

1.10 PUMPS

1.10.1 INTRODUCTION

The pumps are defined as the hydraulic machines which convert the mechanical energy into hydraulic energy which is mainly in the form of pressure energy.

If the mechanical energy is converted into hydraulic energy, by means of centrifugal force acting on the fluid, the pump is known as centrifugal pump.

But if the mechanical energy is converted into hydraulic energy (or pressure energy) by sucking the liquid into a cylinder in which a piston is reciprocating (moving backwards and forwards), which exerts the thrust on the liquid and increases its hydraulic energy (pressure energy), the pump is known as reciprocating pump.

1.10.2 CLASSIFICATION OF PUMPS

The pumps are mainly classified into the following two types:

- (i) Positive displacement pumps and
- (ii) Rotodynamic pumps.

Those pumps, in which the liquid is sucked and then it is actually displaced (or pushed) due to the thrust exerted on it by a moving member, are known as positive displacement pumps. These pumps have one or more chambers (or cylinders) which are alternately filled with the liquid to be pumped and then emptied again. In case of positive displacement pumps, a member (say a piston) is moving backward and forward inside a chamber (or inside a cylinder). As the member starts moving backwards a partial vacuum is created in the chamber and liquid is sucked inside the chamber from the sump through the suction pipe. The chamber is filled with the liquid. When the member starts moving forward, the thrust is exerted on the liquid and the liquid is forced into the delivery pipe and is lifted to a required height. Reciprocating pumps are the most common example of the positive displacement type of pumps.

Those pumps which have a rotating element are known as rotodynamic pumps. In these pumps, the liquid passes through the rotating element and its angular momentum changes. Due to the change of angular momentum, the pressure energy of the liquid increases. The centrifugal pumps are the most common type of rotodynamic pumps.

1.11. CENTRIFUGAL PUMP

Centrifugal pump is hydraulic machine with a rotating part called Impeller. In this pump, mechanical energy is converted, into pressure energy by means of centrifugal force acting on the fluid. The liquid enters the pump at the peripheral hub and leaves the casing radially. The centrifugal pump acts as a reversed of an inward radial flow reaction

turbine. This means that the flow in centrifugal pumps is in the radial outward directions. The centrifugal pump works on the principle of forced vortex flow which means that when a certain mass of liquid is rotated by an external torque, the rise in pressure head of the rotating liquid takes place., the rise in pressure head at any point of the rotating liquid is proportional to the square of tangential velocity of the liquid at that point (i.e., rise in pressure head= $v^2/2g$ or $\frac{1}{2}r^2\omega^2/2g$). Thus at the outlet of the impeller, where radius is more, the rise in pressure head will be more and the liquid will be discharged at the outlet with a high pressure head. Due to this high pressure head, the liquid can be lifted to a high level.

1.11.1 TYPES OF CENTRIFUGAL PUMPS

Centrifugal pumps may be classified as follows:

1. According to the type of casing
 - i. Volute casing
 - ii. Vortex casing
 - iii. Diffuser casing
2. According to the number of stages
 - i. Single stage
 - ii. Multi stage
3. According to the types of impellers
 - i. Single suction impeller
 - ii. Double suction impeller
4. According to the shape of the vanes (blades) of the impeller
 - i. Radial flow impeller
 - ii. Axial flow impeller
 - iii. Mixed flow impeller

1.11.2 MAIN PARTS OF A CENTRIFUGAL PUMP

The following are the main parts of a centrifugal pump:

1. Impeller
2. Casing
3. Suction pipe with a foot valve and a strainer
4. Delivery pipe

All the main parts of the centrifugal pump are shown in Fig. 1.12

1. **Impeller:** The rotating part of a centrifugal pump is called 'impeller'. It consists of a series of backward curved vanes or blades. The impeller is mounted on a shaft which is connected to the shaft of an electric motor. The impellers may be classified as

