DEPARTMENT OF MECHANICAL ENGINEERING

BAPATLA ENGINEERING COLLEGE

SCHEME OF EVALUATION

FLUID MECHANICS AND HYDRAULIC MACHINES

18ME304

PAPER SET - 2

Dept. of Mechanical Engineering
Bapatla Engg College.
Fluid Mechanics & Hydraulic Machines
18ME304

1(a) Kinematic viscosity is defined as the ratio of dynamic viscosity to the mass density of a fluid.

$$\nu = \frac{\mu}{\rho}$$

Units – m^2/s.

1(b) It states that the rate of increase of pressure in a vertically downward direction is equal to the weight density of the fluid at that point.

1(c) Buoyancy: the tendency for an immersed body to be lifted up in the fluid due to an upward force opposite to action of gravity is known as buoyancy.

Meta centre: It is defined as a point of intersection of the axis of body passing through centre of gravity(G) and original centre of buoyancy (B) and a vertical line passing through the centre of buoyancy (B_1) of the tilted position of the body.

1(d) Compressible flow: It is that type of flow in which the density of the fluid changes from point to point.

$$\rho \neq C$$

Incompressible flow: It is that type of flow in which the density is constant for fluid flow.

$$\rho = C$$

1(e) Units – Mass flow rate – kg/s
– Volume flow rate – m^3/s

1(f) Loss of head due to friction in a pipe

$$h_f = \frac{4fLV^2}{d \times 2g}$$

1(g) Force exerted by the jet of water in the direction of jet for stationary curved plate

$F_x = \rho a v^2 (1+\cos\theta)$ → strikes at the centre

$F_x = 2\rho a v^2 \cos\theta$ → strikes at one of the tips.

1(h) Condition for maximum efficiency for a pelton wheel turbine $u = \frac{V_1}{2}$

1(i) Specific speed of a centrifugal pump

It is defined as the speed at which a pump runs when the head developed is 1 metre and discharge is one cubic metre.

$N_s = \frac{N\sqrt{Q}}{H_m^{3/4}}$

1(j) Reciprocating pump

slip $= Q_{the} - Q_{act}$ ⇒ It is defined as the difference b/w theoretical discharge & actual discharge of a pump.

% of slip $= \frac{Q_{the} - Q_{act}}{Q_{the}} \times 100$.

UNIT – I

2(a) Given data

Sp. gravity of oil $S = 0.75$

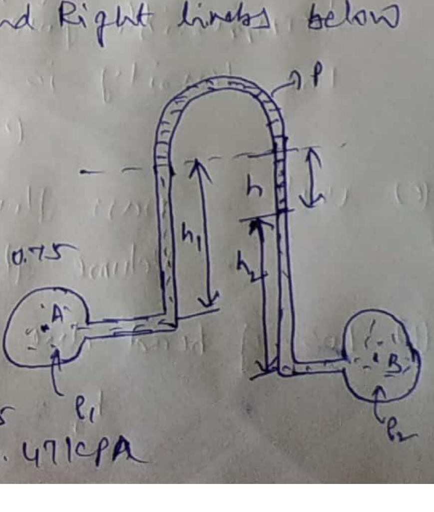
Sp. gravity of water in pipe A + B, $S_1, S_2 = 1$

Find $P_B - P_A = ?$

Sol Difference of oil in the two limbs

$= (450+200) - 450 = 200\,mm$

Pressure heads on the left and Right limbs below the datum line are equal



$P_A - \rho_1 g h_1 = P_B - \rho_2 g h_2 - \rho g h$

$h_A - \frac{450}{1000} \times 1 = h_B - \frac{450}{1000} \times 1 - \frac{200}{1000} \times 0.75$

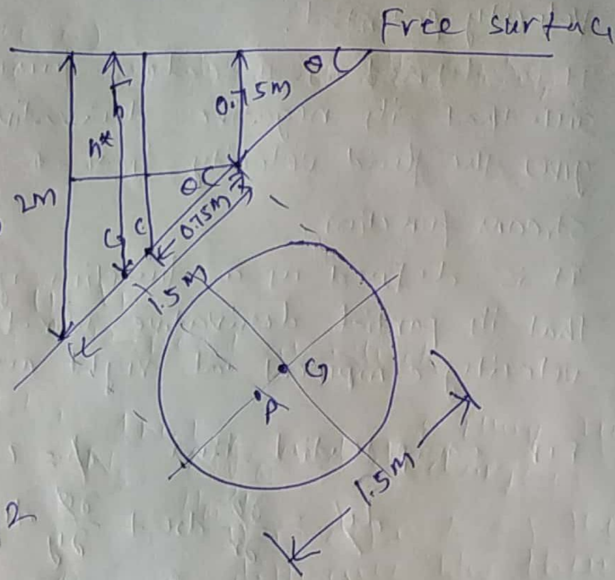
$h_A - 0.45 = h_B - 0.6$

$h_B - h_A = 0.15\,M$

$\frac{P_B}{\rho g} - \frac{P_A}{\rho g} = \rho g \times 0.15$

$= 1.471\,kPA$

2(b)



