35

Centrifugal Pumps

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35·1 Introduction

Since the olden times, the man has been trying to find some convenient ways of lifting water to higher levels, for water supply or irrigation purposes. It is believed, that the idea of lifting water, by centrifugal force, was first given by L.D. Vinci (an Italian scientist and engineer) in the end of 16th century. Then this idea was put to experiments by French scientist and they designed centrifugal pump, having impeller and blades. At that time, the reciprocating* pumps were very popular. Then a continuous advancement of this pump has brought it to a high degree of perfection, which is used all over the world these days.

35·2 Types of Pumps

Though there are many types of pumps these days, yet the following two are important from the subject point of view:

1. Centrifugal pump, and
2. Reciprocating pump.

In this chapter, we shall discuss the centrifugal pumps only.

35·3 Centrifugal Pump

A pump, in general may be defined as a machine, when driven from some external source, lifts water or some other liquid from a lower level to a higher level. Or in other words, a pump may also be defined as a machine, which converts mechanical energy into pressure energy. The pump which raises water or a liquid from a lower level to a higher level by the action of centrifugal force, is known as a centrifugal pump.

It will be interesting to know that the action of a centrifugal pump is that of a reversed reaction turbine. In a reaction turbine, the water at high pressure, is allowed to enter the casing which gives mechanical energy at its shaft; whereas in a pump, the mechanical energy is fed into the shaft and water enters the impeller (attached to the rotating shaft) which increases the pressure energy of the out-going fluid. The water enters the impeller radially and leaves the vanes axially.

35·4 Types of Casings for the Impeller of a Centrifugal Pump

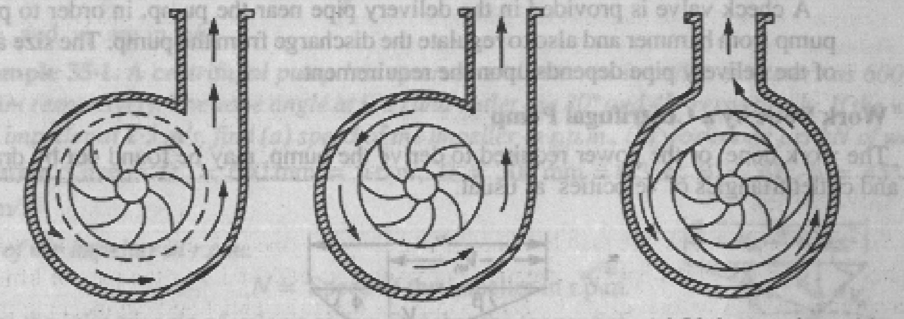
We have discussed in Art 35·3 that a centrifugal pump consists of an impeller, similar to that of a turbine, to which curved vanes are fitted. The impeller is enclosed in a water-tight casing, having a delivery pipe in one of its sides. The casing for a centrifugal pump is so designed that the kinetic

*Reciprocating pumps will be discussed in the next chapter.

energy of the water is converted into pressure energy before the water leaves the casing. This considerably increases the efficiency of the pump. Following are the three types of casings o chambers of centrifugal pumps :

1. Volute casing (spiral casing),
2. Vortex casing, and
3. Volute casing with guide blades.

35·5 Volute Casing (Spiral Casing)



(a) Volute casing (b) Vortex casing (a) Volute casing with guide blades

Fig. 35·1

In a volute chamber, the impeller is surrounded by a spiral casing as shown in Fig. 35·1(a) Such a casing provides a gradual increase in the area of flow; which decreases the velocity of water with a corresponding increase in pressure.

A considerable loss takes place due to the formation of eddies in this type of casing.

35·6 Vortex Casing

It is an improved type of a volute casing, in which the spiral casing is combined with a circula chamber as shown in Fig. 35·1 (b). In a vortex casing, the eddies are reduced to a considerable exter and an increased efficiency is obtained.

35·7 Volute Casing with Guide Blades

In this type of casing, there are guide blades surrounding the impeller as shown in Fig. 35·1 (c These guide blades are arranged at such an angle, that the water enters without shock and forms passage of increasing area, through which the water passes and reaches the delivery pipe.

The ring of the guide blades is called difuser and is very efficient.

35·8 Piping System of a Centrifugal Pump

The successful working of a centrifugal pump depends upon the correct selection and lay ou of its piping system. An extreme care should always be taken in selecting the sizes of the pipes an their arrangement. In general, a centrifugal pump has (a) suction pipe, and (b) delivery pipe.

(a) *Suction pipe*

The suction pipe, of a centrifugal pump, plays an important role in the successful an smooth working of the pump. A poorly designed suction pipe causes insufficient n positive suction head (brief written as *NPSH), vibration, noise, water hummer, excessiv wear etc. While laying the pipe, a great care should be taken to make it air tight. A strain foot-valve is connected at the bottom of the suction pipe to avoid the entry of foreig

*It is an important term in pumps. For details please refer to Art. 37·9.

matter. Since the pressure at the inlet of the pump is suction (*i.e.*, negative) and its value is limited to avoid cavitation, it is therefore essential that the losses in the suction pipe should be as small as possible. For this purpose, bends in the suction pipe are avoided and its diameter is often kept larger.

Sometimes, to reduce the axial thrust, the suction pipe is branched into two parts and the liquid is allowed to enter the impeller from both sides. Such a pump is called double suction pump.

(*b*) *Delivery pipe*

A check valve is provided in the delivery pipe near the pump, in order to protect the pump from hammer and also to regulate the discharge from the pump. The size and length of the delivery pipe depends upon the requirement.

35·9 Work Done by a Centrifugal Pump

The work done, or the power required to derive the pump, may be found out by drawing the inlet and outlet triangles of velocities as usual.

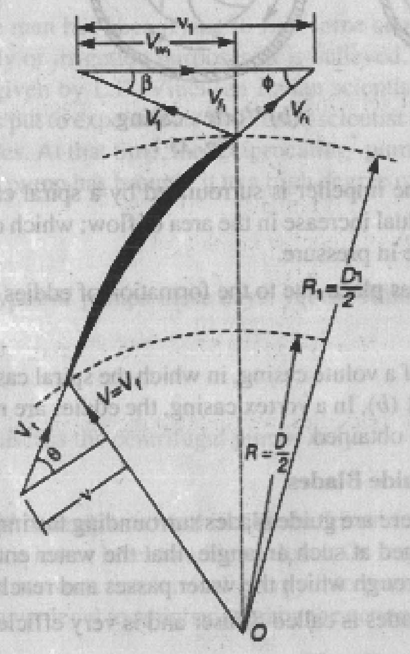


Fig. 35·2. Inlet and outlet triangle of velocities

Consider a centrifugal pump lifting water from a lower level to a higher level. Now draw the inlet and outlet triangle of velocities as shown in Fig. 35·2.

Let V = Absolute velocity of the entering water,

D = Diameter of the impeller at inlet (inner diameter),

v = Tangential velocity of impeller at inlet (Also known as peripheral velocity at inlet),

V_r = Relative velocity of water to the wheel at inlet,

V_f = Velocity of flow at inlet,

N = Speed of the impeller in r.p.m.,

θ = Vane angle at inlet.

β = Angle at which the water leaves the impeller,

φ = Vane angle at outlet.

Since the water enters the impeller radially, therefore the velocity of whirl at inlet (V_w = 0).

∴ Work done per kN of water

$$= \frac{V_{w1} \cdot v_1}{g} \text{ kN-m}$$

where V_{w1} and v_1 are in m/s.

