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S.Y. Diploma : Sem. IV [ME/MH/MI/PG/PT/FE/FG]

Fluid Mechanics and Machinery

Prelim Question Paper Solution

1. (a) (i) **(1) Newtonian fluid :** A fluid in which the shear stress is directly proportional to rate of shear strain i.e. which follows Newton's law of viscosity $\tau = \mu \frac{du}{dy}$ is known as Newtonian fluid. Example : air, water, gasoline.

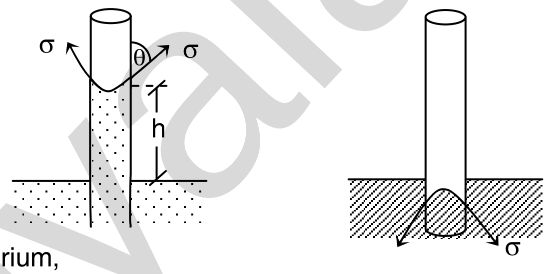
(2) Non-Newtonian fluid : A fluid in which the shear stress is not linearly proportional to rate of shear strain i.e. which does not follow Newton's law of viscosity $\tau = \mu \frac{du}{dy}$ is known as non-Newtonian fluid.

Example : Human blood, lubricating oil, buffer.

1. (a) (ii) Capillarity

When a thin tube is dipped in a liquid, then the liquid will rise or fall in the tube. This phenomenon is known as capillarity.

It is due to both cohesion and adhesion. If adhesion is more than cohesion $\rightarrow$ liquid will rise. If cohesion is more than adhesion $\rightarrow$ liquid will fall.



For equilibrium,

wt. of liquid column 'h' = vertical components of surface tension.

$$\frac{\pi d^2}{4} \times h \times w = \pi d \, \sigma \cos \theta$$

$$\therefore \quad h = \frac{4 \sigma \cos \theta}{wd}$$

1. (a) (iii) Gauge Pressure

If the pressure is measured above or below the atmospheric pressure as a datum it is called as gauge pressure.

Above the atmospheric pressure $\rightarrow$ positive gauge pressure. Below the atmospheric pressure $\rightarrow$ negative gauge pressure vacuum pressure.

Absolute Pressure

If pressure is measured above the absolute zero (complete vacuum) then it is called as absolute pressure.

1. (a) (iv) Laminar Flow

Is that type of flow in which the fluid particals more along well defined paths or stream line and all the stream lines are straight and parallel.

Turbulent Flow

Is that type of flow in which the fluid particals move in a zig-zag way. The paths of individuals particals cross each other.

1. (a) (v) (1) Penstocks

These are the pipes of large diameter which carry water under pressure from reservoir to turbine.

(2) Fore bay

It is also called as small reservoir generally provided at head of penstocks, to store water temporary and is provided when power house is situated away from storage reservoir.

1. (a) (vi) Impulse turbine : Energy available at inlet is only K.E. e.g. Pelton turbine.

Reaction turbine : Energy at inlet is K.E. as well as pressure energy, e.g. Francis turbine.

1. (a) (vii)(1) Delivery Head (h_d)

- It is a vertical distance between the center line of pump and the water surface in the tank to which water is delivered, it is denoted by h_d.
- For single stage pump delivery head is limited to about 30 m.

(2) Static Head (H_s)

- The sum of suction head and delivery head is known as static head. It is denoted by (H_s).

  $\therefore \quad H_s = h_s + h_d$

1. (a) (viii) Hydraulic Losses

(1) Eddy losses at the inlet and exit from the impeller.
(2) Losses due to friction in impeller.
(3) Frictional and Eddy losses in guide vanes and casing.
(4) Frictional and other minor losses in suction and delivery pipes.

1. (b) (i) (1) Surface Tension (σ) : The property of a liquid which offers a tensile resistance at its surface is called surface tension. It is due to cohesion.

Cohesion – It is the property of liquid due to which the molecules of same kind are attracted to each other.

Adhesion – It is the property of liquid due to which the molecules are attracted by the molecules of another body.

Unit of surface tension is N/m
For water σ = 0.073 N/m at 20°C
For mercury σ = 0.5 N/m.

Examples : (i) Surface tension on hollow bubble $\sigma = \frac{pd}{8}$ or $p = \frac{8\sigma}{d}$.

(ii) Surface tension on droplet $\sigma = \frac{pd}{4}$ or $p = \frac{4\sigma}{d}$

Due to surface tension leaf for needle floats on water surface, soap bubbles, Droplet of water remains spherical.

(2) Vapour Pressure

The liquid kept in closed vessel evaporates even at room temperature and this vapour occupies the space above the liquid surface. The pressure exerted by the vapour formed on the surface of the liquid is called as vapour pressure. It increases with the rise in temperature.

The vapour pressure of water at 20°C is 2340 N/m^2.

Important – pressure units

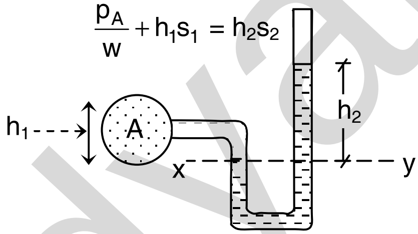
(i) m of liquid column (ii) N/m^2 (iii) bar

Note : p = wh, 1 bar = 10^5 N/m^2.

