$$P_u = \frac{P}{H^{3/2}}$$

Suppose N_1, Q_1, P_1 and N_2, Q_2 and P_2 be speeds, discharge and power of a turbine at heads H_1 and H_2 respectively. Then

$$N_u = \frac{N_1}{\sqrt{H_1}} = \frac{N_2}{\sqrt{H_2}}$$

$$Q_u = \frac{Q_1}{\sqrt{H_1}} = \frac{Q_2}{\sqrt{H_2}}$$

$$P_u = \frac{P_1}{H_1^{3/2}} = \frac{P_2}{H_2^{3/2}}$$

Therefore speed, discharge and power of a turbine can be calculated at different heads.

10·14. Pump

A pump is a hydraulic machine which converts mechanical energy into hydraulic energy. Mechanical energy is supplied to liquid by pumps as a result of which pressure energy of liquid increases. Pressure energy is therefore termed as static or potential energy as liquid is raised to height from lower datum.

A pump is usually mounted above certain height of a liquid reservoir. Pumps are generally used to such water from depth. Consider fig. 10·11 given below.

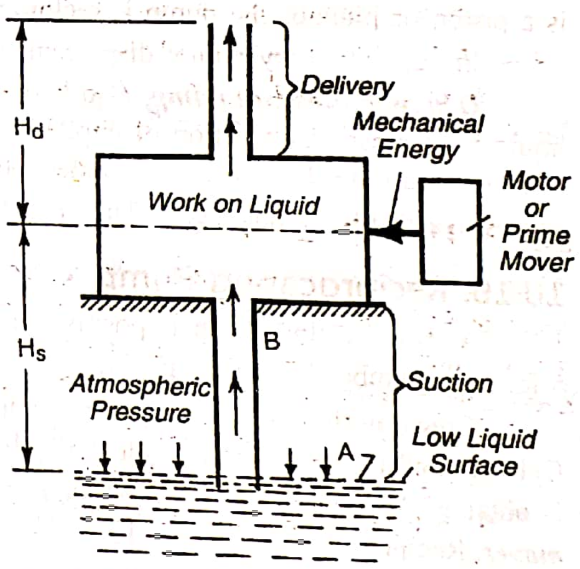


Fig. 10·11

Action of a pump can be distributed as—

(a) Suction

(b) Works on liquid

(c) Delivery

Pressure difference is generated between pump inlet and bottom of suction pipe. Pressure at A is atmospheric pressure but suction pressure at B is less than atmospheric pressure. Liquid is sucked inside suction pipe and reaches inlet of pump.

Work is done on liquid inside the pump which raises pressure of the liquid. Thus liquid is lifted through delivery pipe.

The depth from which liquid has to be sucked through suction pipe is known as ***suction head***. It is denoted by H_s. Surface of water reservoir is usually exposed to atmosphere. So, theoretical values of H_s is 10·3 m. However, H_s is limited to 7·5 m due to friction and other losses. This is because water shall start evaporating below this pressure.

The vertical height from the centre of pump to which liquid has to be raised is known as ***delivery head***. It is denoted by H_d. Sum of suction head and delivery head is known as static head.

$$\textbf{Static head} = H_s + H_d$$

10·15. Classification of Pumps

- Pumps
  - Positive Displacement Pumps
    - Reciprocating pumps
      - Piston Pump
      - Plunger Pump
      - Bucket Pump
    - Rotary pumps
      - Constant Delivery Pump
      - Variable Delivery Pump
  - Dynamic Pressure Pumps or Rotodynamic Pump
    - Centrifugal Pumps
      - Volute Type Pump
      - Turbine Type Pump
    - Propeller Pumps

Positive displacement are those pumps in which liquid is sucked and actually displaced due to thrust exerted on it by a moving member of pump. Liquid is then pushed to required height. If moving member is a piston or plunger the pump is reciprocating.

In case of rotary pump, displacement of liquid is obtained by rotary motion of member.