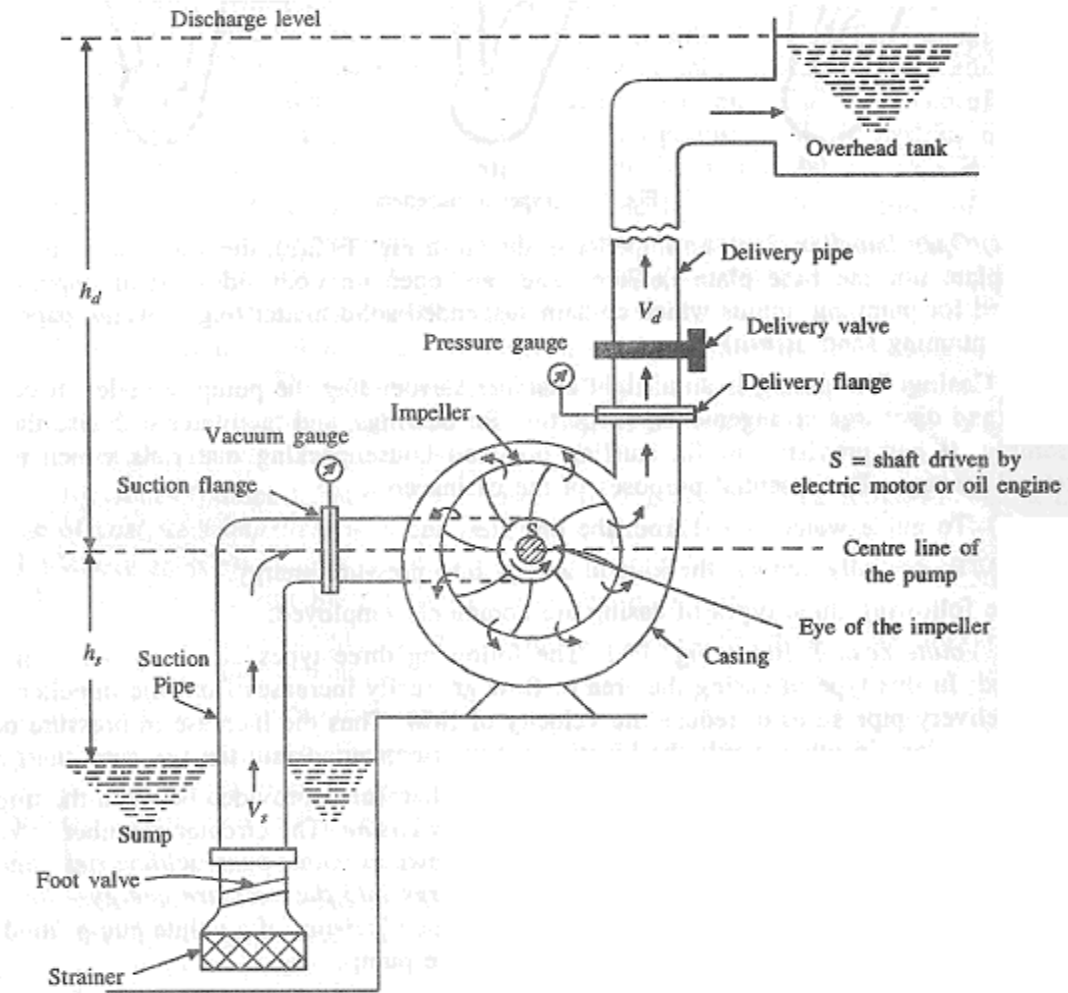


Fig.1.12 Volute type centrifugal components

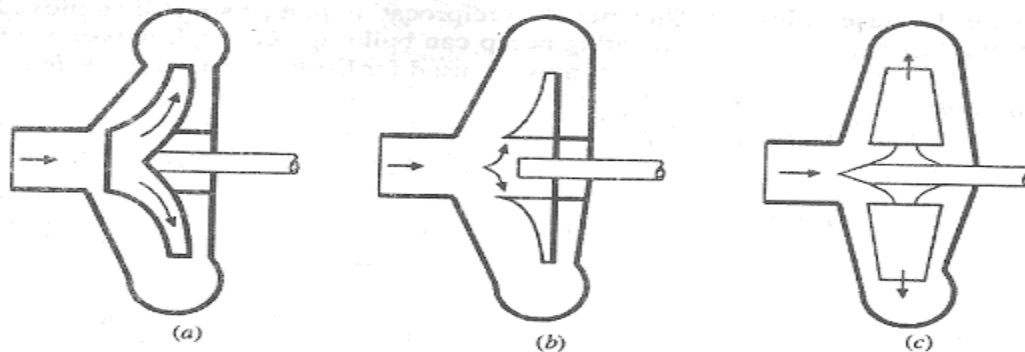


Fig. 1.13 Types of Impeller

Closed Impeller: A closed impeller (fig. 1.13 (a)) has vanes with metal cover plates on both sides. These plates are known as crown plate and lower or base plate. The closed impeller provides better guidance for the liquid. It is more efficient. However, this type of impeller is suited when the liquid to be pumped is

pure.

Semi open Impeller: Semi open Impeller (fig. 1.13 (b)) has vanes with base plate only and no crown plate. It is suitable even for liquids with dirt.

Open Impeller: Open Impeller (fig. 1.13 (c)) vanes have neither crown plate nor base plate. It is useful for pumping liquids containing suspended solid matter such as sewage.

2. **Casing:** The casing of a centrifugal pump is similar to the casing of a reaction turbine. It is an air-tight passage surrounding the impeller and is designed in such a way that the kinetic energy of the water discharged at the outlet of the impeller is converted into pressure energy before the water leaves the casing and enters the delivery pipe. The following three types of casings are commonly adopted:
 - a. Volute casing as shown in Fig. 1.12
 - b. Vortex casing as shown in Fig.
 - c. Diffuser casing or Casing with guide blades as shown in Fig.