Given data

d = 1.5m

Greatest depth = 2m

Least depth = 0.75m

Find

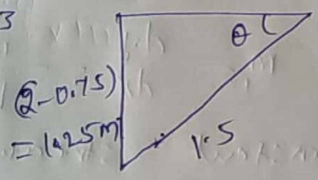
F = ?

h* = ?

Area of plate = $\frac{\pi}{4} d^2$

$= \frac{\pi}{4} \times 1.5^2 = 1.767 m^2$

$\sin\theta = \frac{2-0.75}{1.5} = 0.8333$



$\bar{h} = 0.75 + 0.75 \sin\theta$

$= 0.75 + 0.75 \times 0.8333 = 1.375m$

Total pressure

$F = \rho g A \bar{h} = 1000 \times 9.81 \times 1.767 \times 1.375$

$= 23.83$ KN

Centre of pressure

$$h^* = \frac{I_G \sin^2\theta}{A\bar{h}} + \bar{h} \qquad I_G = \frac{\pi}{4} d^4$$

$$= \frac{\frac{\pi}{4}(1.5)^4 \times (0.833)^2}{1.767 \times 1.375} + 1.375$$

$h^* = 1.446m$

3a) <u>Velocity potential</u>:

It is defined as a scalar function of space and time such that its negative derivative w.r.t any direction gives the fluid velocity in that direction.

<u>Stream function</u>:

It is defined as a function of space and time, such that its partial derivative w.r.t any direction gives the velocity component at right angles to this direction.

For equipotential line $\phi = c$ $d\phi = 0$

$$d\phi = \frac{\partial \phi}{\partial x} dx + \frac{\partial \phi}{\partial y} dy \qquad \frac{d\phi}{dx} = -u \quad \frac{d\phi}{dy} = -v$$

$$d\phi = -u\,dx - v\,dy$$

$$0 = -u\,dx - v\,dy$$

$$m_1 = \frac{dy}{dx} = -\frac{u}{v}$$

For constant stream line $\psi = c$ $d\psi = 0$

$$d\psi = \frac{\partial \psi}{\partial x} dx + \frac{\partial \psi}{\partial y} dy \qquad u = \frac{\partial \psi}{\partial y} \quad v = -\frac{\partial \psi}{\partial x}$$

$$d\psi = -v\,dx + u\,dy$$

$$0 = -v\,dx + u\,dy$$

$$m_2 = \frac{dy}{dx} = \frac{v}{u}$$

Intersection of stream lines and potential lines

$$m_1 \times m_2 = -\frac{u}{v} \times \frac{v}{u} = -1$$

Which shows stream lines and potential lines intersect orthogonally.

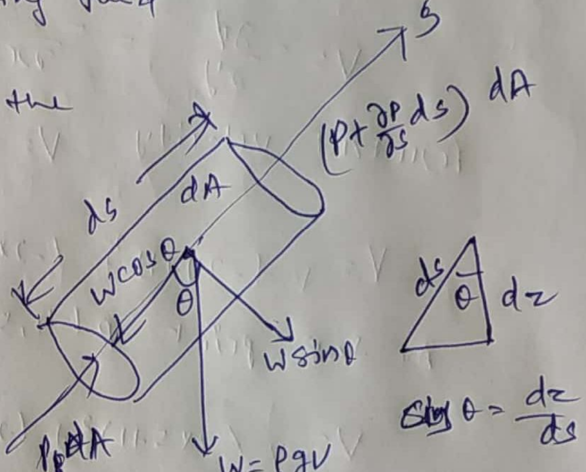
4(a) In an Ideal compressible fluid when the flow is steady and continuous, the sum of pressure energy, kinetic energy and potential energy is constant along a stream line.

Derivation

Consider a steady flow of an ideal fluid along the stream tube.