Dynamic pressure pump, also known as ***rotodynamic pump*** are those in which pressure energy of liquid is increased by rotation of impellers. A dynamic pressure pump can be assumed as reverse process of Kaplan turbine. Now it can be understood that dynamic pressure pump does not push liquid as in case of positive displacement pump. The centrifugal pumps are very common example of this category.

10·16. Reciprocating Pump

A reciprocating pump is positive displacement pump which increases pressure energy of liquid by a moving member known as piston.

Construction—A reciprocating pump consists of a ***cylinder***, sometimes called ***chamber*** and a ***piston***. Cylinder and piston maintain a close fit. Piston moves to and fro in the cylinder. The movement of piston is obtained by connecting it to ***piston rod, connecting rod*** and ***crank***. The crank is rotated by a ***prime mover***. Reciprocating pumps are low speed pumps therefore they can be run by ***electric motor*** through belt.

Cylinder is fitted with ***suction pipe*** and ***delivery pipe***. Each pipe is provided with a ***non-return valve*** known as ***suction valve*** and ***delivery valve***. Function of non-return is to allow flow of liquid in one direction only.

Cylinder is generally made of ***cast iron***. Cylinder and piston maintain close ***liquid tight fit***. Piston is fitted with ***piston rings*** to avoid leakage of liquid from one side of piston to other side when piston moves to and fro in the cylinder. ***Glands*** are used between piston rod and cylinder to avoid leakage of liquid. Sometimes brass or bronze lining are fitted in cylinder bore.

Reciprocating motion is obtained by crank and connecting rod mechanism. Crank is rotated by some prime mover which may be an engine or electric motor.

Disc type valves are most common in reciprocating pumps. Valve is a ***rubber disc*** with a hole at centre. A bolt is passed through hole which aligns its movement. When valve moves up, it is pushed back to seat by ***spring force***. In case of hot liquid metal valve are used.

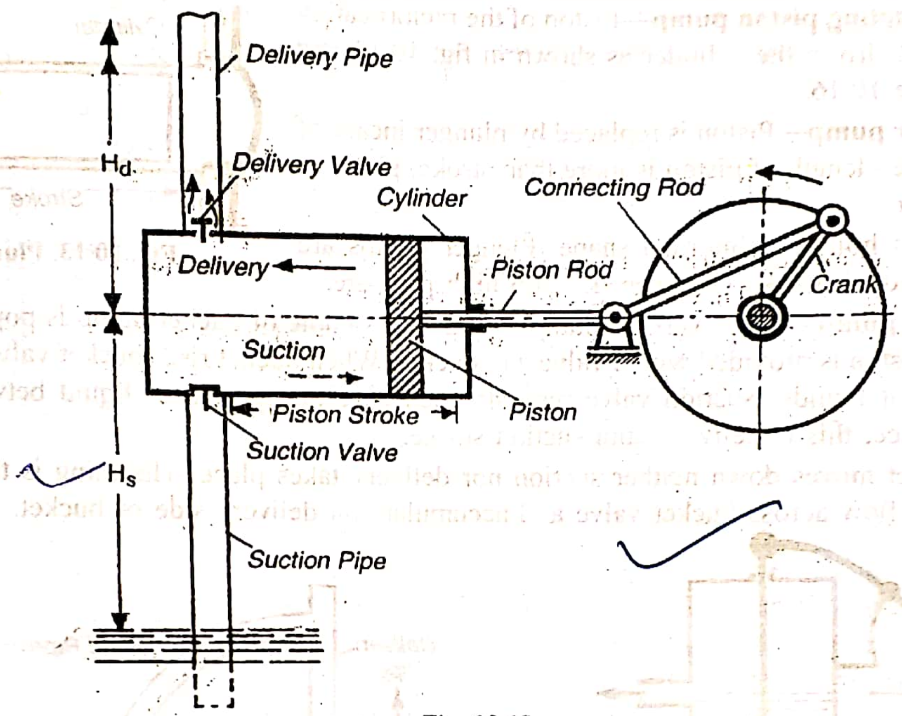


Fig. 10·12

Sometimes rubber valves are provided with metal cap to make it strong. Ball shaped hollow valve of bronze are used for viscous liquid.