(a) Volute Casing: Fig. 1. 12 Shows the volute casing, which surrounds the impeller. It is of spiral type in which area of flow increases gradually. The increase in area of flow decreases the velocity of flow. The decrease in velocity increases the pressure of the water flowing through the casing. It has been observed that in case of volute casing, the efficiency of the pump increases slightly as a large amount of energy is lost due to the formation of eddies in this type of casing.

(b) Vortex Casing: A circular chamber is introduced between the volute casing and the impeller as shown in Fig. 1.14, known as Vortex Casing or whirlpool chamber. The liquid leaving the impeller blades at a high pressure moves freely in this vortex chamber. Its velocity head is gradually transformed into pressure head. Afterwards, the liquid is flowing through volute chamber. In the volute chamber, pressure of the liquid is further increased. It is then discharged through the delivery pipe. By introducing the circular chamber, the loss of energy due to the formation of eddies is reduced to a considerable extent. Thus the efficiency of the pump is more than the efficiency when only volute casing is provided.

(c) Casing with Guide Blades: This casing is shown in Fig.1.15, in which the impeller is surrounded by a concentric casing with fixed guide vanes. The ring of fixed guide vanes is known as diffuser. . The guide vanes are designed in which a way that the water from the impeller enters the guide vanes without shock. Also the area of the guide vanes increases, thus reducing the velocity of flow through guide vanes and consequently increasing the pressure of water. The water from the guide vanes then passes through the surrounding casing, which is in most of the cases concentric with the impeller as shown in Fig.