1. (b) (ii) Simple U–tube Manometer : It consists of a glass tube bend in U–shape, one end which is connected to a point at which pressure is to be measured and other end remains open to the atmosphere.

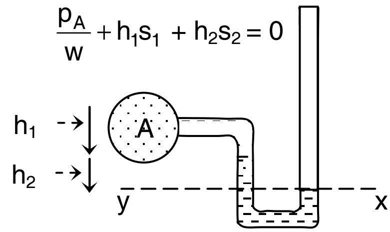
The tube generally contains mercury or any other liquid whose sp. gravity is greater than the sp. gravity of the liquid whose pressure is to be measured.

$$\frac{p_A}{w} + h_1 s_1 = h_2 s_2$$



For gauge pressure

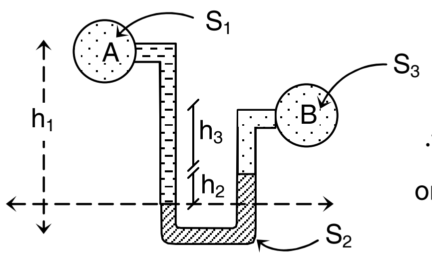
$$\frac{p_A}{w} + h_1 s_1 + h_2 s_2 = 0$$



For vacuum pressure

Differential Manometer

It is used for measuring the difference of pressure between any two points in a pipe or in two different pipes. It consists of a glass U – tube containing heavy liquid. The two ends of U–tube are connected at a point whose pressure difference is to be found out.



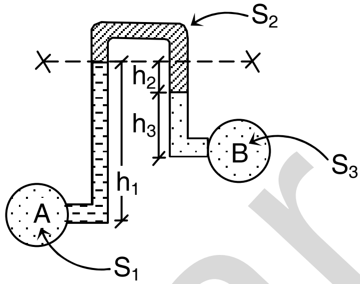
$$\frac{p_A}{w} + h_1 s_1 = \frac{p_B}{w} + h_2 s_2 + h_3 s_3$$

$$\therefore \frac{p_A}{w} - \frac{p_B}{w} = h_2 s_2 + h_3 s_3 - h_1 s_1$$

or $h_A - h_B = h_2 s_2 + h_3 s_3 - h_1 s_1$

Inverted U–tube Differential Manometer

It consists of an inverted U – tube containing a light liquid. It is made of glass. It is used for measuring the difference of low pressure between two points where accuracy is important. The two points are connected to the points whose difference of pressure is to be measured. Light liquid is used as manometric Liquid because it may come down and flow in low pressure pipe.

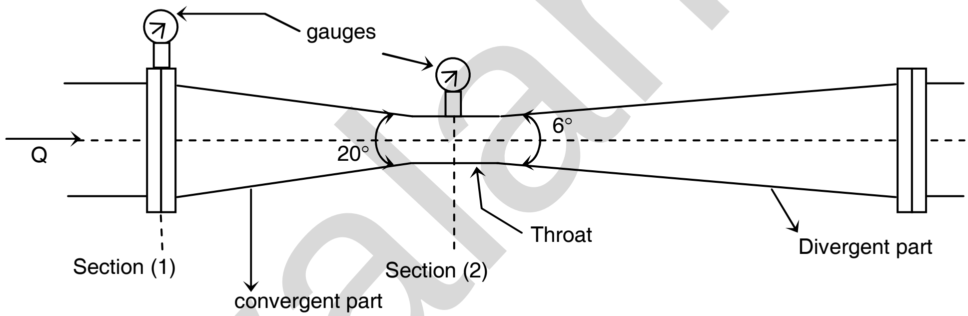


$$\frac{p_A}{w} - h_1 s_1 = \frac{p_B}{w} - h_3 s_3 - h_2 s_2$$

$$\therefore \quad \frac{p_A}{w} - \frac{p_B}{w} = h_1 s_1 - h_3 s_3 - h_2 s_2$$

1. (b) (iii) Venturimeter

A venturimeter is a device used for measuring the rate of flow of a fluid flowing through a pipe.



The basic principle on which a venturimeter works is that by reducing the cross sectional area of the flow passage, a pressure difference givens quantity of liquid flowing through the pipe.

- *Convergent cone* : A pipe of decreasing diameter from d_1 (diameter of pipe) to d_2 (diameter of throat).
- *Throat* : A small piece of uniform diameter d_2.
- *Divergent cone* : A tapering pipe from diameter of throat (d_2) to diagram of pipe (d_1).

Generally length of divergent cone is 2 to 3 times than of convergent cone to avoid separation of flow and the losses.

The diameter of throat is kept (1/2) to (3/4) diameter of pipe to avoid cavitation.