Let us consider a small element of cross sectional area dA and length ds from stream tube as a free body from the moving fluid

Net forces acting on the fluid element, ΣF_s



~~$= p_1A_1$~~

$= pdA - (p+\frac{\partial p}{\partial s}ds)dA - \rho g V\cos\theta$

$= pdA - pdA - \frac{\partial p}{\partial s}dAds - \rho g\, dAds\cos\theta$

According to Newton's 2nd law

$\Sigma F_s = ma_s$

$a_s = \frac{dv}{dt} = \frac{\partial v}{\partial s}\frac{ds}{dt} + \frac{\partial v}{\partial t}\frac{dt}{dt}$

$a_s = v\frac{\partial v}{\partial s}$ For steady flow $\frac{\partial v}{\partial t} = 0$

$-\frac{\partial p}{\partial s}dAds - \rho g dAds\cos\theta = \rho dAds\, v\frac{\partial v}{\partial s} \rightarrow (1)$

divide the eq (1) with $\rho dAds$

$\frac{1}{\rho}\frac{\partial p}{\partial s} + g\cos\theta + v\frac{\partial v}{\partial s} = 0$

$\frac{1}{\rho}\frac{\partial p}{\partial s} + g\frac{dz}{ds} + v\frac{\partial v}{\partial s} = 0$

$$\frac{1}{\rho}\partial P + v\,dv + g\,dz = 0$$

divide with 'g' on both sides

$$\frac{dp}{\rho g} + \frac{v}{g}dv + dz = 0 \rightarrow \text{Eulers eq of motion} \quad (2)$$

Bernoulli's eq is obtained by integrating eq (2)

$$\frac{1}{\rho g}\int dP + \frac{1}{g}\int v\,dv + \int dz = 0$$

$$\frac{P}{\rho g} + \frac{V^2}{2g} + z = C \rightarrow (3)$$

which is called Bernoulli's eq.

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

4(b) Given data

$d_1 = 300\,mm = 0.3\,m$

$a_1 = \frac{\pi}{4} \times 0.3^2 = 0.07\,m^2$

$d_2 = 150\,mm = 0.15\,m$

$a_2 = \frac{\pi}{4} \times 0.15^2 = 0.01767\,m^2$

$S_H = 13.6$

$S = 0.8$

$x = 260\,mm = 0.26$

$$h = \left(\frac{P_1}{\rho g} + z_1\right) - \left(\frac{P_2}{\rho g} + z_2\right) = x\left(\frac{S_H}{S} - 1\right)$$

$$= 0.26\left(\frac{13.6}{0.8} - 1\right) = 4.16\text{ m of oil}$$

Discharge

$$Q = C_d \frac{a_1 a_2 \sqrt{2gh}}{\sqrt{a_1^2 - a_2^2}}$$

$$= 0.98 \frac{0.07 \times 0.15 \times \sqrt{2 \times 9.81 \times 4.16}}{\sqrt{0.07^2 - 0.01767^2}}$$

$= 0.98 \frac{0.01117}{0.0677} = 0.1617$

$Q = 0.1617 \ m^3/s$

2) Pressure difference b/w entrance & throat section

$h = \left(\frac{P_1}{\rho g} + z_1\right) - \left(\frac{P_2}{\rho g} + z_2\right)$

$4.16 = \frac{P_1}{\rho g} - \frac{P_2}{\rho g} + z_1 - z_2$

$z_2 - z_1 = 300mm = 0.3m$

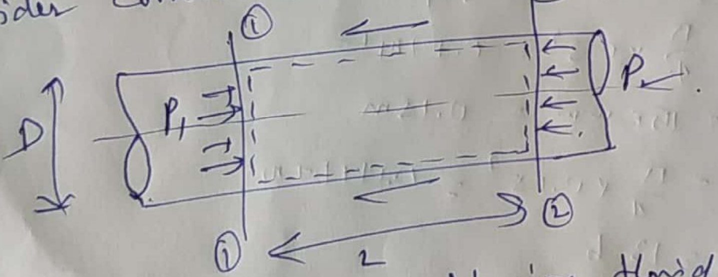
$\frac{P_1}{\rho g} - \frac{P_2}{\rho g} = 4.16 + 0.3$

$P_1 - P_2 = 56.19 \ KN/m^2$

(OR)

5(a) Loss of head due to friction in a pipe

Fig. shows a horizontal pipe having steady flow. Consider control volume b/w section ① & ②