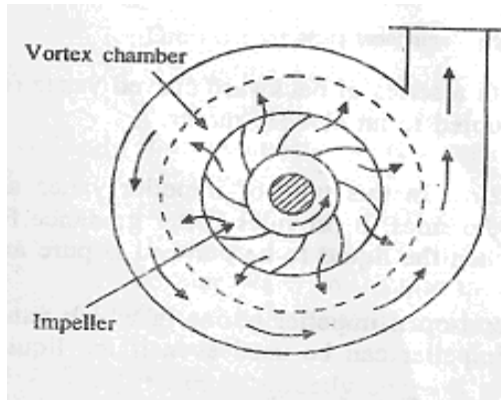


Fig. 1.14 Vortex casing

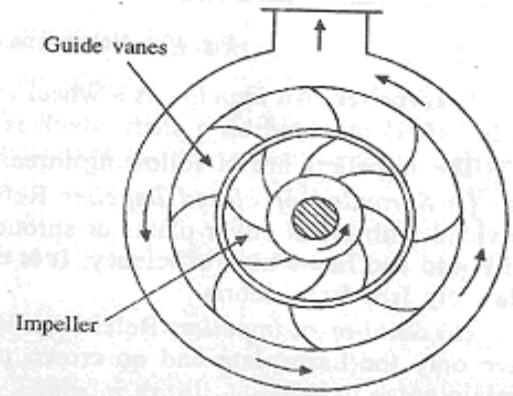


Fig. 1.15 casing with guide blades

3. **Suction Pipe with a foot-valve and a strainer:** Suction pipe is connected at its upper end to the inlet of the pump at the center of the impeller, i.e at the suction eye of the Impeller. The lower of the suction pipe dips into liquid in a sump from which the liquid is to be lifted up. The liquid from the sump enters the strainer. The strainer filters the impurities and the liquid then passes through foot valve to enter the suction pipe. Foot valve is a non return valve. i.e one way valve. It opens only in the upward direction. Therefore, the liquid will pass through the foot valve upwards only. It will not allow the liquid to flow downwards back to the pump.
4. **Delivery Pipe:** A pipe whose one end is connected to the outlet of the pump and other end delivers the water at a required height is known as delivery pipe. Just near the outlet of the pump on the delivery pipe, a delivery valve is provided. It controls the flow of fluid from the pump into the delivery pipe.
5. **Shaft:** Shaft is coupled to motor. It transfers the torque from motor to impeller.
6. **Stuffing Box:** It is used to stop leakage of air into the casing when the pressure in the casing is below atmospheric. It also stops the leakage of liquid under pressure from the casing of the pump. The stuffing box packing consists of a semi plastic material. This plastic material is cut in rings. It fits around the shaft or shaft sleeve.

Working Principle

The working / operation of a centrifugal pump is explained step wise below:

1. The delivery valve is closed and the pump is primed that is, suction pipe, casing and portion of the delivery pipe upto the delivery valve are completely filled with the liquid (to be pumped) so that no air pocket is left.
2. Keeping the delivery valve still closed the electric motor is started to rotate the impeller. The rotation of the impeller causes strong suction or vacuum just at the eye of the casing.

3. The speed of the impeller is gradually increased till the impeller rotates at its normal speed and develops normal energy required for pumping the liquid.
4. After the impeller attains the normal speed the delivery valve is opened when the liquid is continuously sucked (from sump well) up to the suction pipe, it passes through the eye of casing and enters the impeller at its center or it enters the impeller vanes at their inlet tips. This liquid is impelled out by the rotating vanes and it becomes out at the outlet tips of the vanes into the casing. Due to impeller action the pressure head as well as velocity head of the liquid are increased (some of this velocity head is converted into pressure head in the casing and in the diffuser blades / vanes if they are also provided).
5. From casing, the liquid passes into pipe and is lifted to the required height (and discharged from the outlet or upper end of the delivery pipe).
6. So long as motion is given to the impeller and there is supply of liquid to be lifted the process of lifting the liquid to the required height remains continuous.
7. When the pump is to be stopped the delivery valve should be first closed, otherwise there may be some backflow from the reservoir.

1.11.3 PRIMING:

The first step in the operation of a centrifugal pump is priming. Priming means removal of air from the pump casing and suction line. If an impeller is made to rotate in the presence of even a small air packet in any portion of the pump, only a negligible pressure would be produced. The result is that no liquid will be lifted by the pump.

1.11.4 CAVITATION

Cavitation is defined as the phenomenon of formation of vapor bubbles of a flowing liquid in a region where the pressure of the liquid falls below its vapor pressure and the sudden collapse of these vapor bubbles in region of higher pressures. When the vapor bubbles collapse, a very high pressure is created. The metallic surfaces, above which these vapor bubbles collapse, is subjected to these high pressures, which cause pitting action on the surface. Thus cavities are formed on the metallic surface and also considerable noise and vibrations are produced.