Derivation for discharge through venturimeter : Applying Bernoulli's equation at section (1) and (2)

$$\frac{p1}{w} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{w} + \frac{V_2^2}{2g} + z_2$$

Assuming horizontal venturimeter

$$z_1 = z_2 = 0$$

$$\therefore \quad \frac{p_1}{w} + \frac{V_1^2}{2g} = \frac{p_2}{w} + \frac{V_2^2}{2g}$$

$$\therefore \quad \frac{p_1}{w} - \frac{p_2}{w} = \frac{V_2^2}{2g} - \frac{V_1^2}{2g} \qquad \text{taking } h = \frac{p_1}{w} - \frac{p_2}{w}$$

$$\therefore \quad h = \frac{V_2^2}{2g} - \frac{V_1^2}{2g} \qquad \dots (1)$$

Applying continuity equation of section (1) and (2)

$$a_1V_1 = a_2V_2$$

$$\therefore \quad V_1 = \frac{a_2}{a_1}V_2 \text{ put in equation}$$

$$\therefore \quad h = \frac{V_2^2}{2g} - \frac{\left(\frac{a_2}{a_1}V_2\right)^2}{2g} = \frac{V_2^2}{2g}\left(1 - \frac{a_2^2}{a_1^2}\right)$$

$$\therefore \quad V_2 = \frac{a_1\sqrt{2gh}}{\sqrt{(a_1^2 - a_2^2)}}$$

But discharge = $Q = a_2v_2$

$$\therefore \quad Q = \frac{a_1a_2\sqrt{2gh}}{\sqrt{a_1^2 - a_2^2}}$$

and

$$Q_{actual} = C_d\frac{a_1a_2\sqrt{2gh}}{\sqrt{a_1^2 - a_2^2}}$$

where C_d = coefficient of discharge.

If pressure difference is measured by differential manometer

$$h = x\left(\frac{s_g}{s_0} - 1\right)$$

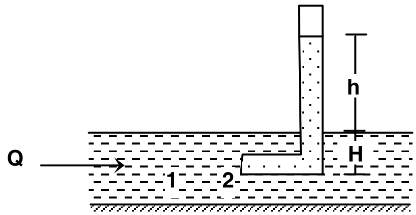
s_g = manometric fluids sp. gravity.
s_0 = flowing fluids sp. gravity.
x = manometric reading

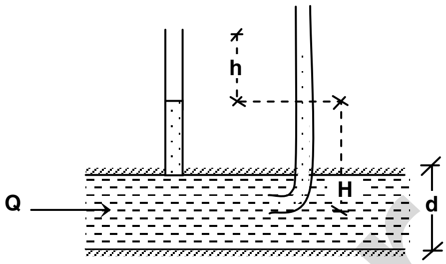
And for inverted diff. manometer

$$h = x\left(1 - \frac{s_g}{s_0}\right)$$

2. (a) Pitot Tube

It is the device used for measuring the local velocity of flow at any point in a pipe or a channel. It's working principle is if velocity of flow at a point becomes zero, there is increase in pressure energy. In its simplest form, it is a glass tube sent at right angles.





Applying Bernoulli's equation at point (1) and (2)

$$\frac{p_1}{w} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{w} + \frac{V_2^2}{2g} + z_2 \quad \ldots (1)$$

Now

$$\therefore \quad \frac{p_1}{w} = H$$

$$\frac{p_2}{w} = H + h$$

$V_2 = 0$ and $z_1 = z_2$ put in equation (1)

$$\therefore \quad H + \frac{V_1^2}{2g} = H + h + 0$$

$$\therefore \quad V_1 = \sqrt{2gh}$$

$$\therefore \quad V_{actual} = C_v\sqrt{2gh}$$

where C_v = coefficient of velocity.

2. (b) Given data : $\rho_{oil} = 980$ kg/m^3, $\tau = 0.25$ N/m^2, $\frac{du}{dy} = 0.3$ sec^{-1}

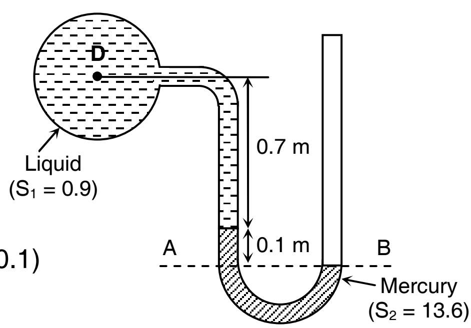
Procedure : By Newton's law of viscosity,

$$\tau = \mu \frac{du}{dy}$$

$$\therefore \quad \mu = \frac{\tau}{\left(\frac{du}{dy}\right)} = \frac{0.25}{0.3} = 0.8333 \text{ N-s/m}^2$$

We have, $$\nu = \frac{\mu}{\rho} = \frac{0.8333}{980} = 8.50 \times 10^{-4} \text{ m}^2\text{/sec}$$

2. (c) Given data: $S_1 = 0.9$, $h_1 = 0.7$
$S_2 = 13.6$, $h_2 = 0.1$ m



Procedure : Let h_D be the pressure head at point D in the pipe. Considering A-B as datum or reference line.

