In such situations, the pump practically stops delivering the liquid. This process is known as *air binding*. This is one of the disadvantages of the centrifugal pumps.

Air binding can be prevented by employing some of the following measures.

(1) A check valve is provided in the suction line, so that the suction line and casing will not drain off the liquid, when pump is shut down.

(2) A self-priming pump is provided, so that air can be removed from casing.

(3) Centrifugal pumps are located at a place, so that the pump suction is under a positive head and thus necessity of priming is eliminated.

Centrifugal Pump—Theory

As mentioned in the working principle of centrifugal pumps, the velocity head of the liquid at the top of the impeller is converted into a

pressure head. Such a conversion depends on:

- Angle of the vanes
- Velocity of the liquid at the outer tip of vanes
- Friction and leakage losses
- Changes in viscosity

Performance of a centrifugal pump : The performance of any particular centrifugal pump is expressed by means of curves called *characteristic curves*. These are usually supplied for pumping water by manufacturers. The performance of a pump is measured in terms of four characteristics.

Capacity : It is expressed in metre cube per hour for liquid pumps and in metre cube per minute for gas pumps, for a given inlet temperature and pressure conditions.

If speed of impeller (revolutions per hour) is increased, the rate of discharge also increases correspondingly. This relationship is expressed as:

Rate of discharge $\propto$ speed of the impeller

$$Q \propto N \tag{6}$$

The volume of discharge depends on the cross section of the passages. Therefore, the size of a centrifugal pump is usually specified by the diameter of the discharge connection.

- For high heads and small volumes of discharge, centrifugal pumps having impellers of large diameters, but with narrow slots are used.
- For low heads and large volumes of discharge, centrifugal pumps having impellers of small diameters, but with wide slots are used.

Pressure head : It is the energy supplied to the fluid per unit mass (increase in pressure/fluid specific weight), i.e., head development (metres). The quantity of fluid discharge is increased as a result of the enhanced head developed by the pump. This relationship is expressed as:

Head developed $\propto$ (rate of discharge)^2

$$H \propto Q^2 \tag{7}$$

It is generally expressed as column of fluid equivalent to the total pressure differential measured immediately before and after the device, for a given adiabatic condition. Head developed by centrifugal pumps is determined largely by:

- Angle of the vanes.
- Speed of the liquid at the tip of the impeller.

Power : It is the energy consumed by the machine per unit time (kilowatts). High speed of impeller, large head generation and high discharge rate obviously consumes more power. This relationship is expressed as:

Power consumed ∝ Rate of discharge × head developed

$$W \propto Q \times H \quad (8)$$

Or $$W \propto Q^2 \times Q \propto Q^3 \quad (9)$$

Or $$W \propto N^3 \quad (10)$$

Equations (6 to 10) are used for the comparison of two pumps.

Efficiency : Energy supplied to the fluid divided by the energy supplied to the machine is referred to as efficiency.

$$\textit{Efficiency of a pump} = \frac{\text{energy supplied to the liquid (i.e., power consumed) (kW)}}{\text{energy supplied to the machine (kW)}} \quad (11)$$

This theoretical relationship is a rough guide to understand the performance of centrifugal pumps.

Power losses : A certain amount of power is lost on account of various reasons, which are listed below:

1. *Mechanical losses* : These are due to friction in bearings, stuffing-box packing etc.
2. *Leakage losses* : These are due to leakage of the liquid from the tip of the impeller back to impeller suction.
3. *Hydraulic losses* : These include:
   (i) the friction between liquid and casing
   (ii) the friction between liquid and faces of the vanes
   (iii) losses due to sudden change in the direction in the volute
   (iv) losses due to sudden change in cross-section, where liquid leaves the impeller
4. *Recirculation losses*: The velocity of the liquid is not uniform in the space between two adjacent vanes of the impeller. This difference in velocity produces circulation of the liquid within the space between the vanes. Such circulation consumes power.

This can be minimized by:

(a) decreasing the distance between adjacent vanes
(b) putting more vanes on the impeller

Such modifications increase the cost of the pump and enhance the friction losses.