Working—When crank rotates from $\theta = 0° \text{ to } 180°$, the piston moves from extreme left to extreme right position. During ***suction stroke*** partial vacuum (pressure below atmospheric pressure) is created in cylinder. Since, liquid is at atmospheric pressure so liquid rises in suction pipe and forces ***suction valve to open***. Cylinder is completely fitted with liquid as soon piston reaches extreme right position. Suction valve is closed at this moment and delivery valve is at the verge of opening.

When crank rotates from $\theta = 180° \text{ to } 360°$, the piston moves from extreme right to extreme left. Pressure inside the cylinder increases above atmosphere. Thus non-return ***suction valve closes*** and ***delivery valve opens during delivery stroke***. Liquid is pushed through delivery pipe upto required height.

When piston reaches extreme left ($\theta = 360°$) one cycle is complete and crank completes one revolution. Both valves are closed at this moment. This cycle repeats again and again.

Starting up—Pump must be lubricated before starting with oil and greese. Pump must be inspected thoroughly.

Suction pipe must be filled with water to replace air. This is known as ***priming***. Pump should be started at low speed initially. It is then given full speed.

Application—Reciprocating pumps are useful incase of high head and small capacity. These pumps are very common in oil drilling operations. Hand pumps used in domestic purposes are example of reciprocating pump.

10·17. Different Types of Reciprocating Pumps

The reciprocating pumps are classified according to name of reciprocating member, number of cylinder and liquid in contact with one side or both side of the piston.

10·22. Comparison Between Reciprocating and Rotary Pump

Reciprocating Pump	Rotary Pump
1. Size is large.	Size is small.
2. It is low speed pump. Speed is limited to 500 r.p.m. for directly coupled prime mover.	It can run upto 5000 r.p.m.
3. Discharge is intermittent.	Discharge is continuous.
4. It has inlet and outlet valves.	It has inlet and outlet ports.
5. It uses crank shaft and piston mechanism.	It uses gear mechanism.
6. Not useful for thick liquids.	Useful for thick liquid.
7. It is high pressure pump.	It is a low pressure pump.
8. Maintenance cost is high.	Maintenance cost is low.
9. Efficiency ranges from 50 to 90%.	Efficiency ranges from 50 to 80%.

10·23. Centrifugal Pump

Centrifugal pumps are rotodynamic pump. Action of a centrifugal pump is reverse of an inward radial flow reaction turbine. During last 50 years the centrifugal pump has been rapidly superseding the reciprocating pumps. Centrifugal are common and can be seen everywhere.

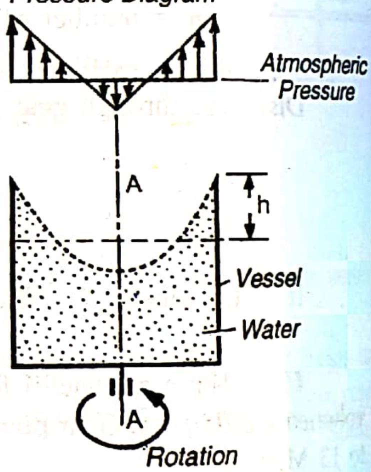


Fig. 10·23

Principle—Centrifugal pump works on centrifugal force. Consider a cylindrical vessel containing water which is being rotated about vertical axis $A - A$ as shown in fig. 10·23. Free surface of water assumes curve which was horizontal before rotation started.

Water in the vessel is subjected to centrifugal force which forces water towards circumference. Since, water can not cross vessel boundary, so water rises upwards upto circumference. Level of water goes down at centre but rises up at circumference.

It can be understood that pressure at centre is less than pressure at circumference on horizontal line. Either partial vacuum is produced at centre or liquid level lowers at centre. Head at circumference is equal to kinetic head.

Suppose more liquid is constantly being supplied at centre of vessel, a continuous supply of liquid can be obtained at higher head.

Construction—Main parts of centrifugal pump are—

impeller, casing, suction pipe, delivery pipe, valve and packing etc.