Example 35·1. *A centrifugal pump has external and internal impeller diameters as 600 mm and 300 mm respectively. The vane angle at inlet and outlet are 30° and 45° respectively. If the water enters the impeller at 2·5 m/s, find (a) speed of the impeller in r.p.m., (b) work done per kN of water.*

Solution. Given : D_1 = 600 mm = 0·6 m; D = 300 mm = 0·3 m; θ = 30°; φ = 45° and V = 2·5 m/s.

(a) Speed of the impeller in r.p.m.

Let N = Speed of the impeller in r.p.m.

From the inlet triangle of velocities, we find that the tangential velocity of impeller at inlet,

$$v = \frac{V}{\tan 30°} = \frac{2·5}{0·5774} = 4·33 \text{ m/s}$$

We know that the velocity of impeller at inlet (v),

$$4·33 = \frac{\pi DN}{60} = \frac{\pi \times 0·3\, N}{60} = 0·0157\, N$$

$$\therefore \quad N = 4·33/0·0157 = 275·8 \text{ r.p.m. } \textbf{Ans.}$$

(b) Work done per kN of water

From the outlet triangle of velocities, we find that the tangential velocity at outlet,

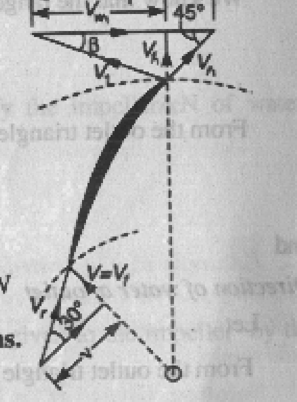


Fig. 35·3

$$v_1 = v \times \frac{D_1}{D} = 4·33 \times \frac{0·6}{0·3} = 8·66 \text{ m/s}$$

and velocity of whirl at outlet,

$$V_{w1} = v_1 - \frac{V_{f1}}{\tan 45°} = 8·66 - \frac{2·5}{1} = 6·16 \text{ m/s}$$

$$(\because V_{f1} = V_f = \ldots$$

Since the tangential velocity of impeller at outlet v_1 (8·66) is more than velocity of whirl at outlet V_{w1} (6·16), therefore shape of the outlet triangle will be as shown in Fig. 35·3. We know that work done per kN of water,

$$W = \frac{V_{w1} \cdot v_1}{g} = \frac{6·16 \times 8·66}{9·81} = 5·44 \text{ kN-m} = 5·44 \text{ kJ } \textbf{Ans.}$$

Example 35·2. *Calculate vane angle at the inlet of a centrifugal pump impeller having 200 mm diameter at inlet and 400 mm diameter at outlet. The impeller vanes are set back at angle of 45° to the outer rim, and the entry of the pump is radial. The pump runs at 1000 r.p.m. and the velocity of flow through the impeller is constant at 3 m/s. Also calculate the work done per kN of water and the*

Solution. Given : $D = 200$ mm $= 0{\cdot}2$ m; s $D_1 = 400$ mm $= 0{\cdot}4$ m; $\phi = 45°$; $N = 1000$ r.p.m. and $V_f = V_{f1} = 3$ m/s

Vane angle at inlet

Let θ = Vane angle at inlet.

We know that the tangential velocity of impeller at inlet,

$$v = \frac{\pi DN}{60} = \frac{\pi \times 0{\cdot}2 \times 1\,000}{60}$$

$$= 10{\cdot}5 \text{ m/s}$$

From the inlet triangle of velocities, we find that

$$\tan\theta = \frac{V_f}{v} = \frac{3}{10{\cdot}5} = 0{\cdot}2857$$

$$\therefore \quad \theta = 15{\cdot}9° \textbf{ Ans.}$$

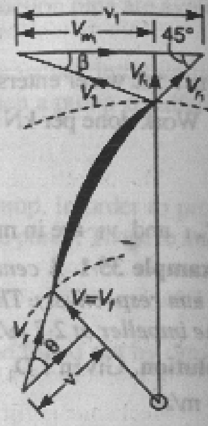


Fig. 35-4

Velocity of water at outlet

We know that the tangential velocity of impeller at outlet,

$$v_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0{\cdot}4 \times 1\,000}{60} = 20{\cdot}9 \text{ m/s}$$

From the outlet triangle of velocities, we find that the velocity of whirl at outlet,

$$V_{w1} = v_1 - \frac{V_{f1}}{\tan 45°} = 20{\cdot}9 - \frac{3}{1} = 17{\cdot}9 \text{ m/s}$$

and

$$V_1 = \sqrt{V_{f1}^2 + V_{w1}^2} = \sqrt{(3)^2 + (17{\cdot}9)^2} = 18{\cdot}1 \text{ m/s } \textbf{Ans.}$$

Direction of water at outlet

Let β = Angle, at which the water leaves the impeller at outlet.

From the outlet triangle of velocities, we also find that

$$\tan\beta = \frac{V_{f1}}{V_{w1}} = \frac{3}{17{\cdot}9} = 0{\cdot}1676 \text{ or } \beta = 9{\cdot}5° \textbf{ Ans.}$$

Work done per kN of water

We also know that work done per kN of water,

$$W = \frac{V_{w1} \cdot v_1}{g} = \frac{17{\cdot}9 \times 20{\cdot}9}{9{\cdot}81} = 38{\cdot}14 \text{ kN-m} = 38{\cdot}14 \text{ kJ } \textbf{Ans.}$$

35·10 Manometric Head

It is an important term, in the field of centrifugal pumps, and may be defined in any one of the following four ways:

1. The manometric head is the actual head against which the pump has to work.
2. Manometric head,

$$H_m = H_s + H_{fs} + H_d + H_{fd} + \frac{V_d^2}{2g}$$

where H_s = Suction lift,

H_{fs} = Loss of head in suction pipe due to friction,

H_d = Delivery lift,

H_{fd} = Loss of head in delivery pipe due to friction,

V_d = Velocity of water in the delivery pipe.

3. Manometric head,

$$H_m = \text{Work done/kN of water} - \text{Losses within the impeller}$$

$$= \frac{V_{w1} \cdot v_1}{g} - \text{Impeller losses}$$

4. Manometric head,

$$H_m = \text{Energy/kN of water at outlet of impeller}$$
$$- \text{Energy/kN of water at inlet of impeller}$$

35·11 Efficiencies of a Centrifugal Pump

A centrifugal pump has the following three types of efficiencies:

1. Manometric efficiency,
2. Mechanical efficiency, and
3. Overall efficiency.

35·12 Manometric Efficiency

It is the ratio of manometric head to the energy supplied by the impeller/kN of water. Mathematically manometric efficiency,

$$\eta_{man} = \frac{H_m}{\dfrac{V_{w1}\, v_1}{g}}$$

35·13 Mechanical Efficiency

It is the ratio of energy available at the impeller, to the energy given to the impeller by the prime power.

35·14 Overall Efficiency

It is the ratio of actual work done by the pump, to the energy supplied to the pump by the prime mover.

35·15 Discharge of a Centrifugal Pump

The discharge of a centrifugal may be found out by the same method as that of a reaction turbine. Now consider a centrifugal pump lifting water from a lower level to a higher level.

Let D = Diameter of impeller at inlet,

V_f = Velocity of flow at inlet,

b = Width of impeller at inlet, and

D_1, b_1, V_{f1} = Corresponding values at the outlet.