Cavitation includes formation of vapor bubbles of the flowing liquid and collapsing of the vapor bubbles. Formation of vapor bubbles of the flowing liquid takes place only whenever the pressure in any region falls below vapor pressure. When the pressure of the flowing liquid is less than its vapor pressure, the liquid starts boiling and vapor bubbles are formed. These vapor bubbles are carried along with the flowing liquid to higher pressure zones where these vapors condense and bubbles collapse. Due to sudden collapsing of the bubbles on the metallic surface, high pressure is produced and

metallic surfaces are subjected to high local stresses. Thus the surfaces are damaged.

EFFECTS OF CAVITATION: The following are the effects of cavitation:

1. The metallic surfaces are damaged and cavities are formed on the surfaces.
2. Due to sudden collapse of vapor bubble, considerable noise and vibrations are produced.
3. The efficiency of a turbine decreases due to cavitation. Due to pitting action the surface of the turbine blades becomes rough and the force exerted by water on the turbine blades decreases. Hence the work done by water or output horse power becomes less and this efficiency decreases.

1.12 RECIPROCATING PUMPS

Reciprocating pump converts the mechanical energy into pressure energy by sucking the liquid into a cylinder, in which a piston is reciprocating. It uses piston or plunger to displace the liquid during each stroke of the piston. Reciprocating pump is a positive displacement pump. This means that the liquid is first sucked into a cylinder and then displaced or pushed by the thrust of a piston. Due to a number of sliding parts, greater attention for lubrication, maintenance and repairs is required.

1.12.1 TYPES OF RECIPROCATING PUMPS

The reciprocating pumps may be classified as:

1. According to the contact of liquid with one side or both sides of the piston
 - i. Single acting reciprocating pump
 - ii. Double acting reciprocating pump
2. According to the number of cylinders
 - i. Single cylinder reciprocating pump
 - ii. Double cylinder reciprocating pump

1.12.2. SINGLE ACTING RECIPROCATING PUMP

If a cylinder uses one side of the piston for pumping fluid, then it is known as a single acting reciprocating pump.