Propelling force on the flowing fluid b/w two sections $= (P_1 - P_2) A$

A → cross sectional area of pipe

Frictional resistance force $= f' P L V^2$

P → wetted perimeter   V = Avg. flow velocity

Under equilibrium condition,

Propelling force = Frictional resistance force

$(P_1 - P_2) A = f' P L V^2$

$\left(\frac{P_1 - P_2}{\rho g}\right) A = \frac{f' P L V^2}{\rho g}$

$$h_f = \frac{f'}{\rho g} \frac{P}{A} L V^2$$

$$h_f = \frac{2gf'}{\rho g}\left(\frac{P}{A}\right)\frac{LV^2}{2g} = \frac{2gf'}{\rho g} \times \frac{L}{m} \times \frac{V^2}{2g}$$

The ratio $\frac{A}{P}$ is also called hydraulic mean depth

$$h_f = f \times \frac{L}{m} \times \frac{V^2}{2g}$$

$m = \frac{A}{P}$ $m = \frac{A}{P}$

$f = \frac{2gf'}{\rho g}$

$$m = \frac{\frac{\pi D^2}{4}}{\pi D} = \frac{D}{4}$$

$$h_f = \frac{4fLV^2}{D \times 2g}.$$

This is known as Darcy-Weisbach equation

$$h_f = \frac{f_1 LV^2}{D \times 2g}$$ $f_1 = 4f$ = friction factor

5(b) Dia, $D = 600$ mm $= 0.6$ m

Length, $L = 1.5$ km $= 1500$ m.

Coefficient of friction $f = 0.01$

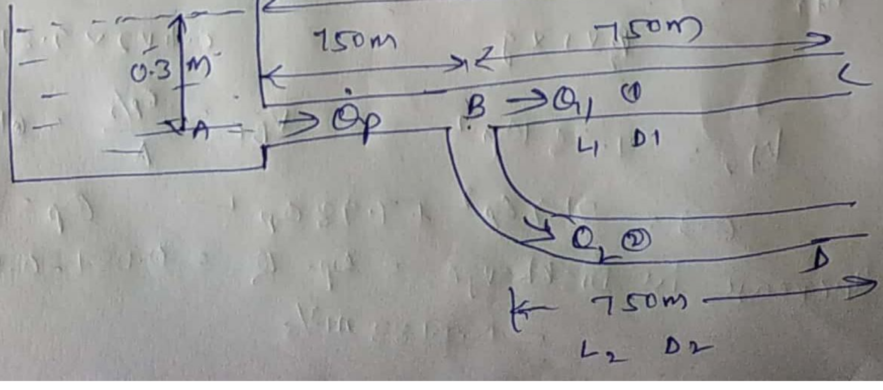
Head at inlet $= 300$ mm $= 0.3$ m

Head at outlet $= 0$ (Atm. head)

Head lost, $h_f = 0.3$

Length of 2nd parallel pipe $L_2 = L_1 = \frac{1500}{2} = 750$ m.

Diameter of 2nd parallel pipe $D_2 = D_1 = 0.6$ m.



Increase in Discharge

case I → Discharge through a single pipe of length 1500 m

$h_f = \frac{4fLV^2}{d \times 2g}$ $\qquad 0.3 = \frac{4 \times 0.01 \times 1500 \times V^2}{0.6 \times 2 \times 9.81}$

$V = 0.243$ m/s

$Q = AV = \frac{\pi}{4}(0.6)^2 \times 0.243 = 0.0687$ m³/s

case II when the additional pipe of length 750 mm is connected

$Q_p = Q_1 + Q_2$

$Q_1 = Q_2 = \frac{Q_p}{2}$

Consider flow through ABC / ABD

Head lost in ABC = Head lost in AB + head lost in BC

$h_f = 0.3$ m

$h_f = h_{f1} + h_{f2}$

$h_{f1} = \frac{4 \times 0.01 \times 750 \times V_{AB}^2}{0.6 \times 2 \times 9.81}$

$V_{AB} = \frac{Q_p}{\frac{\pi}{4} \times 0.6^2} = 3.54\, Q_p$

$h_{f1} = 31.9\, Q_p^2$

$h_{f2} = \frac{4fLV_{BC}^2}{D_2 \times 2 \times g} = \frac{4 \times 0.01 \times 750 \times (1.77\, Q_p)^2}{0.6 \times 2 \times 9.81}$