Then the discharge, $Q = \pi D b V_f = \pi D_1 b_1 V_{f1}$

Example 35·3. *A centrifugal pump is to discharge water at the reate of 110 litres/second at a speed of 1450 r.p.m. against a head of 23 metres. The impeller diameter is 250 mm and its width 50 mm. If the manometric efficiency is 75%, determine the vane angle at the outer periphery.*

Solution. Given : $Q = 110$ litres/s $= 0{\cdot}11$ m³/s; $N = 1450$ r.p.m. $H_m = 23$ m; $D_1 = 250$ mm $= 0{\cdot}25$ m; $D = 50$ mm $= 0{\cdot}05$ m and $\eta_{man} = 75\% = 0{\cdot}75$.

Let ϕ = Vane angle at outlet.

V_{f1} = Velocity of flow at outlet, and

V_{w1} = Velocity of whirl at outlet.

We know that the tangential velocity of impeller at outlet,

$$v_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.25 \times 1450}{60} = 19 \text{ m/s}$$

and discharge of the pump (Q),

$$0.11 = \pi D_1 b_1 V_{f1} = \pi \times 0.25 \times 0.05 \times V_f = 0.039\, V_f$$

$$\therefore \quad V_f = 0.11/0.039 = 2.8 \text{ m/s.}$$

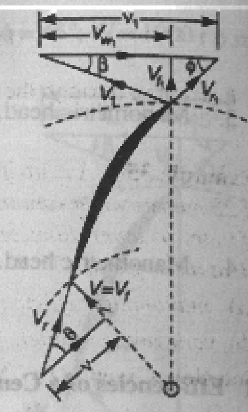


Fig. 35·5

We also know that manometric efficiency (η_{man}),

$$0.75 = \frac{H_m}{\frac{V_{w1} \cdot v_1}{g}} = \frac{23}{\frac{V_{w1} \times 19}{9.81}} = \frac{11.9}{V_{w1}}$$

$$\therefore \quad V_{w1} = 11.9/0.75 = 15.9 \text{ m/s}$$

Now from the outlet triangle of velocities, we find that

$$\tan \phi = \frac{V_{f1}}{v_1 - V_{w1}} = \frac{2.8}{19 - 15.9} = 0.9032 \text{ or } \phi = 42.1° \textbf{ Ans.}$$

Example 35·4. *A centrifugal pump delivers water against a head of 14·5 metres while running at 1000 r.p.m. The vanes are curved back at an angle of 30° with the periphery. The impeller diameter is 300 mm and outlet width 50 mm. If manometric efficiency of the pump is 85%, find the discharge of the pump.*

Solution. Given : $H_m = 14.5$ m; $N = 1000$ r.p.m.; $\theta = 30°$; $D_1 = 300$ mm = 0·3 m; $b_1 = 50$ mm = 0·05 m and η_{man} = 85% = 0·85.

Let V_{w1} = Velocity of whirl at outlet.

We know that tangential velocity of the impeller at outlet,

$$v_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.3 \times 1000}{60} \text{ m/s} = 15.7 \text{ m/s}$$

and manometric efficiency (η_{man}),

$$0.85 = \frac{H_m}{\frac{V_{w1} \cdot v_1}{g}} = \frac{14.5}{\frac{V_{w1} \times 15.7}{9.81}} = \frac{9.06}{V_{w1}}$$

$$\therefore \quad V_{w1} = 9.06/0.85 = 10.7 \text{ m/s}$$

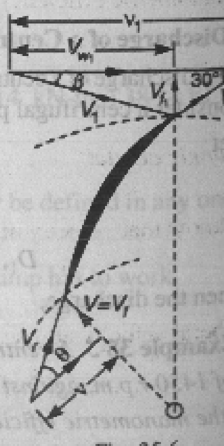


Fig. 35·6

From the outlet triangle of velocities, we find that

$$\tan 30° = \frac{V_{f1}}{v_1 - V_{w1}} = \frac{V_f}{15.7 - 10.7}$$

or $\quad 0.5774 = \frac{V_f}{5}$ or $V_f = 0.5774 \times 5 = 2.89$ m/s

∴ Discharge through the pump,

$$Q = \pi D_1\, b_1\, V_{f1} = \pi \times 0.3 \times 0.05 \times 2.89 = 1.136 \text{ m}^3\text{/s} \textbf{ Ans.}$$

Example 35·5. *A centrifugal pump discharges 7500 litres of water per minute against a total head of 25 metres when running at 660 r.p.m. The outer diameter of the impeller is 600 mm and the ratio of outer to inner diameter is 2. The area of flow, through the wheel is 0·06 m². The vanes are set back at an angle of 45°. Water enters the wheel radially and without shock. Calculate*

(a) manametric efficiency, and

(b) vane angle at inlet.

Solution. Given : Q = 7500 litres/min = 0·125 m³/s; H_m = 25 m; N = 660 r.p.m.; D_1 = 600 mm = 0·6 m; $\frac{D_1}{D} = 2$ or $D = \frac{D_1}{2} = \frac{0.6}{2} = 0.3$ m; Area of flow (A) = πDb = 0·06 m² and ϕ = 45°

(a) Manometric effeciency

We know that peripheral velocity at outlet,

$$v_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.6 \times 660}{60} \text{ m/s} = 20.7 \text{ m/s}$$

and velocity of flow at outlet,

$$V_{f1} = \frac{Q}{\pi D_1 b_1} = \frac{0.125}{0.06} = 2.1 \text{ m/s}$$

From the inlet triangle of velocities, we find that the velocity of whirl at outlet,

$$V_{w1} = v_1 - \frac{V_{f1}}{\tan \phi} = 20.7 - \frac{2.1}{\tan 45°} = 20.7 - \frac{2.1}{1} = 18.6 \text{ m/s}$$

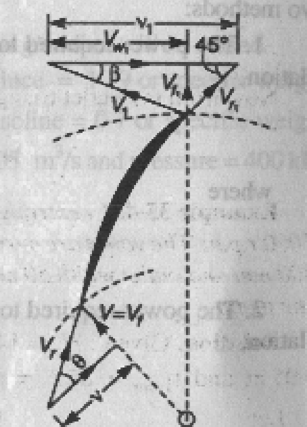


Fig. 35·7

∴ Manometric efficiency

$$\eta_{man} = \frac{H_m}{\frac{V_{w1} \cdot v_1}{g}} = \frac{25}{\frac{18.6 \times 20.7}{9.81}} = 0.637 = 63.7\% \textbf{ Ans.}$$

(b) Vane angle at inlet

Let θ = Vane angle at inlet.

We know that velocity of flow at inlet,

$$V_f = \frac{Q}{\pi Db} = \frac{0.125}{0.06} = 2.1 \text{ m/s} \qquad \text{...(Given } \pi Db = 0.06 \text{ m}^2\text{)}$$

and peripheral velocity at inlet,

$$v = v_1 \times \frac{D}{D_1} = 20.7 \times \frac{0.3}{0.6} = 10.35 \text{ m/s}$$

$$\therefore \quad \tan \theta = \frac{V_f}{v} = \frac{2.1}{10.35} = 0.2029 \text{ or } \theta = 11.5° \textbf{ Ans.}$$