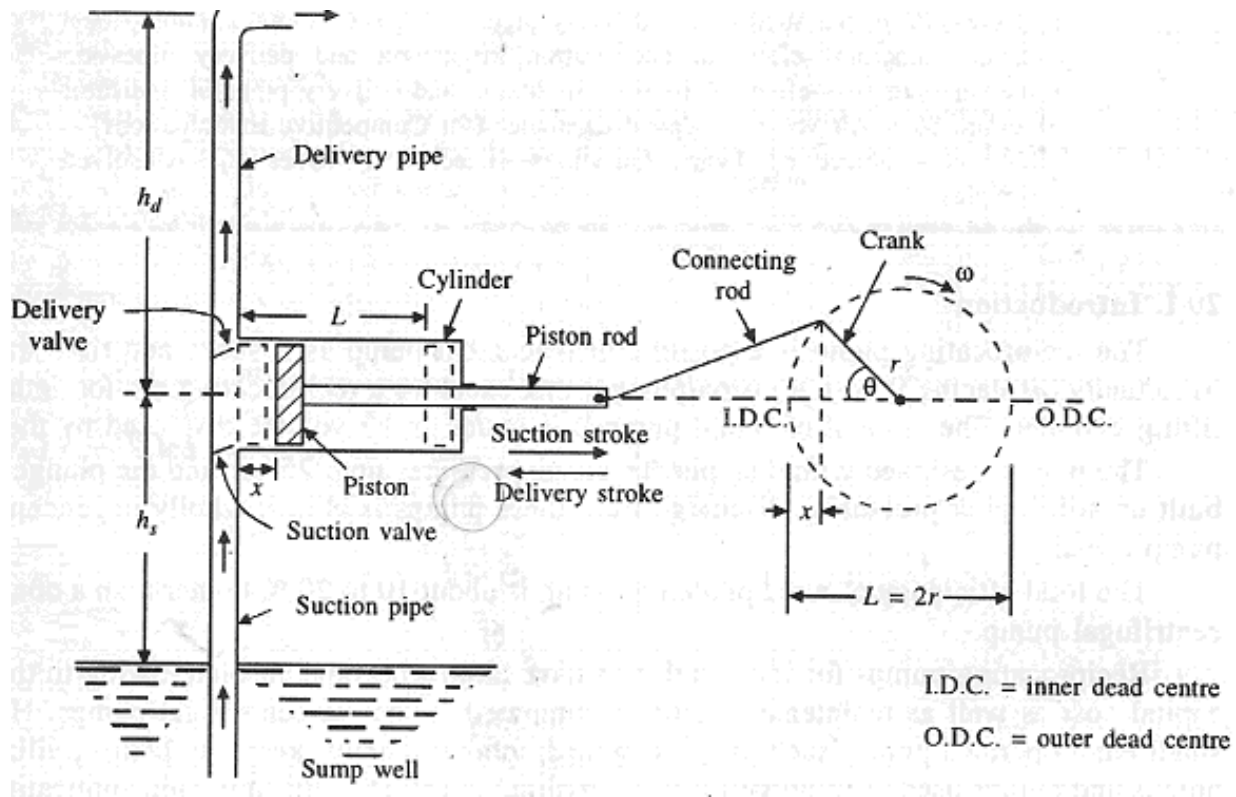


Fig. 1.16 Sectional view of single acting reciprocating pump

The followings are the main parts of a reciprocating pump as shown in fig. 1.16.

1. Cylinder, piston, piston rod, connecting rod and crank suction pipe,
2. Suction pipe and suction valve
3. Delivery pipe and delivery valve

Cylinder, piston, piston rod, connecting rod and crank: A single acting reciprocating pump, which consists of a piston which moves forwards and backwards in a close fitting cylinder. The movement of the piston is obtained by connecting the piston rod to crank by means of a connecting rod. The crank is rotated by means of an electric motor.

Suction pipe and suction valve: Suction pipe is connected to the cylinder. Suction valve is one way valve, i.e., a non return valve. It allows the liquid to flow in one direction only. That is, it allows the liquid from the suction pipe to the cylinder.

Delivery pipe and delivery valve: Delivery pipe is connected to the cylinder.

Delivery valve is also one way valve or non return valve. It allows the liquid to flow in one direction only. That is, it allows the liquid from the cylinder to the delivery pipe.

Working Principle:

When crank starts rotating, the piston moves to and fro in the cylinder. When crank is at A, the piston is at the extreme left position in the cylinder. As the crank is rotating from A to C, (i.e, from $\theta = 0$ to $\theta = 180$), the piston is moving towards right in the cylinder. The movement of the piston towards right creates a partial vacuum in the cylinder. But on the surface of the liquid in the sump atmospheric pressure is acting, which is more than the pressure inside the cylinder. Thus the liquid is forced in the suction pipe from the sump. This liquid opens the suction valve and enters the cylinder.

When crank is rotating from C to A (i.e from $\theta = 180$ to $\theta = 360$), the piston from its extreme right position starts moving towards left in the cylinder. The movement of the piston towards left increases the pressure of the liquid the cylinder more than atmospheric pressure. Hence suction valve closes and delivery valve opens. The liquid is forced into the delivery pipe through the delivery valve. Consequently, the liquid is raised to the required height. Note that the liquid is discharged at every alternate stroke.

1.12.3. DOUBLE ACTING RECIPROCATING PUMP

In case of double acting pump, the water is acting on both sides of the piston as shown in fig. 5.70. Thus we require two suction pipes and delivery pipes for double-acting pump. Thus we require two suction pipes and two delivery pipes for double acting pump. The corresponding two suction valves (S_1 and S_2) and the two delivery valves (D_1 and D_2) are as shown.