Impeller is a wheel or rotor with series of backward curved vanes. Liquid is thrown radially outward by vanes. Liquid enter at centre of impeller known as ***eye***. There may be one to eight vanes on an impeller. Impeller is casted in one piece and made of bronze or some alloys. Impeller is mounted on keyed shaft.

There are three types of impellers : open impeller, semi-open impeller and closed or shrouded impeller. An ***open impeller*** has open vanes as shown in fig. 10·24 (a). It is used for liquid containing suspended solid material.

A ***semi-open impeller*** has a base plate on one side but open from other side as shown in fig. 10·24 (b). This impeller is used for liquid containing impurity.

A closed impeller is closed from both sides as shown in fig. 10·24 (c). This impeller shows better guidance of liquid, hence useful for pure liquids.

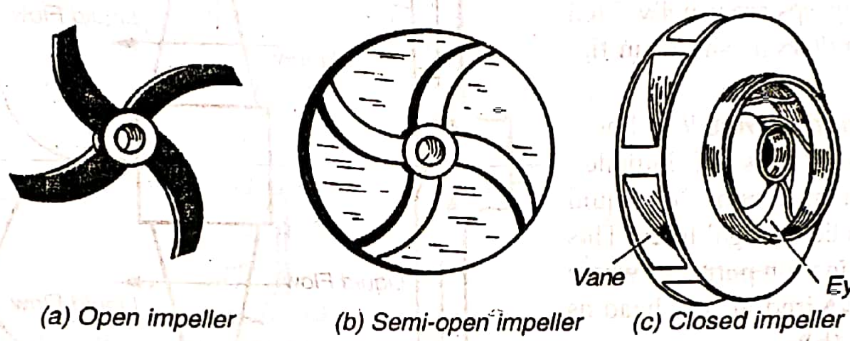


Fig. 10·24

Impeller vanes may be *radially straight*. However, in many cases impeller vanes are ***curved backward, curved forward*** and ***radially curved*** as shown in fig. 10·25.

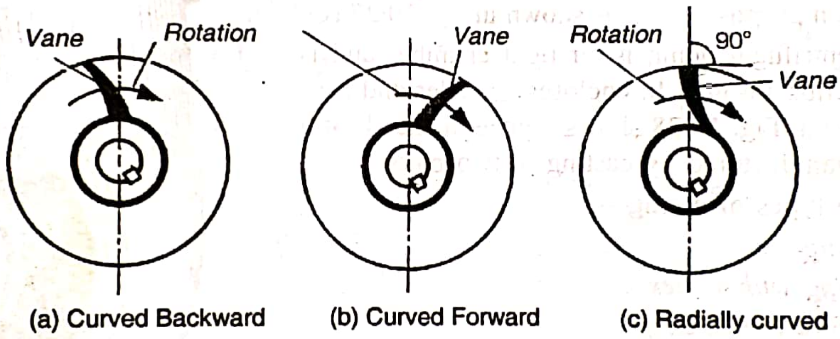


Fig. 10·25

Entry of liquid in the impeller may be from either side as shown in the fig. 10·26. ***Single entry impeller*** and ***double entry impeller.***