$h_{f2} = 7.98\, Q_p^2$ $\qquad V_{BC} = \frac{Q_p/2}{A} = 1.77\, Q_p$

$0.3 = 31.9\, Q_p^2 + 7.98\, Q_p^2$ $\qquad Q_p = 0.087$ m³/s

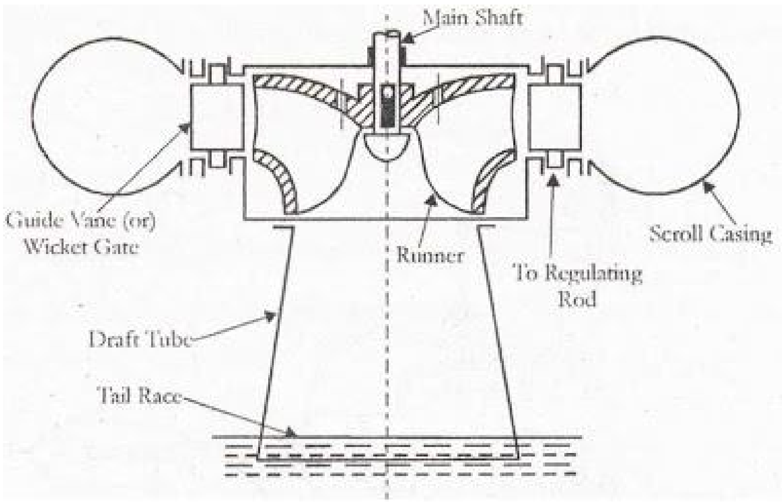
Increase in Discharge $= Q_p - Q = 0.087 - 0.0687$

$= 0.0183$ m³/s

7 a) Explain the construction and working of a Francis Turbine

Main Components

The Various main components of francis turbine are:



1. Spiral casing

It is a spiral casing, with uniformly decreasing cross- section area, along the circumference. Its decreasing cross-section area makes sure that we have a uniform velocity of the water striking the runner blades, as we have openings for water flow in-to the runner blades from the very starting of the casing, so flow rate would decrease as it travels along the casing. So we reduce its cross-section area along its circumference to make pressure uniform, thus uniform momentum or velocity striking the runner blades.

2. Stay vanes

Stay vanes and guide vanes guides the water to the runner blades. Stay vanes remain stationary at their position and reduces the swirling of water due to radial flow, as it enters the runner blades. Thus making turbine more efficient.

3. Guide vanes

Water after passing through stay vanes, glides through guide vanes to enter the runner blades. Guide vanes can change their angle thus can control the angle of attack of water to the runner blades, making them work more efficiently. Moreover they also regulate the flow rate of water into the runner blades thus controlling the power output of a turbine according to the load on the turbine.

4. Runner blades

Design of the runner blades decides how well a turbine is going to perform. So runner blades of mixed flow turbine can be divided into two parts, the upper part of the blades use the reaction force of water flowing through it and the lower half is in the shape of a small bucket using the impulse action of water flowing through it. These two forces together makes the runner to rotate.

5. Draft tube

Draft tube connects the runner exit to the tail race. Its cross-section area increases along its length, as the water coming out of runner blades is at considerably low pressure, so its expanding cross-section area help it to recover the pressure as it flows towards tail race.

Working of Francis Turbine

Water enters the turbine through spiral casing, and starts entering the runner blades, passing through stay vanes and guide vanes, as it moves along the length of casing the decreasing cross-section area of the spiral casing makes sure that the pressure energy of water would remain uniform along its length, as a portion of water is also entering the runner blades, which would reduce its flow rate along the length of the casing. The stay vanes being stationary at their place, removes the swirls from the water, which are generated due to flow through spiral casing and tries it to make the flow of water more linear to be deflected by adjustable guide vanes. The angle of guide vanes decides the angle of attack of water at the runner blades thus make sure the output of the turbine. Guide vanes also controls the flow rate of water in-to the runner blades thus acting according the load on the turbine. The runner blades are stationary and can-not pitch or change their angle so it’s all about the guide vanes which controls the power output of a turbine.

Further-more the upper part of runner blades are designed in such a way that they use the pressure difference between the opposite faces of a blade created by water flowing through it, same as the air-foil uses the pressure difference to generate lift force. And the remaining part of the blade is designed like a small bucket, which makes use of water’s kinetic energy. Thus runner blades make use of both pressure energy and kinetic energy of water and rotates the runner in most efficient way.

The water coming out of runner blades would lack both the kinetic energy and pressure energy, so we use the draft tube to recover the pressure as it advances towards tail race, but still we cannot recover the pressure to that extent that we can stop air to enter into the runner housing thus causing cavitation.