$$h_D + S_1h_1 + S_2h_2 = 0$$

$$\therefore \quad h_D = -S_1h_1 - S_2h_2$$

$$= -(0.9 \times 0.7) - (13.6 \times 0.1)$$

$$h_D = -1.99 \text{ m of water}$$

Therefore, pressure at point D,

$P_D = \rho\, g\, h_D$

$= 100 \times 9.81 \times (-1.99)$

$P_D = -19521.9\ N/m^2$

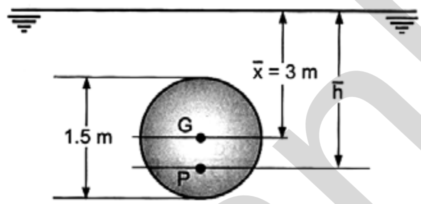
2. (d) Given data: d = 1.5 m

Procedure : $A = \frac{\pi}{4}d^2 = \frac{\pi}{4}\times(1.5)^2 = 1.767\ m^2$

Moment of Inertia about centre of gravity

$I_G = \frac{\pi}{64}d^2 = \frac{\pi}{64}\times(1.5)^4 = 0.2485\ m^4$

$\bar{x} = 3\ m$



1) Total pressure :

$P = wA\,\bar{x} = (\rho g)\,A\,\bar{x} = (1000 \times 9.81) \times 1.767 \times 3$

$= 52002.81\ N$

2) Centre of pressure :

$\bar{h} = \frac{I_G}{A\bar{x}} + \bar{x} = \frac{0.2485}{1.767\times 3} + 3$

$= 3.0468\ m$

2. (e) Bernoulli's Theorem

According to Bernoulli's theorem, "For a perfect incompressible liquid flowing in a continuous stream, the total energy of particle remains the same, while the particle moves from one point to another. This statement is based on the assumption that, there are no losses due to friction in pipe".

Mathematically, $Z + \frac{V^2}{2g} + \frac{P}{\rho g} = \text{constant}$ … (1)

where Z = Potential energy

$\frac{V^2}{2g}$ = Kinetic energy

$\frac{P}{\rho g}$ = Pressure energy

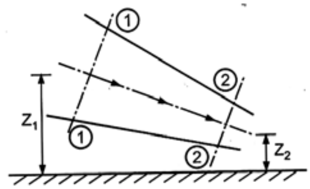


Fig. : Bernoulli's theorem.

Let us consider a non-uniform pipe (converging) having section 1–1 and 2–2. The fluid flow is passing from section 1–1 to section 2–2, i.e. from left to right.

Now, by using Bernoulli's theorem, we can write

Total head at section 1–1 = Total head at section 2–2

$$\therefore \quad \frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

The expression (1) is given in terms of head. The Bernoulli's theorem can be represented in energy form as,

Kinetic energy + Potential energy + Pressure energy = Constant

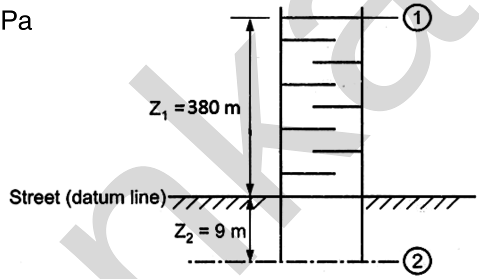
$$\frac{1}{2}mV^2 + mgZ + P\,A\,dS = \text{Constant}$$

2. (f) Given data: $P_1 = 170$ kPa $= 170 \times 10^3$ Pa

$P_1 = 170 \times 10^3$ N/m^2

$Z_1 = 380$ m

$Z_2 = -9$m (Below datum line)



Procedure : As the diameter of pipe is uniform,

$A_1 = A_2$

By continuity equation,

$A_1V_1 = A_2V_2$

$\therefore \quad V_1 = V_2 \quad [\because A_1 = A_2]$

By Bernoulli's theorem,

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

$$\therefore \quad \frac{P_1}{\rho g} + Z_1 = \frac{P_2}{\rho g} + Z_2 \quad [\because V_1 = V_2]$$

$$\therefore \quad \frac{P_2}{\rho g} - \frac{P_1}{\rho g} = Z_1 - Z_2$$

$\therefore \quad P_2 - P_1 = \rho g\,(Z_1 - Z_2)$

$\therefore \quad P_2 = 170 \times 10^3 + 1000 \times 9.81 \times [380 - (-09)]$

$= 3986.09 \times 10^3$ N/m^2

or Pa $= 3986.09$ kPa

3. (a)
- Power is transmitted through the pipes by flowing water or any other liquid flowing through them.
- The power transmitted depends upon,
  (a) Weight of liquid flowing through pipe.
  (b) Net head available at the end of pipe.
- We have, Weight of water flowing per second = w × Q
- If the head available at inlet of pipe = H and Head lost due to friction = h_f, Then, net head available at outlet of pipe = h = H − h_f [Neglecting minor losses]

We have,

$$\begin{bmatrix}\text{power transmitted}\\ \text{through pipe}\end{bmatrix} = \begin{bmatrix}\text{Weight of water}\\ \text{flowing per sec.}\end{bmatrix} \times \begin{bmatrix}\text{Net head available}\\ \text{at outlet of pipe}\end{bmatrix}$$

$\therefore \quad p = (w \times Q) \times h$

$\therefore \quad p = \rho \cdot g \cdot Q \times h$

$\therefore \quad p = \rho \cdot g \cdot Q \times (H - h_f) \qquad [\because\ h = H - h_f]$

$\therefore \quad p = \rho \cdot g \cdot A \cdot V \cdot \left[H - \dfrac{4fLV^3}{d \times 2g}\right]$ in Watts $[\because\ Q = A \cdot V]$

This is power transmitted at outlet of pipe.