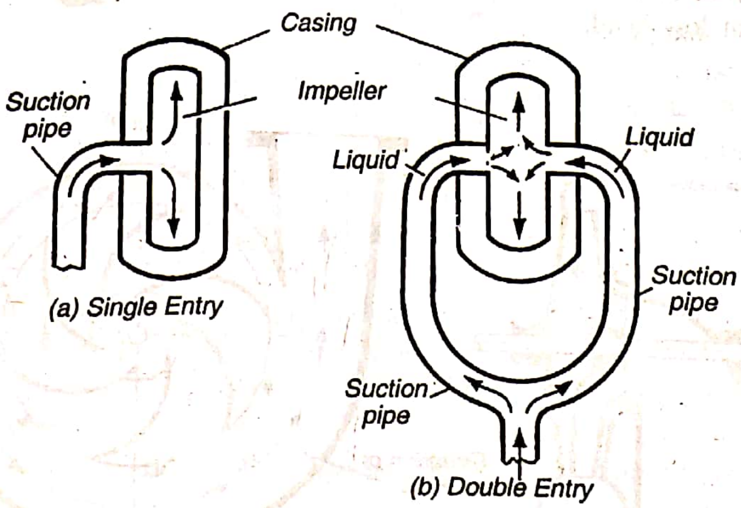
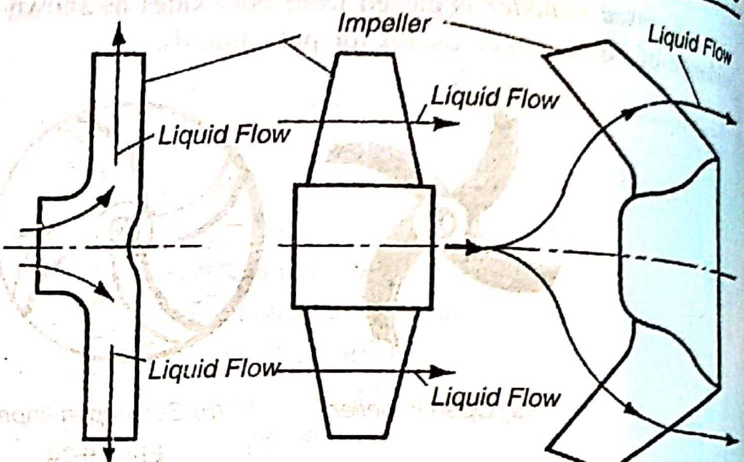


Fig. 10·26

Scanned with CamScanner

Different pumps uses different kind of impellers on the basis of direction of flow. All centrifugal pumps are usually fitted with ***radial flow impellers*** as shown in fig. 10·27 (a).

In case of ***axial flow impellers*** liquid enters parallel to the axis of impeller. Though it is rotodynamic pump but liquid is hardly subjected to centrifugal force. This impeller is used in irrigation purposes where large discharge is required at low head as shown in fig. 10·27 (b).



(a) Radial Flow ***(b) Axial Flow*** ***(c) Mixed Flow***

Fig. 10·27

When flow into impeller is a combination of radial and axial then it is termed as ***mixed flow impellers***. They are also useful for irrigation purposes. This is shown in fig. 10·27 (c).

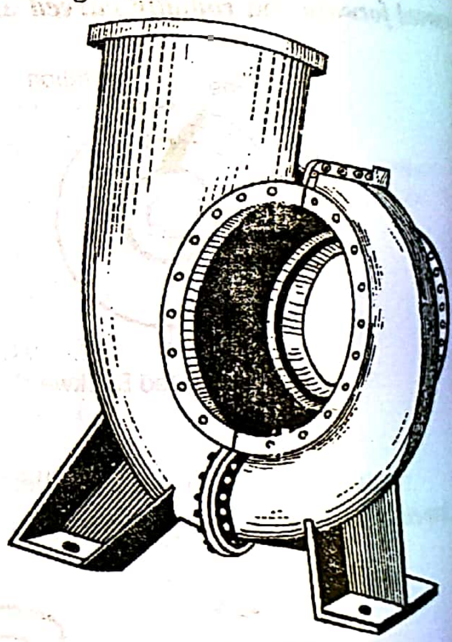


Fig. 10·28

Casing of a centrifugal pump is air tight chamber and is same as that of a reaction turbine. In encloses impeller and runs full of liquid being lifted. Fig. 10·28 shows a general sketch of a typical casing. It is manufactured by casting in two parts.

There are three types of casing—

(i) Volute casing

(ii) Volute casing with vortex

(iii) Diffusor or turbine casing

Fig. 10·29 shows ***volute casing.*** It is spiral and area of flow increases beyond tongue in the direction of flow. Velocity of flow decreases as liquid advances in the casing as a result of which pressure of liquid increases. This casing is useful when large discharge is required at low head.