7 b)

7(b)

Shaft power, P = ~~7375~~ 7357.5 kW

Head, H = 5.5 m

Speed Ratio $= \frac{u_1}{\sqrt{2gH}} = 2.09$

$u_1 = 2.09\sqrt{2 \times 9.81 \times 5.5} = 21.71$ m/s

Flow Ratio $= \frac{V_{f1}}{\sqrt{2gH}} = 0.68$

$V_{f1} = 0.68\sqrt{2 \times 9.81 \times 5.5} = 7.064$ m/s

$\eta_o = 60\% = 0.6$

Diameter of boss $D_b = \frac{1}{3} D_o$

$\eta_o = \frac{SP}{WP} = \frac{7357.5}{\rho g Q H / 1000}$

$Q = 227.27$ m³/s

$Q = \frac{\pi}{4}(D_o^2 - D_b^2) \times V_{f1}$

$D_o = 6.788$ m

$D_b = \frac{1}{3} D_o = 2.262$ m

$u_1 = \frac{\pi D_o N}{60}$

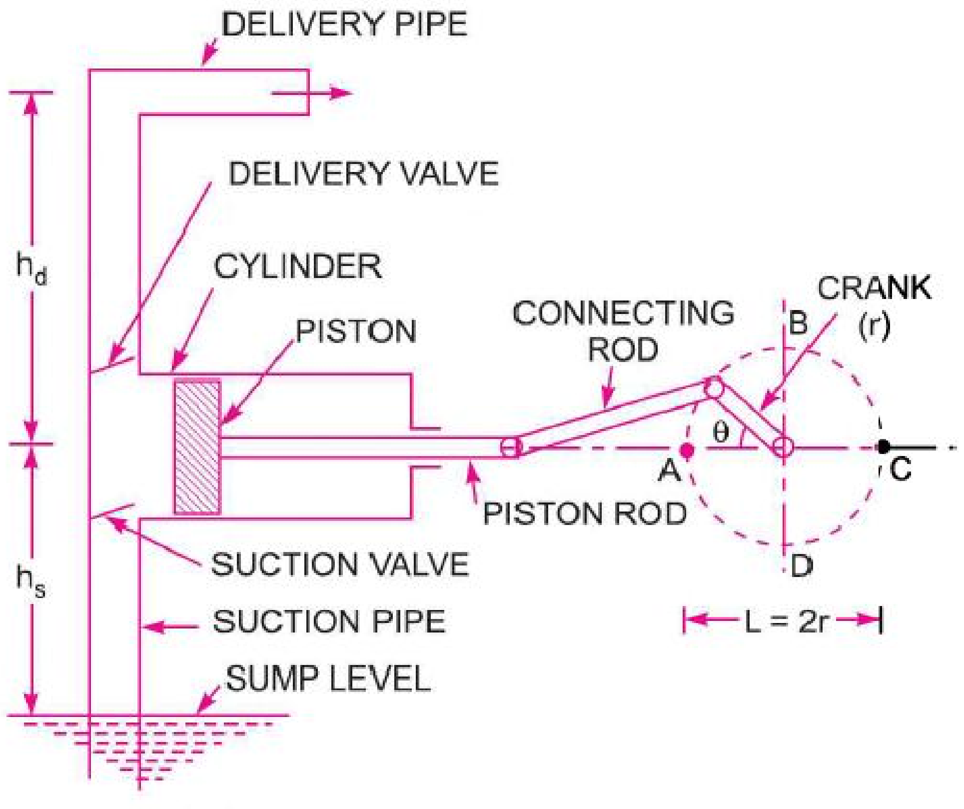
Speed $N = 61.08$ rpm

Specific speed $N_s = \frac{N\sqrt{P}}{H^{5/4}} = 622$ rpm.

8 a) Explain working and construction of a reciprocating pump?

Main Parts of a Reciprocating Pump

The following are the main parts of a reciprocating pump



1. A cylinder with a piston, piston rod, connecting rod and a crank,
2. Suction pipe,
3. Delivery pipe,
4. Suction valve, and
5. Delivery valve.

Working of a Reciprocating Pump

Fig. _ _.1 shows 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 and delivery pipes with suction valve and delivery valve are connected to the cylinder. The suction and delivery valves are one way valves or non-return valves, which allow the water to flow in one direction only. Suction valve allows water from suction pipe to the cylinder which delivery valve allows water from cylinder to delivery pipe only.

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 inside the cylinder more than atmospheric pressure. Hence suction valve closes and delivery valve opens. The liquid is forced into the delivery pipe and is raised to a required height.