EXERCISE 35·1

1. A centrifugal pump has external and internal diameters of 300 mm and 150 mm respectively. The vane angles of inlet and outlet are 25° and 30° and the pump runs at 1450 r.p.m. If the velocity of flow through the pump is constant, find the work done per kN of water. **(Ans. 20·2 kJ)**
2. A centrifugal pump having external and internal diameters as 750 mm and 400 mm respectively is operating at 1000 r.p.m. The vanes are curved back at 35° to the tangent at outlet. If the velocity of flow is constant at 6 m/s, find *(a)* vane angle at inlet, and *(b)* work done per kN of water. **(Ans. 16°; 123 kJ)**
3. A centrifugal pump of 350 mm diameter running at 1000 r.p.m. develops a head of 18 metres. The vanes are curved back at an angle of 30° to the tangent at outlet. If the velocity of flow is constant at 2·4 m/s, find the manometric efficiency of the pump. **(Ans. 76·4%)**
4. A centrifugal pump delivers water to a height of 22 metres at a speed of 800 r.p.m. The velocity of flow is constant at a speed of 2·0 m/s and the outlet vane angle is 45°. If the pump discharges 225 litres of water per second, find the diameter of the impeller and width of the impeller at outlet. **(Ans. 375 mm; 95 mm)**

35·16 Power Required to Drive a Centrifugal Pump

The power required to drive a centrifugal pump may be found out by either of the following two methods:

1. The power required to drive the pump from the manometic head may be found out by the relation,

$$P = \frac{wQH_m}{\eta_0}\ \text{kW}$$

where H_m = Manometric head of water in metres,

Q = Discharge of the pump in m³/sec,

η_0 = Overall efficiency of the pump.

2. The power required to drive the pump from the velocity traingles may be found out by the relation,

$$P = \frac{wQ \cdot V_{w1} \cdot v_1}{g}\ \text{kW}$$

whirl V_{w1} = Velocity of whirl at outlet, and

v_1 = Tangential velocity of impeller at outlet.

Example 35·6. *A centrifugal pump is requird to lift water to a total head of 40 metres at the rate of 50 litres/s. Find the power required for the pump, if its overall efficiency is 62%.*

Solution. Given : H_m = 40 m; Q = 50 litres/s = 0·05 m³/s and η_0 = 62% = 0·62.

We know that power required to drive the pump.

$$P = \frac{wQH_m}{\eta_0} = \frac{9\cdot81 \times 0\cdot05 \times 40}{0\cdot62} = 31\cdot6\ \text{kW}\ \textbf{Ans.}$$

Example 35·7. *A centrifugal pump delivers 30 litres of water per second to a height of 18 metres through a pipe 90 metres long and of 100 mm diameter. If the overall efficiency of the pump is 75%, find the power required to drive the pump Take f 0·012.*

Solution. Given : Q = 30 litres/s = 0·03 m³/s; H = 18 m; l = 90 m; d = 100 mm = 0·1 m; η_0 = 75% = 0·75 and f = 0·012.

We know that cross-sectional area of pipe,

$$a = \frac{\pi}{4} \times (d)^2 = \frac{\pi}{4} \times (0\cdot1)^2 = 7\cdot854 \times 10^{-3}\ \text{m}^2$$

and velocity of water

$$v = \frac{Q}{a} = \frac{0\cdot03}{7\cdot584 \times 10^{-3}} = 3\cdot82\ \text{m/s}$$

We also know that manometric head.

$$H_m = H + \text{Loss of head in pipe} + \text{Loss of head at outlet}$$

$$= 18 + \frac{4flv^2}{2gd} + \frac{v^2}{2g}$$

$$= 18 + \frac{4 \times 0\cdot012 \times 90 \times (3\cdot82)^2}{2 \times 9\cdot81 \times 0\cdot1} + \frac{(3\cdot82)^2}{2 \times 9\cdot81}\ \text{m}$$

$$= 18 + 32\cdot1 + 0\cdot74 = 50\cdot84\ \text{m}$$

and power required to drive the pump.

$$P = \frac{wQH_m}{\eta_0} = \frac{9\cdot81 \times 0\cdot03 \times 50\cdot84}{0\cdot75} = 19\cdot9\ \text{kW}\ \textbf{Ans.}$$

Example 35·8. *A centrifugal pump, having an overall efficiency of 62%, is required to handle brine (sp. gr = 1·19) and gasoline (sp. gr. = 0·7). The discharge of each of these liquids is 50 litres/s against a net pressure of 400 kPa. Show that the same power is required for handling both the above liquids having different specific gravities.*

Also calculate the head in metres of fluid to which the brine and gasoline will be raised.

Solution. Given : η_0 = 62% = 0·62; Specific. gravity of brince = 1·19 or specific weight of brine (w_b) = 9·81 × 1·19 = 11·7 kN/m³; Specific gravity of gasoline = 0·7 or specific weight of gasoline (w_g) = 9·81 × 0·7 = 6·87 kN/m³; Q = 50 litres/s = 0·05 m³/s and pressure = 400 kPa = 400 kN/m².

Head to which brine and gasoline will be raised

We know that head to which the brine will be raised,

$$H_b = \frac{p}{w_b} = \frac{400}{11\cdot7} = 34\cdot2\ \text{m}\ \textbf{Ans.}$$

and head to which the gasoline will be raised,

$$H_g = \frac{p}{w_g} = \frac{400}{6\cdot87} = 58\cdot2\ \text{m}\ \textbf{Ans.}$$

Power required for handling both the liquids

We know that power required to handle the brine,

$$P = \frac{w_b \times Q \times H_b}{\eta_0} = \frac{11\cdot7 \times 0\cdot05 \times 34\cdot2}{0\cdot62} = 32\cdot3\ \text{kW}$$

and power required to handle the gasoline

$$P = \frac{w_g \times Q \times H_g}{\eta_0} = \frac{6\cdot87 \times 0\cdot05 \times 58\cdot2}{0\cdot62} = 32\cdot3\ \text{kW}$$

From both the above results, we find that same power is required for handling both the liquids. **Ans.**

Example 35·9. *A centrifugal pump of 1·5 metre diameter runs at 210 r.p.m. and pumps 1... litres of water per second. The angle which the vane makes, at exit, with the tangent to the impeller is 25°. Assuming radial entry and velocity of flow throughout as 2·5 m/s, determine the power required to drive the pump.*

If manometric efficiency of the pump is 65 per cent, find the average lift of the pump.

Solution. Given : $D_1 = 1.5$ m; $N = 210$ r.p.m.; $Q = 180$ litres/s $= 0.18$ m³/ s $\theta = 25°$;
$V_f = V_{f1} = 2.5$ m/s and $\eta_{man} = 65\% = 0.65$.

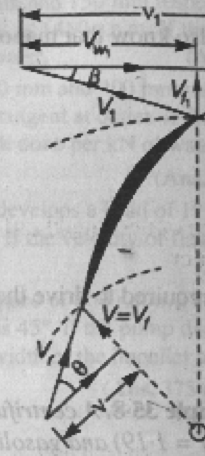


Fig. 35·8

Power required to drive the pump

We know that tangential velocity of the impeller, at outlet,

$$v_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 1.5 \times 210}{60}$$

$$= 16.5 \text{ m/s}$$

From the outlet velocity triangle, we find that velocity of whirl at outlet,

$$V_{w1} = v_1 - \frac{V_f}{\tan\theta}$$

$$= 16.5 - \frac{2.5}{\tan 25°} \text{ m/s}$$

$$= 16.5 - \frac{2.5}{0.4663}$$

$$= 11.1 \text{ m/s}$$

∴ Power required to drive the pump

$$P = \frac{wQ \cdot V_{w1} \cdot v_1}{g} = \frac{9.81 \times 0.18 \times 11.1 \times 16.5}{9.81} \text{ kW}$$

$$= 33.0 \text{ kW } \textbf{Ans.}$$

Average lift of the pump

Let H_m = Average lift of the pump (or manometric head).