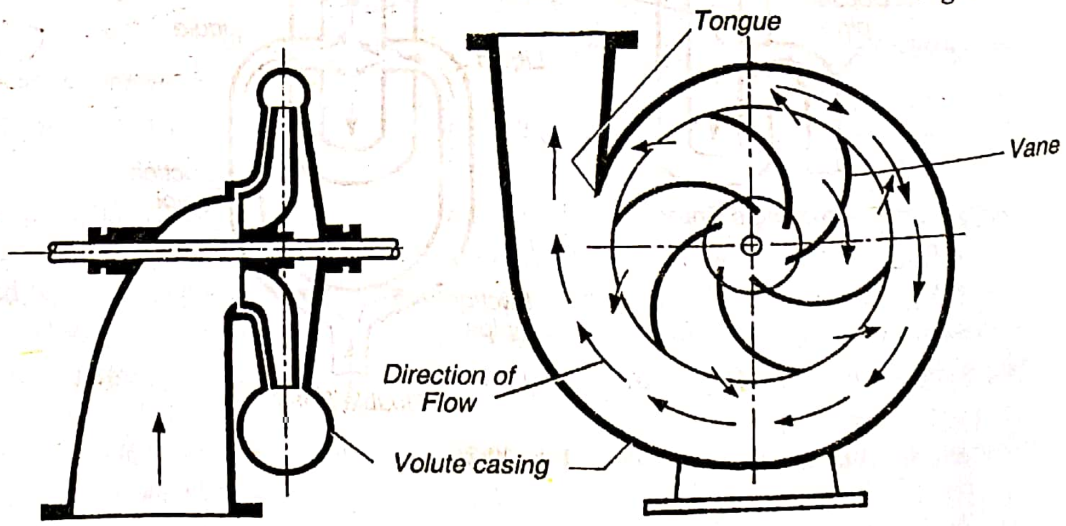


Fig. 10·29. Volute casing

Fig. 10·30 shows ***volute casing with vortex.*** A circular chamber is introduced between volute casing and impeller. It is known as *whirlpool casing* also. Cross-section of circular chamber, also known as vortex chamber, is rectangular. Liquid enters in vortex immediately from impeller. Then flows into volute casing. Energy loss due to formation of eddies is reduced which increase the efficiency of pump.

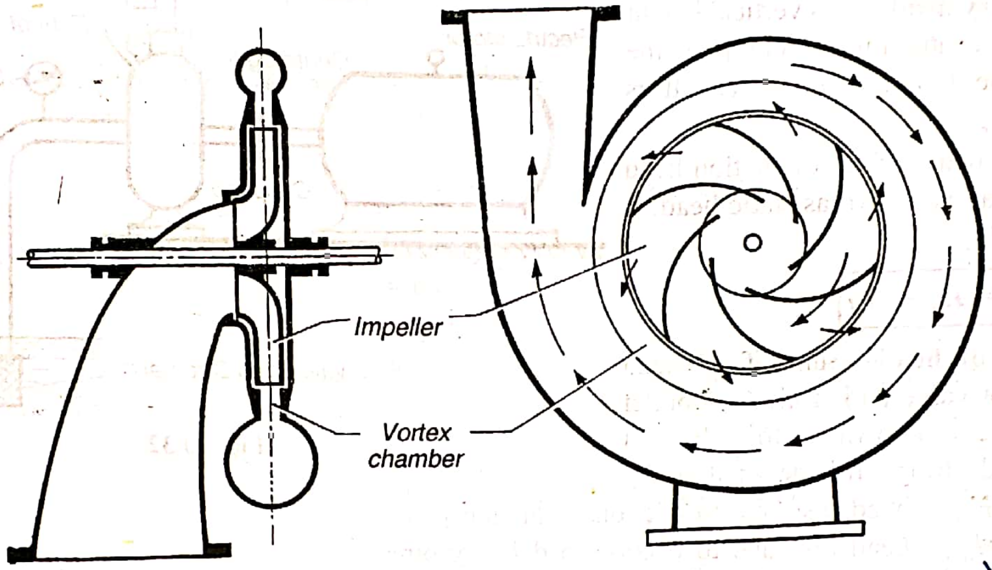


Fig. 10·30. Volute casing with vortex

A diffusor or turbine casing is surrounded by guide vanes mounted on diffusor wheel as shown in fig. 10·31. Water from impeller enters into guide vanes which provide gradually increasing area for flow. Kinetic energy decreases and pressure energy increases. Finally water passes through surrounding casing for discharge.