8 b)

8b)

Given Data

Dia of pump $D = 100\,mm = 0.1\,m$

Length " $L = 300\,mm = 0.3\,m$

Crank radius $r = \frac{L}{2} = 0.15\,m$

Delivery head $h_d = 20\,m$

Diameter of delivery pipe, $d_d = 50\,mm = 0.05\,m$

Length " $L_d = 25\,m$

Seperation of pressure head, $h_{sep} = 2.5\,m$ (abs)

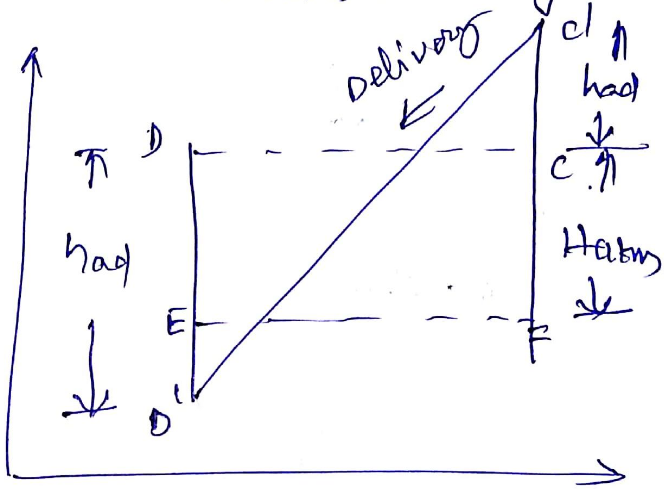
Atmospheric pressure head, $H_{atm} = 10.3\,m$ of water

From Fig

$h_{sep} = h_d + H_{atm} - h_{ad}$

$h_{sep} = 2.5\,m$

$h_{ad} = 27.8\,m$



$$h_{ad} = \frac{l_d}{g} \times \frac{A}{a_d}\,\omega^2 r$$

$$27.8 = \frac{25}{9.81} \times \frac{\frac{\pi}{4} D^2}{\frac{\pi}{4} d_d^2} \times \omega^2 \times 0.15$$

$$\omega = 4.264\ rad/s$$

$$\omega = \frac{2\pi N}{60} \qquad N = 40.72\ rpm$$

9 a) Explain the construction and working of centrifugal pump?

Main Parts of Centrifugal Pump

The Main parts of Centrifugal Pump are:

1. Impeller

It is a wheel or rotor which is provided with a series of backward curved blades or vanes. It is mounded on the shaft which is coupled to an external source of energy which imparts the liquid energy to the impeller there by making it to rotate.

Impellers are divided into 3 types,

1. Open Impeller
2. Semi enclosed Impeller
3. Enclosed Impeller

2. Casing

It is a pipe which is connected at the upper end to the inlet of the pump to the centre of impeller which is commonly known as eye. The double end reaction pump consists of two suction pipe connected to the eye from both sides. The lower end dips into liquid in to lift. The lower end is fitted in to foot valve and strainer.

Commonly three types of casing are used in centrifugal pump,

1. Volute Casing
2. Vortex Casing
3. Casing with Guide Blades

3. Delivery Pipe

It is a pipe which is connected at its lower end to the out let of the pump and it delivers the liquid to the required height. Near the outlet of the pump on the delivery pipe, a valve is provided which controls the flow from the pump into delivery pipe.

4. Suction Pipe with Foot Valve and Strainer

Suction pipe is connected with the inlet of the impeller and the other end is dipped into the sump of water. At the water end, it consists of foot value and strainer. The foot valve is a one way valve that opens in the upward direction. The strainer is used to filter the unwanted particle present in the water to prevent the centrifugal pump from blockage.