Also, $\quad p = \rho \cdot g \cdot A\left[V \cdot H - \dfrac{4fLV^3}{d \times 2g}\right] \qquad \ldots(1)$

- To obtain condition for maximum power transmission, differentiate the above equation with respect to V and equate it to zero.

$$\therefore \quad \frac{d}{dV}(P) = 0$$

$$\therefore \quad \frac{d}{dV}\left[\rho \cdot g A\left(V \cdot H - \frac{4fLV^3}{d \times 2g}\right)\right] = 0$$

$$\therefore \quad \rho \cdot g\, A \cdot \left[\frac{d}{dV}\left(V \cdot H - \frac{4fLV^3}{d \times 2g}\right)\right] = 0$$

$$\therefore \quad \frac{d}{dV}\left(V \cdot H - \frac{4ftV^3}{d \times 2g}\right) = 0$$

$$H - 3 \times \left(\frac{4fLV^2}{d \times 2g}\right) = 0$$

$$\therefore \quad H - 3 \cdot h_r = 0 \qquad \left[\because\ h_f = \frac{4fLV^2}{d \times 2g}\right]$$

$$H = 3h_f, \text{ or } h_f = \frac{H}{3}$$

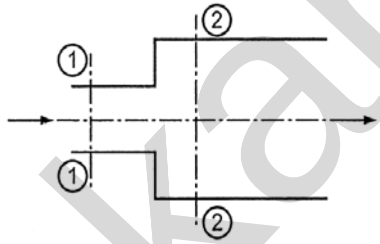
3. (b) Hydraulic Gradient

- Hydraulic Gradient line is defined as, “the line, which gives the sum of pressure head and datum head of flowing fluid in a pipe with respect to some reference line”.
- Hydraulic gradient line may rise or fall depending upon the pressure changes.
- Hydraulic gradient line lies below total energy line by, $\dfrac{V^2}{2g}$.
- H.G.L. $= Z + \dfrac{P}{\rho \cdot g}$

Total Energy Line (TEL)

- "Total energy line is defined as, "the line, which gives sum of pressure head, datum head and kinetic head of a flowing fluid in a pipe with respect to some reference line."
- When the fluid flows along the pipe, there is loss of head and total energy decreases in the direction of low.

3. (c) Given data: $d_1 = 25$ cm = 0.25 m,
$d_2 = 50$ cm = 0.5 m,
Q = 350 lit/sec = 350×10^{-3} m^3/sec.



Procedure: We have,

$$A_1 = \frac{\pi}{4}d_1^2 = \frac{\pi}{4} \times (0.25)2 = 0.04908 \text{ m}^2$$

$$A_2 = \frac{\pi}{4}d_2^2 = \frac{\pi}{4} \times (0.5)^2 = 0.1963 \text{ m}^2$$

By continuity equation,

$$Q = A_1V_1 = A_2V_2$$

$$\therefore \quad V_1 = \frac{Q}{A_1} = \frac{350\times10^{-3}}{0.04908} = 7.131 \text{ m/sec}$$

$$\text{and} \quad V_2 = \frac{Q}{A_2} = \frac{350\times10^{-3}}{0.1963} = 1.783 \text{ m/sec}$$

Head lost due to sudden enlargement.

$$h_e = \frac{(V_1 - V_2)^2}{2g} = \frac{(7.131-1.783)^2}{2\times9.81} = 1.457 \text{ m}$$

3. (d) Let, a = cross-sectional area of jet in m^2
V = Velocity of jet in m/s

Mass of water striking the plate per second
$= \rho \cdot a \cdot V$ in kg/sec

Here, final velocity in the direction of jet is zero.

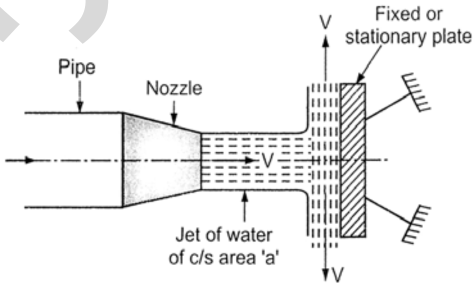


Fig. : Direct impact of jet on a stationary flat plate

By applying impulse-momentum equation,
Force exerted by jet on the plate = Rate of change of momentum

$$F = \begin{bmatrix} \text{Mass of water} \\ \text{striking per second} \end{bmatrix} \times \begin{bmatrix} \text{change in} \\ \text{velocity} \end{bmatrix}$$

$$= \rho aV \times \begin{bmatrix} \text{Initial} & - & \text{Final} \\ \text{velocity} & & \text{velocity} \end{bmatrix}$$

$$F = \rho aV\,(V - 0) = \rho aV^2$$

3. (e) Given data: d = 50 mm = 0.05 m h = 70 m, $C_V = 0.9$.