We know that manometric efficiency (η_{man}),

$$0.65 = \frac{H_m}{\frac{V_{w1} \cdot v_1}{g}} = \frac{H_m}{\frac{11.1 \times 16.5}{9.81}} = \frac{H_m}{18.7}$$

∴ $H_m = 0.65 \times 18.7 = 12.2$ m **Ans.**

Example 35·10. *A centrifugal pump delivers 50 litres of water per second against a total head of 24 metres running at 1500 r.p.m. The velocity of flow is maintained constant at 2·4 m/s and the blades are curved back at 30° to the tangent at exit. The inner diameter is half of the outer diameter. If the manometric efficiency is 80%, find:*

(a) *blade angle at inlet, and*

(b) *power required to drive the pump.*

Solution. Given : $Q = 50$ litres/s $= 0.05$ m³/s; $H_m = 24$ m; $N = 1500$ r.p.m.;

$V_f = V_{f1}$ 2·4 m/s; $\phi = 30°$ $D = \frac{D_1}{2}$ or $\frac{D}{D_1} = \frac{1}{2}$ and $\eta_{man} = 80\% = 0.8$

(a) Blade angle at inlet

Let θ = Blade angle at inlet.

We know that manometric efficiency (η_{man}),

$$0.8 = \frac{H_m}{\frac{V_{w1} \cdot v_1}{g}} = \frac{24}{\frac{V_{w1} \cdot v_1}{9.81}}$$

$$= \frac{235.4}{V_{w1} \cdot v_1}$$

∴ $V_{w1} \cdot v_1 = 235.4/0.8 = 294.3$ ...(*i*)

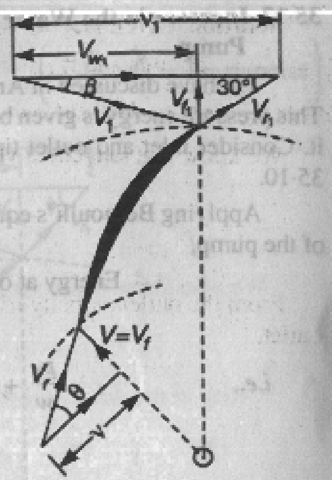


Fig. 35·9

From the outlet triangle of velocities, we find that the velocity of whirl at outlet,

$$V_{w1} = v_1 - \frac{V_{f1}}{\tan 30°} = v_1 - \frac{2.4}{0.5774}$$

$$= v_1 - 4.16$$

Substituting this value of V_{w1} in equation (*i*),

$$(v_1 - 4.16) \times v_1 = 294.3$$

$$v_1^2 - 4.16\, v_1 = 294.3 = 0$$

This is a quadratic equation for v_1. Therefore

$$v_1 = \frac{4.16 \pm \sqrt{(4.16)^2 \pm 4 \times 294.3}}{2} = 19.3 \text{ m/s}$$

We know that peripheral valocity of impeller at inlet

$$v = \frac{D}{D_1} \times v = \frac{1}{2} \times 19.3 = 9.65 \text{ m/s}$$

From the inlet triangle of velocities, we find that

$$\tan\theta = \frac{V_f}{v} = \frac{2.4}{9.65} = 0.2487 \text{ or } \theta = 14° \textbf{ Ans.}$$

(b) Power required to drive the pump

We also know that power required to drive the pump

$$P = \frac{wQ \cdot V_{w1} \cdot v_1}{g} = \frac{9.81 \times 0.05 \times (294.3)}{9.81} = 14.7 \text{ kW } \textbf{Ans.}$$

EXERCISE 35·2

1. A centrifugal pump delivers 60 litres of water per second to a tank situated at a height of 20 metres. If the overall efficiency of the pump is 70%, find the power required for the pump. **(Ans. 16·8 kW)**
2. A centrifugal pump having an overall efficiency of 75% is discharging 30 litres of water per second through a pipe of 150 mm diameter and 125 m long. Calculate the power required to drive the pump, if the water is lifted through a height of 25 metres. Take coefficient of friction as 0·01. **(Ans. 11·7 kW)**
3. A centrifugal pump having an impeller of diameter 500 mm delivers 140 litres of water per second. The velocity of flow is 1 m/s and the vanes are curved back at outlet at 30° to the wheel tangent. If the impeller speed is 400 r.p.m., find the power to drive the pump. **(Ans. 12·9 kW)**
4. A centrifugal pump of 1·2 m diameter delivers 2000 litres of water per second against a head of 6 metres at 200 r.p.m. The vanes are curved back at an angle of 26° to the tangent at outlet and velocity of flow is constant at 2·4 m/s. Find the manometric efficiency and power required to operate the pump. **(Ans. 61·2%; 119·4 kW)**

35·17. Increase in the Water Pressure while Flowing through the Impeller of a Centrifugal Pump

We have discussed in Art. 35·3 that a pump converts mechanical energy into pressure energy. This pressure energy is given by the impeller to the water flowing through it. Consider inlet and outlet tips of a centrifugal pump as shown in Fig. 35·10.

Applying Bernoulli's equation to the inlet and outlet of the impeller of the pump,

Energy at outlet = Energy at inlet + Work done by the impeller

i.e.,
$$\frac{p_1}{w} + \frac{V_1^2}{2g} = \frac{p}{w} + \frac{V^2}{2g} + \frac{V_{w1} \cdot v_1}{g}$$
...(Taking $Z_1 = Z$)

$$\therefore \quad \frac{p_1}{w} - \frac{p}{w} = \frac{V^2}{2g} - \frac{V_1^2}{2g} + \frac{V_{w1} \cdot v_1}{g}$$

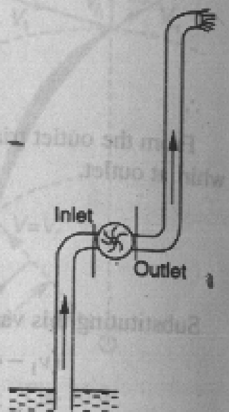


Fig. 35·10
Increase in water pressure.

where $\left(\frac{p_1}{w} - \frac{p}{w}\right)$ represents the increase in the pressure of water, while flowing through the impeller, in terms of head of water.

Example 35·11. *From first principles, and writing down all steps of calculation, show the theoretical pressure rise through the impeller of a centrifugal pump is given by:*

$$\frac{1}{2g}(V_f^2 + v_1^2 - V_{f1}^2 \operatorname{cosec}^2 \phi)$$

where V_f = *Velocity of flow at inlet,*
V_{f1} = *Velocity of flow at outlet,*
v_1 = *Peripheral velocity of impeller at outlet, and*
ϕ = *Impeller angle at outlet.*

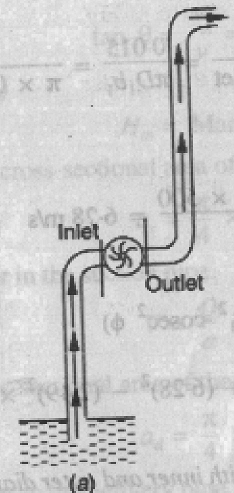
Solution. Given. V_f = Velocity of flow at inlet,
V_{f1} = Velocity of flow at outlet,
v_1 = Peripheral velocity of impeller at outlet, and
ϕ = Impeller angle at outlet.