Work done or efficiency : The centrifugal pumps are usually rated on the basis of *head* and *capacity* at the point of maximum efficiency. The work done is expressed as:

Work done = rate of fluid flow × differential height of the column of fluid

$$\textit{Work done}\ (\text{kW·h}) = \text{capacity}\ (\text{m}^3/\text{h}) \times \text{head}\ (\text{m}) \quad (12)$$

Work must be done on the pump system in order to lift any liquid against the gravity. The pump actually raises the liquid and forces it into a pressure vessel or it may provide enough head to overcome the pipe friction. In such cases, the *hydraulic efficiency* is expressed as:

$$\textit{Hydraulic efficiency} = \frac{\text{power of the runner (kW)}}{\text{actual input power (kW)}} \quad (13)$$

It is possible to estimate the theoretical work required of a pump as shown below.

$$\textit{Power output}\ (\text{kW}) = \frac{HQ\rho}{3.670 \times 10^{-5}} \quad (14)$$

where H = total dynamic head of liquid, m
ρ = density of the liquid, kg/m^3
Q = capacity, m^3/h

The dynamic head (H) of a pump can be calculated using the equation (15).

$$H = \text{total discharge head} - \text{total suction head} \quad (15)$$

The power input of a pump should be greater than the power output, because the internal losses resulting from friction, leakage etc. The efficiency of a pump is therefore defined in simple terms as:

$$\textit{Efficiency of a pump} = \frac{\text{power output (kW)}}{\text{power input (kW)}} \quad (16)$$

Reciprocating Pumps Vs. Centrifugal Pumps

A comparison of features of reciprocating and centrifugal pumps is given in Table 3-1.

TABLE 3-1
Comparison of Characteristics of Reciprocating and Centrifugal Pumps

Reciprocating pumps	*Centrifugal pumps*
1. These are designed for higher heads.	These are designed for lower heads
2. The cost of these pumps is lower than centrifugal pumps for the same capacity.	The simplest pumps are cheaper than the simplest reciprocating pumps. For the same capacity, centrifugal pumps are costly.
3. The efficiency of these pumps is constant over a wider range of discharge rates.	In moderate sizes, the efficiency of these pumps is higher.
4. There is no possibility of air binding	Air binding is possible. So special provisions are made for priming.
5. These pumps are more flexible in their operations.	Less flexible in their operations.
6. Discharge of liquid may be pulsating in lower versions.	Deliver liquid at uniform pressure, without shocks and pulsation.
7. Common types are steam driven.	These are commonly power driven
8. Distribution of steam and collection of exhaust are not simple.	Distribution of electric power is simpler.
9. Used for liquids that are not too viscous, corrosive and abrasive.	These can handle suspensions with large solids and corrosive liquids.

MISCELLANEOUS PUMPS

Peristaltic Pumps

Principle : In peristaltic pumps, silicon rubber or other suitable elastic (resilient) tubing is clamped in a U-shaped fashion against a rotating mechanical device (such as 'finger' or 'rollers'). The tubing is compressed in stages by means of rotor. As the rollers rotate, they flatten the tube against the tract at the points of contact. These *flats* move the fluid by positive displacement and the flow can be precisely controlled by the speed of the rotor. The tube quickly recovers its original shape after squeezing.

Uses : Peristaltic pumps are particularly useful for biological fluids where all forms of contact must be avoided. These are increasingly used for pumping emulsions, creams and similar fluids in laboratories and industry, where freedom from glands, avoidance of aeration and corrosion resistance are valuable. In a hospital setup, these are used for pumping parenteral nutrition infusions to the patients and blood pumping in case of surgical operations.

Advantages : (1) Simple and inexpensive (to purchase and operate). (2) Easy to clean.

Disadvantages : (1) Linearity and often accuracy decreases as the pump speed increases.
(2) Accuracy varies as the tubing wears and fatigues.
(3) Effectiveness is limited by liquid viscosity.

Glossary of Symbols

H = Dynamic head, m.
H = Head, m.
N = Speed of the impeller, r/h.
Q = Rate of discharge, m^3/h.
ρ = Density of the liquid, kg/m^3
W = Power consumed, kWh.

QUESTION BANK

Each question carries 2 marks

1. What type of pump would you recommend for pumping slurries with 40-50% solids? Give reasons.
2. Describe the working of a self priming pump.
3. What is meant by 'air binding' in pumps? How do you overcome the problem?
4. What are the design features and merits of a turbine pump?
5. Write notes on check valves.

Each question carries 5 marks

1. Write the construction and working of a turbine pump.
2. Describe the construction and principle of rotary positive displacement pump for liquid transport.
3. Describe the construction and applications of any one positive displacement pump.
4. Compare the characteristics of centrifugal pumps and reciprocating pumps.
5. Classify reciprocating pumps with descriptions of various terms.
6. Draw the diagram of a piston type of reciprocating pump and explain its operation.

Each question carries 10 marks

1. Describe the principle and construction of a centrifugal pump of your choice. How do you compare a centrifugal pump with reciprocating pump?
2. Describe the construction, working, merits and demerits of a double-action reciprocating pump.