Procedure: Area of jet, $a = \frac{\pi}{4}d^2 = \frac{\pi}{4} \times (0.05)^2 = 1.9634 \times 10^{-3}\ m^2$

Velocity of jet, $V = C_V\sqrt{2gh}$

$\therefore \quad V = 0.9 \times \sqrt{2 \times 9.81 \times 70} = 33.35$ m/s

Force exerted by jet, $F = \rho aV^2 = 1000 \times 1.9634 \times 10^{-3} \times (33.35)^2$
$= 2183.73$ N

3. (f) Given data: d = 50 mm = 0.05 m, V = 15 m/s, u = 6 m/s.

Procedure: Area of jet, $a = \frac{\pi}{4}d^2 = \frac{\pi}{4} \times (0.05)^2 = 1.9634 \times 10^{-3}\ m^2$

(i) Force exerted by the jet:

$$F = \rho aV\,(V - u) = 1000 \times 1.9634 \times 10^{-3} \times 15 \times (15 - 6)$$
$$= 265.06 \text{ N}$$

(ii) Work done by jet:

$$W = F \cdot u = 265.06 \times 6 = 1590.36 \text{ N·m/sec or J/sec}$$

(iii) Efficiency of jet: $\eta = \dfrac{\text{Work done}}{\text{Kinetic energy of jet}} = \dfrac{1590.36}{\frac{1}{2}\rho aV^3}$

$$= \frac{1590.36 \times 2}{1000 \times 1.9634 \times 10^{-3} \times (15)^3} = 0.48 = 48\%$$

Note: Efficiency can also be calculated using formula,

$$\eta = \frac{2u\,(v - u)}{V^2} = \frac{2 \times 6 \times (15 - 6)}{(15)^2} = 0.48 = 48\%$$

4. (a) Governing of Pelton Wheel Turbine

- Governing of a turbine is defined as, "the operation by which, the speed of turbine is kept constant under all conditions of working".
- This is necessary, because turbine is coupled to an electric generator, which is required to run at constant speed under all fluctuating load conditions. This enables the generator to produce power at constant frequency under all varying conditions. The speed of generator will be constant, when the speed of turbine is constant.

Construction:

- Governing of pelton wheel turbine is done by means of an oil pressure governor, consisting of following parts.
  (a) Oil sump.
  (b) Gear pump (oil pump) driven by power obtained from turbine.
  (c) Servomotor (Relay cylinder).
  (d) Control valve (Relay valve).
  (e) Centrifugal governor.
  (f) Spear.

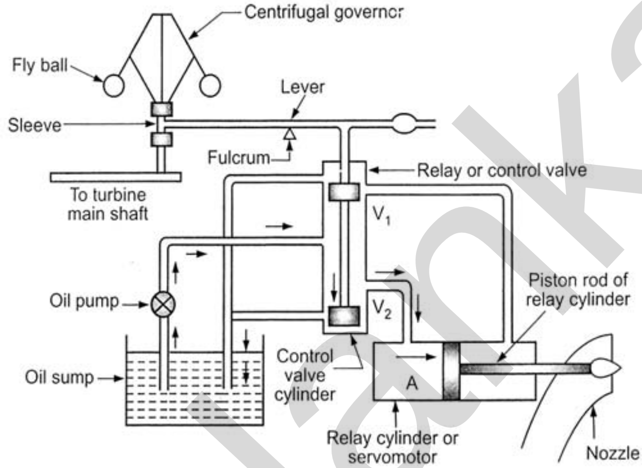


Fig. : Governing of pelton turbine

Working: Figure shows the position of piston in the relay cylinder, position of control or relay valve and flyballs of the centrifugal governor, when the turbine is running at the normal speed.

(a) When the load on the generator decreases:

- When the load on the generator decreases, speed of generator increases. This increases the speed of turbine beyond the normal speed. Therefore, the centrifugal governor, which is connected to main shaft of turbine will be rotating at an increased speed.
- As the speed of centrifugal governor increases, the flyballs move outwards due to increased centrifugal force on them.
- Due to outward movement of flyballs, the sleeve will also move upward.
- A horizontal lever, supported over a fulcrum, connects the sleeve and piston rod of control valve.
- As the sleeve moves up, the lever turns about the fulcrum and piston rod of control valves moves downwards.
- The closes the valve V_1 and opens the valve V_2.
- The oil pumped by oil pump from the oil sump, flows under pressure through valve V_2 to relay cylinder (servomotor) and exerts force on the face A of piston of relay cylinder.
- The piston alongwith piston rod and spear will move towards right, thereby decreasing the area of flow of water from nozzle to turbine, which consequently reduces the speed of turbine.

- When the speed of turbine becomes normal, the flyballs, sleeve, lever and piston rod of control valve come to normal position as shown in figure.