Applying Bernoulli's equation at inlet and outlet of the impeller of the pump,

$$\frac{p_1}{w} + \frac{V_1^2}{2g} = \frac{p}{w} + \frac{V^2}{2g} + \frac{V_{w1} \cdot v_1}{g}$$

or
$$\frac{p_1}{w} - \frac{p}{w} = \frac{V^2}{2g} - \frac{V_1^2}{2g} + \frac{V_{w1} \cdot v_1}{g}$$

$$\therefore \text{Pressure rise} = \frac{V^2}{2g} - \frac{V_1^2}{2g} + \frac{V_{w1} \cdot v_1}{g} \qquad ...\left(\because \frac{p_1}{w} - \frac{p}{w} = \text{Pressurerise}\right)$$



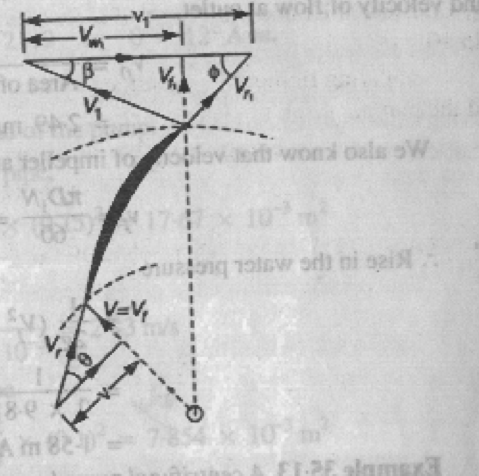


Fig. 35·11.

$$= \frac{1}{2g}\left[V^2 - V_1^2 + 2V_{w1} \cdot v_1\right]$$

$$= \frac{1}{2g}\left[V_f^2 - V_1^2 + 2V_{w1} \cdot v_1\right] \qquad (\because V = V_f)$$

$$= \frac{1}{2g}\left[V_f^2 - \left(V_{w1}^2 + V_{f1}^2\right) + 2V_{w1} \cdot v_1\right]$$

$$= \frac{1}{2g}\left[V_f^2 - V_{f1}^2 - \left(v_1 - V_{f1} \cot \phi\right)^2 + 2v_1\left(v_1 - V_{f1} \cot \phi\right)\right]$$
$$(\because V_{w1} = v_1 - V_{f1} \cot \phi)$$

$$= \frac{1}{2g}\left[V_f^2 - V_{f1}^2 - \left(v_1^2 + V_{f1}^2 \cot^2 \phi - 2v_1 V_{f1} \cot \theta\right) + 2v_1^2 - 2v_1 V_{f1} \cot \phi\right]$$

$$= \frac{1}{2g}\left[V_f^2 - V_{f1}^2 - v_1^2 - V_{f1}^2 \cot^2 \phi + 2v_1 V_{f1} \cot \phi + 2v_1^2 - 2v_1 V_{f1} \cot \phi\right]$$

$$= \frac{1}{2g}\left[V_f^2 + v_1^2 - V_{f1}^2\left(1 + \cot^2 \phi\right)\right]$$

$$= \frac{1}{2g}\left[V_f^2 + v_1^2 - V_{f1}^2 \operatorname{cosec}^2 \phi\right] \textbf{ Ans.}$$

Example 35·12. *A centrifugal pump is discharging water at the rate of 15 litres/s at 500 r.p.m. The internal and external diameters and the impeller widths are 120 mm, 240 mm, 16 mm and 8 mm respectively. The vanes are curved back at 25° to the tangent at outlet. Find the rise in the water pressure, when it passes through the pump.*

Solution. Given : Q = 15 litres/s = 0·015 m³/s; N = 500 r.p.m.; D = 120 mm ... = 240 mm = 0·24 m; b = 16 mm = 0·016 m; b_1 = 8 mm = 0·008 m and ϕ = 25°

We know that velocity of flow at inlet,

$$V_f = \frac{Q}{\text{Area of flow at inlet}} = \frac{0.015}{\pi D b} = \frac{0.015}{\pi \times 0.12 \times 0.016} \text{ m/s}$$

$$= 2.49 \text{ m/s}$$

and velocity of flow at outlet,

$$V_{f1} = \frac{Q}{\text{Area of flow at outlet}} = \frac{0.015}{\pi D_1 b_1} = \frac{0.015}{\pi \times 0.24 \times 0.008} \text{ m/s}$$

$$= 2.49 \text{ m/s}$$

We also know that velocity of impeller at outlet,

$$v_f = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.24 \times 500}{60} = 6.28 \text{ m/s}$$

∴ Rise in the water pressure

$$= \frac{1}{2g}\left(V_f^2 + v_1^2 - V_{f1}^2 \operatorname{cosec}^2 \phi\right)$$

$$= \frac{1}{2 \times 9.81}\left[(2.49)^2 + (6.28)^2 - (2.49)^2 \times \operatorname{cosec}^2 25°\right] \text{m}$$

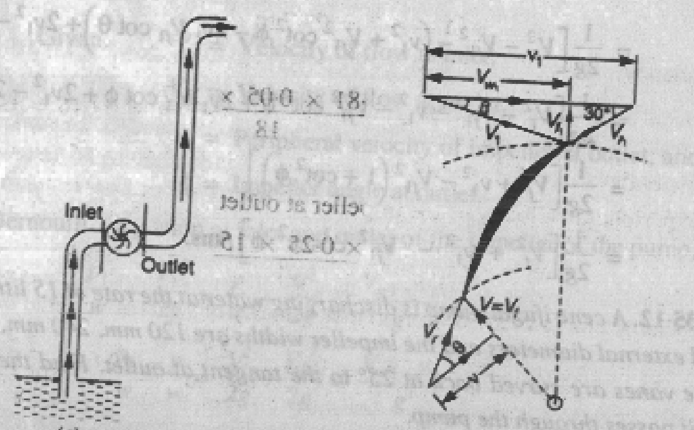
$$= 1.58 \text{ m } \textbf{Ans.}$$

Example 35·13. *A centrifugal pump has an impeller with inner and outer diameters of 150 mm and 250 mm respectively. It delivers 50 litres of water per second at 1500 r.p.m. The velocity of flow through impeller is constant at 2·5 m/s. The blades are curved back at angle of 30° to the tangent at exit. The diameters of the suction and delivery pipes are 150 mm and 100 mm respectively. The pressure head at suction is 4 m below and that at delivery is 18 m above atmosphere. The power required to drive the pump is 18 kW. Find (i) vane angle at inlet, (ii) overall efficiency, and (iii) monometric efficiency.*

Solution. Given : D = 150 mm = 0·15 m; D_1 = 250 mm = 0·25 m; Q = 50 litres/s = 0·05 m²/s; N = 1500 r.p.m.; $V_f = V_{f1}$ = 2·5 m/s; ϕ = 30°; d_s = 150 mm = 0·15 m; d_d = 100 mm = 0·1 m; $\frac{p}{w} = H_{atmos} - 4$ = 10·3 − 4 = 6·3 m; $\frac{p_1}{w} = H_{atmos}$ + 18 = 10·3 + 18 = 28·3 m and P = 18 kW

(i) Vane angle at inlet

Let θ = Vane angle at inlet.



We know that tangential velocity of impeller at inlet,

$$v = \frac{\pi D N}{60} = \frac{\pi \times 0.15 \times 1500}{60} = 11.8 \text{ m/s}$$

and from inlet velocity triangle, we find that

$$\tan\theta = \frac{V_f}{v} = \frac{2.5}{11.8} = 0.2119 \quad \text{or} \quad \theta = 12° \textbf{ Ans.}$$

(ii) Overall efficiency

Let H_m = Manometric head of the pump.