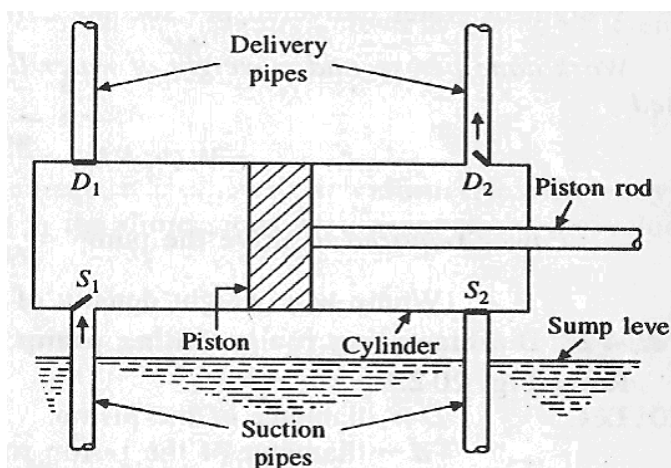


Fig. 1.17 Double acting reciprocating pump

During each stroke, when the suction takes place on one side of the piston, the other side delivers the liquid. In this way, in the case of a double acting pump, in one complete revolution of the crank, there are two suction strokes and two delivery strokes. Therefore, the liquid is delivered by the pump during these two delivery strokes.

1.12.4. CLASSIFICATION ACCORDING TO THE NUMBER OF CYLINDERS

1.12.4.1 SINGLE CYLINDER RECIPROCATING PUMP

As the name suggests, a reciprocating pump having only one cylinder is known as single cylinder reciprocating pump. Fig. 1.16. shows a single cylinder single acting reciprocating pump. Note that a single cylinder pump may also be a double acting reciprocating pump.

1.12.4.2 DOUBLE CYLINDER RECIPROCATING PUMP

A double cylinder (single acting) reciprocating pump (fig. 1.18) is the one which has two single acting cylinders. Each cylinder is provided with a suction pipe fitted with a suction valve and a delivery pipe fitted with a delivery valve. Also, there is a separate piston for each of the two cylinders as shown. Both the pistons are simultaneously driven from cranks set at 180°

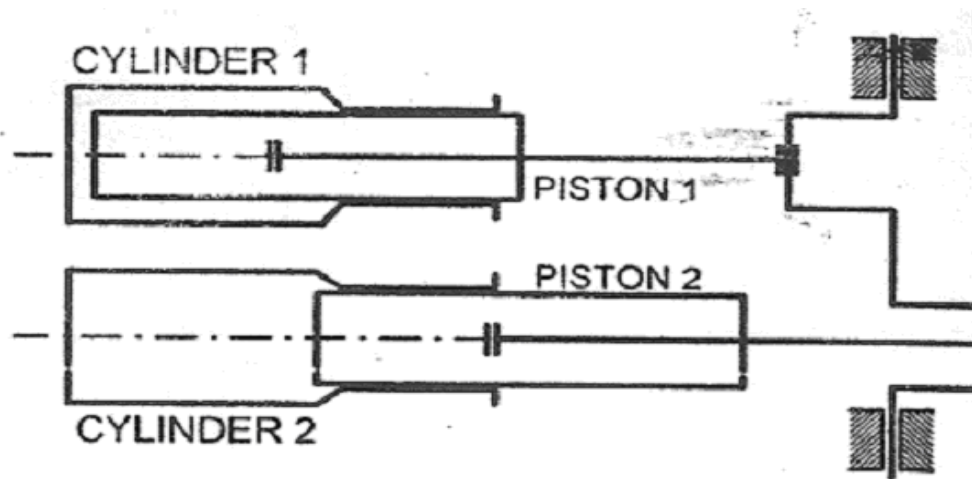


Fig. 1.18 Double cylinder Reciprocating pump

1.12.5 DISCHARGE, WORK DONE AND POWER REQUIRED TO DRIVE RECIPROCATING PUMP

Consider a single acting reciprocating pump as shown in fig. 1.16

Let D = Diameter of the cylinder, m

A = Cross sectional area of the piston / cylinder =

r = radius of crank, m

N = Speed of the crank, r.p.m

L = Length of the stroke ($=2r$), m

h_s = height of the centre of the cylinder above the liquid surface, m and

h_d = height to which the liquid is raised above the center of the cylinder, m

Volume of the liquid sucked in during suction stroke $= A \times L, m^3$

$$\therefore \text{Discharge of the pump per second, } Q = A \times L \times \frac{N}{60}$$

$$\text{Weight of water delivered per second, } W = w Q = \frac{w A L N}{60}$$

Work done per second = weight of water lifted/sec. $\times$ total height through which liquid is lifted

$$= W (h_s + h_d) = \frac{w A L N}{60} (h_s + h_d)$$

$$\therefore \text{Power required to drive the pump} = \frac{w A L N}{60 \times 1000} (h_s + h_d) \text{ kW}$$