(b) When the load on the generator increases:

- When the load on the generator decreases, the speed of generator and hence turbine speed decreases.
- This reduces the speed of centrifugal governor and also decreases the centrifugal force on the flyballs. The flyballs move inwards due to decreased centrifugal force on them.
- Due to this, sleeve moves downward and lever turns around the fulcrum, moving the piston rod of control valve in the upward direction.
- This closes the valve V_2 and opens the valve V_1. The oil under pressure from control valve, will move through valve V_1 to the servomotor and will exert a force on the face B of the piston. This will move the piston along with the piston rod and spear towards left, increasing the area of flow of water at the outlet of nozzle.
- This will increase the rate of flow of water to the turbine and consequently, the speed of turbine will also increase, till it becomes normal.

4. (b)
- Figure (a), (b) and (c) shows velocity triangles at the tips of Pelton wheel bucket for slow, medium and fast runner.
- As Pelton wheel turbine is a tangential flow impulse turbine, the inlet angle of jet is assumed as zero, therefore, $\theta = 0$ and $\alpha = 0$.

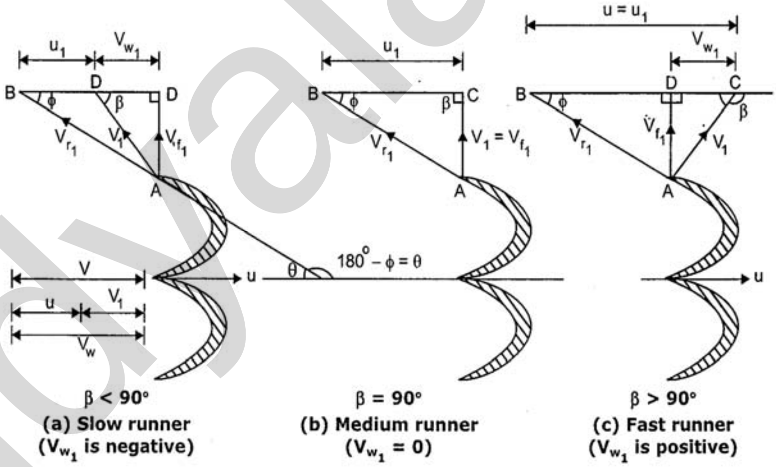


Fig.: Inlet and outlet velocity triangles for Pelton wheel turbine.

- Velocities V and u are collinear, thus the velocity triangle at inlet is a straight line and therefore, $V_r = V - u$ and $V_w = V$.
- The velocity triangle at outlet tip can be drawn in three ways, depending upon the speed of runner.
- As the inlet and outlet tips are at same radial distance, the tangential velocity of bucket at both the tips is same, i.e. $u = u_1$.
- Also, $V_{r_1} = V_r = V - u$.

- [Refer figure (a)].
- From the outlet velocity triangle, $V_{w_1} = V_{r_1} \cos\phi - u_1 = V_{r_1} \cos\phi - u$ ... (1)
- Work done by water jet striking per second = $\frac{W}{g}\left(V_w + V_{w_1}\right)\times u$

$$= \frac{W}{g}\left(V + V_{r_1}\cos\phi - u\right)\times u \quad \text{[From equation (1)]}$$

$$= \frac{W}{g}\left[V + (V-u)\cos\phi - u\right]\times u$$

Work done $= \frac{W}{g}(V-u)(1+\cos\phi)\cdot u$

4. (c) Given data: H = 25 m, N = 200 rpm, Q = 9 m^3/sec, η_O = 90% = 0.9.
Procedure: For head of 25 m,

We have, $\eta_O = \frac{S.P.}{W.P.}$

$\therefore$ S.P. $= \eta_O \times$ W.P.

$\therefore$ S.P. $= 0.9 \times \rho g \cdot Q \cdot H$

i.e. $P = 0.9 \times 1000 \times 9.81 \times 9 \times 25$

$\therefore$ $P = 1986.525 \times 10^3$ W = 1986.525 kW

If we want to evaluate the performance of turbine under new head of 20 m; it means we have to calculate speed, discharge, power and specific speed at H_1 = 20 m.

(a) Speed of turbine:

$$N_1 = \frac{N\sqrt{H_1}}{\sqrt{H}} = \frac{200\times\sqrt{20}}{\sqrt{25}} = 178.88 \text{ rpm}$$

(b) Discharge:

$$Q_1 = \frac{Q\sqrt{H_1}}{\sqrt{H}} = \frac{9\times\sqrt{20}}{\sqrt{25}} = 8.05 \text{ m}^3\text{/sec}$$

(c) Power developed:

$$P_1 = \frac{P\,(H_1)^{3/2}}{(H)^{3/2}} = \frac{1986.525\times(20)^{3/2}}{(25)^{3/2}} = 1421.44 \text{ kW}$$

(d) Type of turbine: Let us calculate specific speed at H_1 = 20 m

$$N_S = \frac{N_1\sqrt{P_1}}{H_1^{5/4}} = \frac{178.88\times\sqrt{1421.44}}{(20)^{5/4}} = 159.45$$

As N_S lies between 60 to 400, the type of turbine is Francis turbine.

5. (a) Kaplan Turbine
It is an axial flow turbine of reaction type.