We know that cross-sectional area of the suction pipe,

$$a_s = \frac{\pi}{4} \times (d_s)^2 = \frac{\pi}{4} \times (0.15)^2 = 17.67 \times 10^{-3} \text{ m}^2$$

and velocity of water in the suction pipe,

$$V = \frac{Q}{a} = \frac{0.05}{17.67 \times 10^{-3}} = 2.83 \text{ m/s}$$

Similarly cross-sectional area of the delivery pipe

$$a_d = \frac{\pi}{4} \times (d_d)^2 = \frac{\pi}{4} \times (0.1)^2 = 7.854 \times 10^{-3} \text{ m}^2$$

and velocity of water in the delivery pipe,

$$V_1 = \frac{Q}{a_d} = \frac{0.05}{7.854 \times 10^{-3}} = 6.37 \text{ m/s}$$

Applying Bernoulli's equation at inlet outlet of the impeller,

$$\frac{p_1}{w} + \frac{V_1^2}{2g} = \frac{p}{w} + \frac{V^2}{2g} + H_m \quad \text{...(Assuming } Z_1 =$$

or

$$H_m = \left(\frac{p_1}{w} + \frac{V_1^2}{2g}\right) - \left(\frac{p}{w} + \frac{V^2}{2g}\right)$$

$$= \left(28.3 + \frac{(6.37)^2}{2 \times 9.81}\right) - \left(6.3 + \frac{(2.83)^2}{2 \times 9.81}\right) \text{m}$$

$$= 30.4 - 6.7 = 23.7 \text{ m}$$

∴ Overall efficiency,

$$\eta_0 = \frac{wQH_m}{P} = \frac{9.81 \times 0.05 \times 23.7}{18} = 0.646 = 64.6\% \textbf{ Ans.}$$

(iii) Manometric efficiency

We know that peripheral velocity of the impeller at outlet,

$$v_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.25 \times 1500}{60} = 19.6 \text{ m/s}$$

and from the outlet triangle of velocities, we find that velocity of whirl at outlet,

$$V_{w1} = v_1 - \frac{V_{f1}}{\tan\theta} = 19.6 - \frac{2.5}{\tan 30°} = 19.6 - \frac{2.5}{0.5774} \text{ m/s}$$

$$= 15.3 \text{ m/s}$$

∴ Manometric efficiency,

$$\eta_{man} = \frac{H_m}{\frac{V_{w1} \cdot v_1}{g}} = \frac{23 \cdot 7}{\frac{15 \cdot 3 \times 19 \cdot 6}{9 \cdot 81}} = 0 \cdot 772 = 77 \cdot 2\% \textbf{ Ans.}$$

35·18 Minimum Starting Speed of a Centrifugal Pump

A centrifugal pump will start delivering the liquid, only when the head developed by it is equal to the manometric head. At the time of start, the liquid velocities are zero, therefore the pressure head caused by the centrifugal force

$$= \frac{v_1^2}{2g} - \frac{v^2}{2g} = \frac{v_1^2 - v^2}{2g}$$

This pressure head must give the required manometric head, *i.e.*,

$$\frac{v_1^2 - v^2}{2g} = H_m = \eta_{man} \times \frac{V_{w1} \cdot v_1}{g} \qquad \left[\because \eta_{man} = \frac{H_m}{\frac{V_{w1} \, v}{g}}\right]$$

Example: 35·14. *A centrifugal pump has to discharge 2000 litres of water per second and develop a total head of 22·5 metres, when the impeller rotates at 240 r.p.m. The impeller diameter is 1·5 meter and velocity of flow at outlet is 2·5 m/s. If the vanes are set back at an angle of 30° at the outlet, find*

1. manometric efficiency of the pump, and

2. power required to drive the pump.

If the inner diameter is half of the outer diameter, find the minimum speed to start pumping.

Solution. Given : Q = 2000 litres/s = 2 m³/s; H_m = 22·5 m; N = 240 r.p.m.; D_1 = 1·5 m; V_{f1} = 2·5 m/s and ϕ = 30°.

1. Manometric efficiency of the pump

We know that tangential velocity of the impeller at outlet,

$$v_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 1 \cdot 5 \times 240}{60} = 18 \cdot 8 \text{ m/s}$$

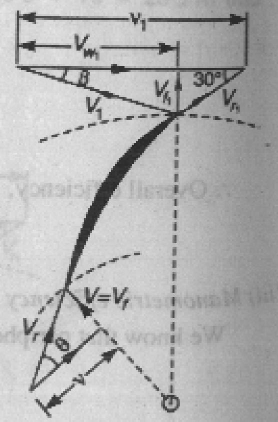


Fig. 35·13

and from outlet triangle of velocities, we find that velocity of whirl at outlet

$$V_{w1} = v_1 - \frac{V_{f1}}{\tan \phi} = 18 \cdot 8 - \frac{2 \cdot 5}{\tan 30°} \text{ m/s}$$

$$= 18 \cdot 8 - \frac{2 \cdot 5}{0 \cdot 5774} = 14 \cdot 5 \text{ m/s}$$

∴ Manometric efficiency,

$$\eta_{man} = \frac{H_m}{\frac{V_{w1} \cdot v_1}{g}} = \frac{22 \cdot 5}{\frac{14 \cdot 5 \times 18 \cdot 8}{9 \cdot 81}} = 0 \cdot 81 = 81\% \textbf{ Ans.}$$

35·19 Multistage Centrifugal Pumps

In the previous articles, we have seen that the head developed by a centrifugal pump is proportional to the diameter and speed of the impeller. Since there is a limitation for the diameter and speed of the impeller, therefore the head developed by a centrifugal pump is ordinarily limited to 50 metres. In some special pumps, higher heads up to 100 metres may also be developed. For still larger heads, it will be necessary to put two or more pumps in series. Liquid from one pump, is brought to the inlet of another pump, which further increases the head developed.

This type of arrangement is also possible, if we provide two or more impellers (instead of two or three pumps) and key them to the same shaft and put them in the same casing. Such a pump is called a multistage pump. For special duties, the pumps with as many as 100 stages have been manufactured.

Example 35·15. *Each impeller, of a three-stage centrifugal pump has external diameter of 375 mm and width 20 mm. The pump is discharging 3600 litres of water per minute at 900 r.p.m. The vanes are curved back at 45° to the tangent at outlet.*

If the manometric efficiency is 84%, find the manometric head generated by the pump.

Solution. Given : No. of stages = 3; D_1 = 375 mm = 0·375 m; b_1 = 20 mm = 0·02 m; Q = 3600 litres/min = 60 litres/s = 0·06 m²/s; N = 900 r.p.m.; ϕ = 45°; and η_{man} = 84% = 0·84.

Let H_m = Manometric head of each stage.

We know that tangential velocity of the impeller at outlet,

$$v_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0 \cdot 375 \times 900}{60} = 17 \cdot 7 \text{ m/s}$$

and velocity of flow at outlet,

$$V_{f1} = \frac{Q}{\pi D_1 b_1} = \frac{0 \cdot 06}{\pi \times 0 \cdot 375 \times 0 \cdot 02} = 2 \cdot 55 \text{ m/s}$$

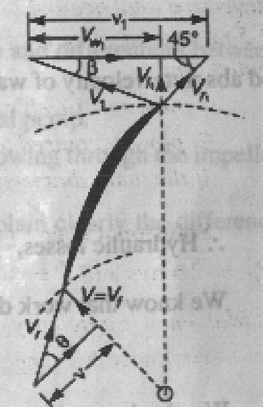


Fig. 35·14.