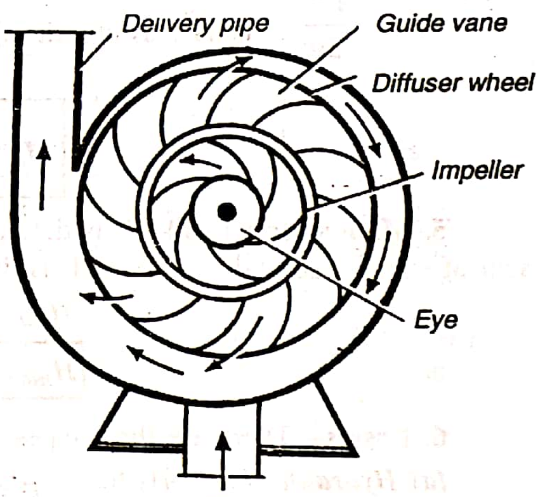


Fig. 10·31

A pipe whose one end is connected to the inlet of pump and other end immersed in water pump is known as ***suction pipe***. A ***non-return valve*** and ***strainer*** is also fitted at lower end of suction pipe. A non-return valve open only when water moves upward. It is known as ***foot valve*** also. Strainer is provided to filter out debris, leaves etc. from pump.

A pipe whose end is connected to the outlet of pump and other end delivering water at desired height, is known as ***delivery pipe***.

Working—Impeller is driven by some prime mover usually an electrical motor. Since, suction pipe is connected at inlet so water enters through eye of the pump. Water is forced to circumference due to centrifugal force by impeller. Thus partial vacuum is created at centre. Water starts entering into the pump continuously from eye.

Water passes through casing where kinetic energy starts decreasing. Increase in pressure energy raises water to desired height.

10·23·3. Multi Stage Centrifugal Pump

If a centrifugal pump consists of two or more then two impellers, the pump is called multi stage centrifugal pump. All impellers of such pumps are mounted on same shaft and enclosed in side same casing.

Consider fig. 10·34. water enters in first impeller from suction pipe. At outlet of first impeller water is discharged with increased pressure. Water is now fed at inlet of second impeller. From outlet of second impeller water is again fed at inlet of third impeller. Lastly water is sent to discharge pipe.

Thus pressure of water increases in steps. Guide vanes guides water during transfer from outlet of one impeller to inlet of next impellers. This arrangement is used to obtain high pressure. Number of impellers are usually taken upto eight. However, higher number of stages can also be employed.

10·24. Priming

Before starting a centrifugal pump, the suction pipe, casing of pump and a part of delivery pipe upto delivery valve at least should be completely filled with liquid from outside source. Therefore, air, gas or vapour from these parts are removed and pump is full of liquid to be raised. It is known as ***priming***.

Since priming is always necessary before starting a centrifugal pump, so pumps are equipped with self-priming devices now-a-days.

(a) Pouring water—Priming funnel is used to prime pump by water or liquid to be raised. Delivery valve remains closed and air vent is kept open during priming. It is closed after priming is over.

(b) Priming chamber—Small pumps are provided with a priming chamber towards delivery side. Liquid is stored in chamber when pump is discharging. This liquid fills impeller and suction line before restarting.