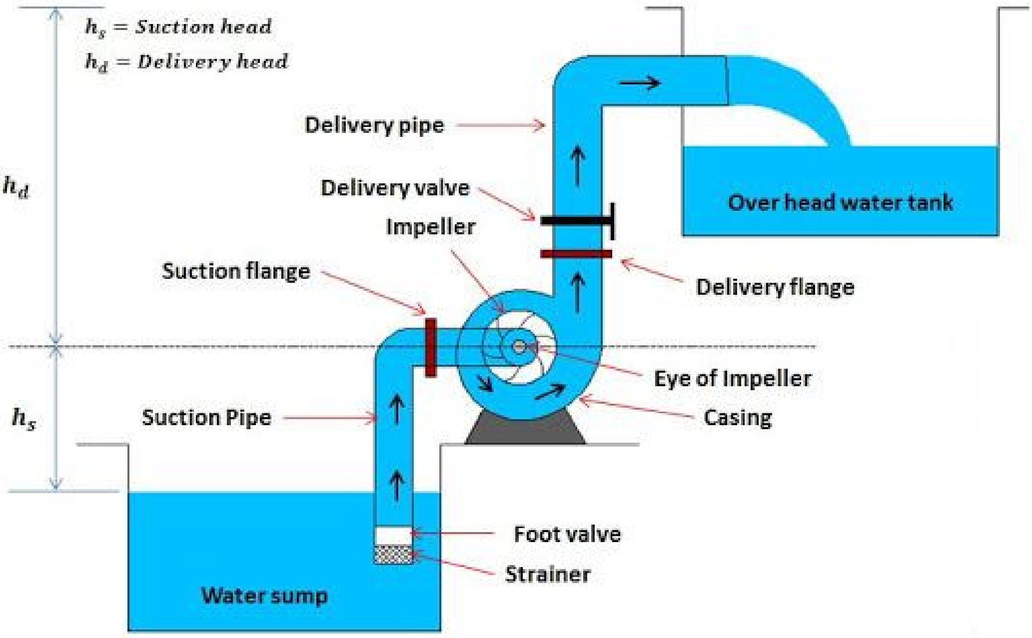
Working of Centrifugal Pump

The first step in the operation of a centrifugal pump is priming.

Priming:

Priming is the most basic and first step in the working of centrifugal pump. The process of filling the casing, suction pipe and delivery pipe upto the delivery valve before starting the pump is known as priming. In order to remove the air gap present in pump, it is filled by liquid. Pressure developed inside the pump is directly proportional to the density of liquid in it. If there is air in pump and an impeller is allowed to rotate then pressure energy cannot be developed as density of fluid is less due to presence of air. So it is very important to prime a centrifugal pump carefully.

Its working can be summarized into following points.



Centrifugal Pump Working

- First priming is done before starting the pump. Delivery valve is still kept closed.
- Now the motor starts. The rotation of impeller in the casing full of liquid accelerates liquid and there is generation of powerful centrifugal force which results in enhancement in liquid pressure.
- This increase in pressure is directly proportional to the square of angular velocity and distance of point from the axis.
- Therefore, if the impeller rotates with faster speed, there is greater amount of production of required pressure energy.
- Now the delivery valve open and allow liquid to flow at desired location.
- Liquid comes out of impeller with high velocity. This increasing kinetic energy due to increased velocity can be wasted in eddies which result in decreasing the efficiency of pump. So safety should be taken to reduce this speed as that of lower velocity of delivery pipe

9 b) Given Data

$Q = 0.118\ m^3/s$

$N = 1450\ rpm$

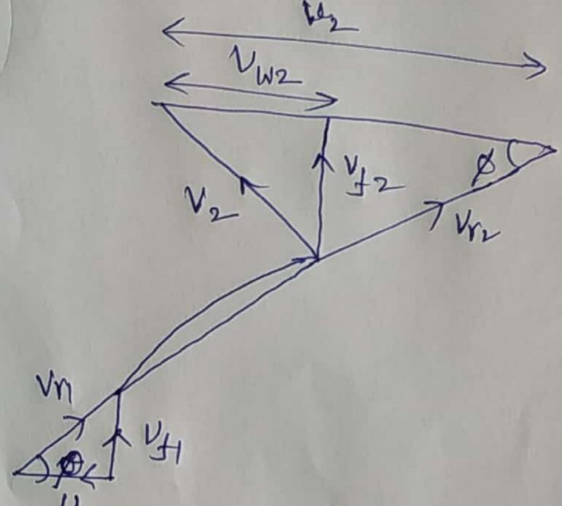
$H_m = 25\ m$

$D_2 = 250\ mm = 0.25\ m$

$B_2 = 50\ mm = 0.05\ m$

$\eta_{man} = 75\% = 0.75$

Vane angle at outlet $\phi = ?$



Tangential velocity

$$u_2 = \frac{\pi D_2 N}{60} = 18.98\ m/s$$

$$Q = \pi D_2 B_2 \times V_{f2}$$

$$V_{f2} = 3\ m/s$$

$$\eta_{man} = \frac{gH_m}{V_{w2} u_2} \Rightarrow V_{w2} = 17.23\ m/s$$

$$\tan\phi = \frac{V_{f2}}{u_2 - V_{w2}} = \frac{3}{18.98 - 17.23}$$

$$\phi = 59.74^\circ.$$