(Where w = weight density of liquid in N/m^3)

Double acting reciprocating pump

Consider fig. 1. 17

D = diameter of the piston,

d = diameter of the piston rod,

$$A_{pr} = \text{cross-sectional area of the piston rod} = \frac{\pi}{4} d^2$$

$$\text{Area on one side of the piston, } A = \frac{\pi}{4} D^2$$

Area on other side of the piston where piston rod is connected to the piston,

$$A' = A - A_{pr} = \frac{\pi}{4} D^2 - \frac{\pi}{4} d^2 = \frac{\pi}{4} (D^2 - d^2).$$

Volume of liquid delivered in one revolution of crank

$$= A L + A' L = (A + A') L = \left[\frac{\pi}{4} D^2 + \frac{\pi}{4} (D^2 - d^2) \right] L$$

$$\therefore \text{Discharge of the pump per second} = \left[\frac{\pi}{4} D^2 + \frac{\pi}{4} (D^2 - d^2) \right] L \times \frac{N}{60}$$

If the diameter of the piston rod ' d ' is very small as compared to the diameter of the piston ' D ' then it can be neglected and hence discharge of the pump per second will become

$$Q = \left(\frac{\pi}{4} D^2 + \frac{\pi}{4} D^2 \right) \times \frac{L N}{60} = 2 \times \frac{\pi}{4} D^2 \times \frac{L N}{60} = \frac{2 A L N}{60}$$

Evidently the output of a double acting pump is two times that of a single acting pump.

Work done per second = weight of water delivered $\times$ total height through which liquid is lifted

$$= \left(w \times \frac{2 A L N}{60} \right) \times (h_s + h_d)$$

$$= \frac{2 w A L N}{60} (h_s + h_d)$$

Power required to drive the pump, $P = \frac{2 w A L N}{60 \times 1000} (h_s + h_d) \text{ kW}$

(Where w = weight density of liquid in N/m^3)

1.12.6 COEFFICIENT OF DISCHARGE

In a reciprocating pump, the actual discharge (Q_{act}) is always slightly different from the theoretical discharge (Q_{th}) due to the following reasons:

1. Leakage through the valves, glands and piston packing,
2. Imperfect operation of the valves (suction and discharge) and
3. Partial filling of cylinder by the liquid.

The ratio between actual discharge and theoretical discharge is known as the coefficient of discharge (C_d) of the pump. That is

$$C_d = \frac{\text{Actual discharge}}{\text{Theoretical discharge}} = \frac{Q_{\text{act}}}{Q_{\text{th}}} \text{ -----}$$

When the value C_d is expressed in percentage, it is known as “Volumetric efficiency” of the pump. Volumetric efficiency depends upon the dimensions of the pump and its value ranges from 85 – 98%

1.12.7 SLIP

The difference between the theoretical discharge and actual discharge is called “slip” of the pump. That is

$$\text{Slip} = Q_{\text{th}} - Q_{\text{act}}$$

In most of the reciprocating pumps Q_{act} is less than Q_{th} ; in such a case the value of C_d is less than unity and the slip of the pump is positive. However, in some cases Q_{act} may be more than Q_{th} ; in such case C_d is more than unity and the slip will be negative. The slip will be negative when there is direct connection between the suction and delivery sides before the end of suction stroke. This happens if the momentum of liquid in the suction pipe is large enough to open the delivery valve before the beginning of delivery stroke. The negative slip is possible in case of pumps having long suction pipe and short delivery pipe, especially when these are opening at high speeds.