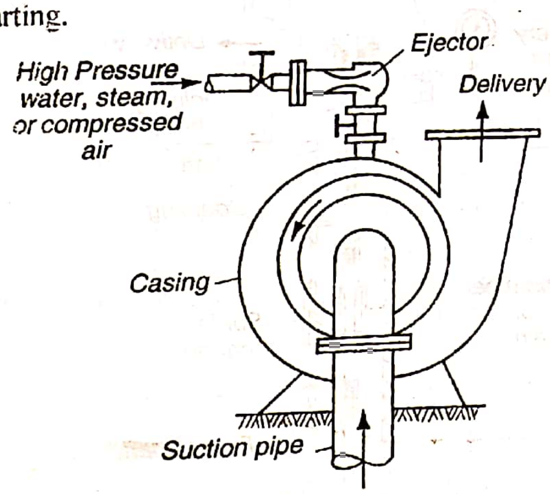


Fig. 10·35

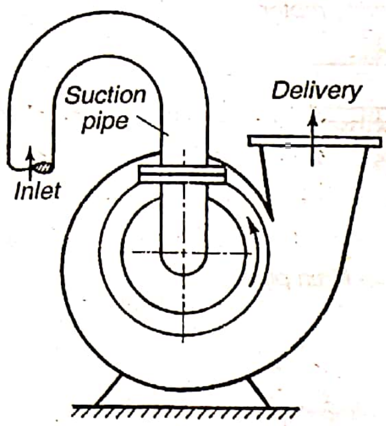


Fig. 10·36

(c) Vacuum producing devices—The suction line and pump are evacuated of all air so that atmospheric pressure at sump may force water into pump.

Evacuation is done using high pressure water or compressed air by ejector.

(d) Self priming devices—Few pump manufacturers connect inlet pipe to pump from top. Water in suction pipe fills pump and suction when switched-off. Hence, pump is always self primed. It is shown in fig. 10·36.

10·25. Submersible Bore Hole Pump

This pump is used to lift water from deep bore well. It is a centrifugal diffusor pump of vertical shaft. Number of impellers are mounted on same shaft as per the requirement of head. Hence, a submersible bore hole pump is a multistage centrifugal pump.

Solution : Discharge,

$$Q = \eta_v \times \frac{L \times (2A - a)N}{60} \text{ m}^3/\text{s}$$

$$= \frac{0.9 \times 0.2(2 \times 0.0314 - 0.002)}{60} \times 39 = \mathbf{0.00711\ m^3/s} \quad \textbf{Ans.}$$

***Example 3 :** A pump discharges water at rate of 0·0125 m^3/s against 2800 m head. If pump is run by a 500 kW electric motor then determine efficiency of pump.* **(Rajasthan)**

Solution : Weight of water per second W = discharge $\times \rho g$

$$= 0.0125 \times 1000 \times 9.81 = 122.625 \text{ N/s}$$

Power imparted to water, $P = \frac{W \times H}{1000}$

$$= \frac{122.625 \times 2800}{1000} = 343.350 \text{ kW}$$

$$\therefore \quad \eta = \frac{\text{Power imparted to water}}{\text{Power of motor}}$$

$$= \frac{343.35}{500} = 0.6867 = \mathbf{68.67\%} \quad \textbf{Ans.}$$

10·27. Cavitation

We know that when flow velocity increases pressure of liquid decreases in accordance with Bernoulli's theorem. We also know that a liquid evaporates if atmospheric pressure drop to vapour pressure or falls below atmospheric pressure.

When pressure of flowing liquid in any part of turbine or pump falls below vapour pressure, the liquid boils. Large number of small bubbles are formed. When bubbles are carried away by liquid in high pressure part of turbine or pump bubbles suddenly collapse. Bubble convert into liquid again. ***Cavities*** are formed at point of collapse of bubble. Liquid rushes to fill cavities from all directions. Local pressure increases to very high value. Magnitude of high local pressure is in the order 10^8 pascals. This process repeats again and again about thousand times each second. It causes ***pitting*** on metallic surfaces of impeller vanes and draft tubes. The phenomenon of pitting of metal by this process is known as ***cavitation***.

Turbines and pumps are designed to avoid cavitation. Cavitation not only damages metallic surfaces by pitting but reduces efficiency also.

Cavitation depends upon velocity of water at runner exit, suction head H_s, vapour pressure and atmospheric pressure.

10·28. Hydraulic Press

Hydraulic press was built by Bramah in 1790. Since then it is in use. Hydraulic press is based on ***Pascal's law***. Device is used to lift heavy loads with small amount of force.

Hydraulic press, as shown in fig. 10·39, consists of two cylinders of unequal cross-section. Large cylinder is fitted with ***ram*** and small cylinder is fitted with ***plunger***.