From the outlet triangle of velocities, we find that the velocity of whirl at outlet,

$$V_{w1} = v_1 - \frac{V_{f1}}{\tan \phi} = 17 \cdot 7 - \frac{2 \cdot 55}{\tan 45°} = 15 \cdot 15 \text{ m/s}$$

We also know that manometric efficiency (η_{man}),

$$0 \cdot 84 = \frac{H_m}{\frac{V_{w1} \cdot v_1}{g}} = \frac{H_m}{\frac{15 \cdot 15 \times 17 \cdot 7}{9 \cdot 81}} = \frac{H_m}{27 \cdot 3}$$

or $H_m = 0 \cdot 84 \times 27 \cdot 3 = 22 \cdot 9$ m

∴ Total manometric head due to three stages

$$= 3 \times 22 \cdot 9 = 68 \cdot 7 \text{ m } \textbf{Ans.}$$

Example 35·16. *A multistage centrifugal pump is discharging 45 000 litres of water per minu[te] against a monometric head of 60 metres. There are four equal impellers, keyed to the same sha[ft] which is running at 350 r.p.m. The vanes are curved back at an angle of 60° to the tangent at out[let] pheriphery. The velocity of flow at outlet is 0·27 times the corresponding pheripheral velocity, a[nd] the hydraulic losses in the pump are 1/3 of the velocity head at outlet of the impeller. Find*

1. Diameter of the impeller and 2. Manometric efficiency.

Solution. Given : Q = 45 000 litres/min = 750 litres/s = 0·75 m^3/s; Total manometric head = 60 m; No. of stages = 4 or manometric head for each stage (H_m) = 60/4 = 15 m; N = 350 r.p.m.; ϕ = 60°; $V_{f1} = 0{\cdot}27\ v_1$ and hydraulic losses $= \frac{1}{3} \times \frac{v_1^2}{2g} = \frac{v_1^2}{6g}$

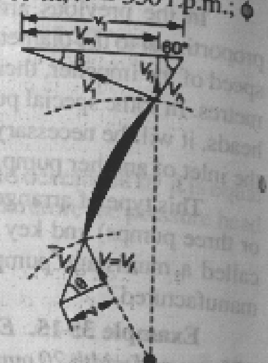


Fig. 35·15.

1. *Diameter of the impeller*

Let D_1 = Diameter of the impeller.

We know that the pheripheral velocity at outlet,

$$v_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times D_1 \times 350}{60} \text{ m/s}$$

$$= 18{\cdot}3\ D_1 \text{ m/s}$$

∴ Velocity of flow at outlet,

$$V_{f1} = 0{\cdot}27 \times 18{\cdot}3\ D_1 = 4{\cdot}94\ D_1 \text{ m/s}$$

From the outlet triangle of velocities, we find that the velocity of whirl at outlet,

$$V_{w1} = v_1 - \frac{V_{f1}}{\tan \phi} = 18{\cdot}3\ D_1 - \frac{4{\cdot}94\ D_1}{\tan 60°}$$

$$= 18{\cdot}3\ D_1 - \frac{4{\cdot}94\ D_1}{1{\cdot}732} = 15{\cdot}5\ D_1 \text{ m/s}$$

and absolute velocity of water leaving the impeller,

$$V_1 = \sqrt{V_{f1}^2 + V_{w1}^2} = \sqrt{(4{\cdot}94\ D_1)^2 + (15{\cdot}5\ D_1)^2} \text{ m/s}$$

$$= 16{\cdot}3\ D_1 \text{ m/s}$$

∴ Hydraulic losses,

$$= \frac{V_1^2}{6g} = \frac{(16{\cdot}3\ D_1)^2}{6 \times 9{\cdot}81} = 4{\cdot}51\ D_1^2 \text{ m}$$

We know that work done by the pump per kN of water

$$W = \frac{V_{w1} \cdot v_1}{g} = \frac{15{\cdot}5\ D_1 \times 18{\cdot}3\ D_1}{9{\cdot}81} = 28{\cdot}9\ D_1^2 \text{ kN-m}$$

We also know that work done by the pump per kN of water (W),

$$28{\cdot}9\ D_1^2 = \text{Manometric head + Hydraulic losses}$$

$$= 15 + 4{\cdot}51\ D_1^2$$

$$24{\cdot}39\ D_1^2 = 15$$

$$\therefore \quad D_1^2 = 15/24{\cdot}39 = 0{\cdot}615 \quad \text{or} \quad D_1 = 0{\cdot}784 \text{ m} \quad \textbf{Ans.}$$

2. *Manometric efficiency*

We also know that manometric efficiency,

$$\eta_{man} = \frac{H_m}{\dfrac{V_{w1} \cdot v_1}{g}} = \frac{15}{\dfrac{(15{\cdot}5 \times 0{\cdot}784) \times (18{\cdot}3 \times 0{\cdot}784)}{9{\cdot}81}}$$

$$= 0{\cdot}844 = 84{\cdot}4\% \textbf{ Ans.}$$

Exercise 35·3

1. A centrifugal pump is discharging water at the rate of 100 litres/s. The ineternal and external diameters of the impeller are 150 mm and 300 mm respectively. The width of the impeller at inlet and outlet are 12 mm and 6 mm. The vanes are curved badc at 45° to the tangent at outlet. Find the increase in pressure as the water passes through the impeller. **(Ans.** 28·1 m**)**

2. Find the minimum speed at which a centrifugal pump will start functioning against a head of 7·5 m, if the diameters of the impeller at outlet and inlet are 1 m and 0·5 m respectively. **(Ans.** 267·4 r.p.m.**)**

3. Determine the least no. of stages for a multistage pump to deliver 60 litres of water per second against a total head of 210 metres at 1450 r.p.m. The speed of the pump is not to exceed 670 r.p.m. **(Ans.** 5**)**

4. Each impeller of a two stage centrifugal pump has outer diameter of 40 mm and a width of 25 mm. The pump is discharging 60 litres of water per second at 1000 r.p.m. If the vane angle at outlet is 30°, find the total manometric head developed by the pump. Assume manometric efficiency of the pump as 80%. **(Ans.** 60·2 m**)**

QUESTIONS

1. What is a centrifugal pump ? On what principle does it work ?
2. What are the different types of pumps ? Explain the working principles of a centrifugal pump with sketches.
3. Name the different types of casings for the impeller of a centrifugal pump.
4. Explain the function of spiral casing for a centrifugal pump.
5. Name the different types of efficiencies of a centrifugal pump and differentiate between overall efficiency and manometric efficiency.
6. Derive an equation for the power required to drive a centrifugal pump.
7. Obtain an equation for the increase in water pressure, while flowing through the impeller of a centrifugal pump.
8. What do you understand by the term 'multistage pump'? Explain clearly the difference between a single stage and a multistage centrifugal pump.

OBJECTIVE TYPE QUESTIONS

1. In a centrifugal pump the water
   (*a*) enters the impeller radially and leaves the vanes axially
   (*b*) enters the impeller radially and leaves the vanes radially
   (*c*) enters the impeller axially and leaves the vanes radially
   (*d*) enters the impeller axially and leaves the vanes axially.
2. In the casing of a centrifugal pump, the kinetic energy of the water is converted into
   (*a*) potential energy (*b*) pressure energy (*c*) heat energy (*d*) all of these
3. In a centrifugal pump the liquid enters
   (*a*) at the centre (*b*) at the top (*c*) at the bottom (*d*) from sides
4. A multistage pump is used to
   (*a*) give high discharge (*b*) produce high heads
   (*c*) pump viscous fluides (*d*) pump chemicals

ANSWERS

1. (*a*) 2. (*b*) 3. (*a*) 4. (*b*)