Construction:

- Its working is very much similar to Francis turbine. It consists of scroll casing, guide vanes and draft tube. It has a vertical hollow shaft, which is enlarged at the bottom in the shape of propeller called as “hub or boss”.

- Runner of a Kaplan turbine has four to six blades. These blades are attached to a hub or boss and are shaped, such that, water flows axially through the runner.
- The blades of runner are adjustable and can be rotated about the pivots fixed to the boss of the runner, so that, their angle of inclination may be adjusted.
- As the guide vane angle and runner blade angle can be varied, a very high efficiency can be maintained over a wide range of operating conditions.
- In this turbine, the water from penstock enters the scroll casing into the guide vanes.
- The water from guide vanes turns through 90° enters the runner vanes axially.
- In case of Francis turbine, the water enters the runner radially, while in Kaplan turbine, the water strikes the runner axially. Thus, Kaplan turbine has purely axial flow.

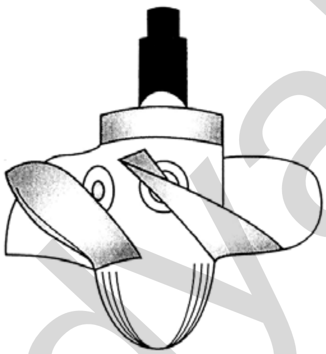


Fig. 1: Runner of a Kaplan turbine.

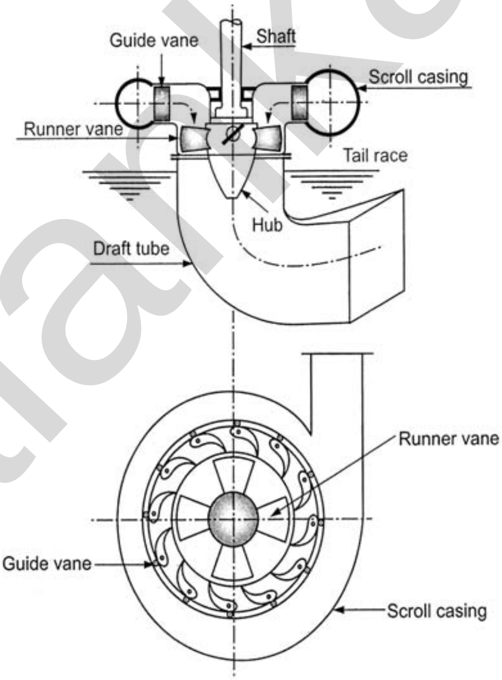


Fig. 2: Kaplan turbine.

5. (b) Functions of Draft Tube in reaction turbine

- It converts the kinetic energy of water at exit of runner into useful pressure energy and the water discharges into tail race at very low velocity. Therefore, the pressure head increases.
- Utilization of K.E. at the exit of runner increases the power output and efficiency of the turbine.
- It permits the negative head to be established at outlet of runner; hence it increases the net head available to turbine.
- It allows the turbine to be set above tail-race level, without loss of head, to facilitate inspection and maintenance.
- It increases the head on the turbine by an amount equal to the height of runner outlet above the tail race.

5. (c) **Cavitation in Turbines**

- Cavitation is, "the formation, growth and collapse of vapour filled cavities or bubbles in a flowing liquid due to local fall in fluid pressure".
- If the pressure of liquid during flow is reduced below its evaporation pressure at a given temperature, the liquid will boil and small vapour bubbles are formed. These bubbles are carried along by the fluid during its flow to high pressure region, where the vapours condense and the bubbles suddenly collapse. It results into formation of cavity.
- The surrounding liquid rushes with a very great velocity (and hence with very great force) to occupy the empty spaces thus created. It causes series of violent, irregular spherical shock waves.
- When the cavities collapse (the collapsing pressure is of the order of 100 times the atmospheric pressure) on the surface of a body, due to repeated 'hammering' action, the metal particles are subjected to fatigue stresses leading to wear and erosion. This erosion of pipe material is called 'pitting'. It generates lot of noise and vibrations and shock waves are formed.
- Only reaction turbines are subjected to cavitation. The cavitation may occur at inlet of draft tube, where the pressure is considerably reduced, which may be below the vapour pressure of the liquid flowing through the turbine.

Effects of Cavitation:

- Flow pattern of fluid is modified with reduced flow rate.
- Pitting and erosion of metal parts.
- Collapse of cavities cause noise and vibrations of various parts.
- Power and efficiency of turbine decreases due to cavitation.
- Structural failure may take place due fatigue, because of high rate of bubble collapse.

5. (d) **Casing for a Centrifugal Pump**

(a) Volute casing

- Here, the area of flow gradually increases from impeller outlet to the delivery pipe, so as to reduce the velocity of flow.
- Thus, the increase in pressure occurs in volute casing i.e. kinetic energy is converted to pressure energy. Refer figure 1(a).

(b) Vortex casing

- If circular chamber is provided between the impeller and the volute chamber, then casing is known as vortex casing. Refer figure 1(b).
- This circular chamber is known as vortex or whirlpool chamber and such pump is called as volute pump with vortex chamber. The vortex chamber converts some of the kinetic energy into pressure energy. Then the volute chamber further increases the pressure energy.
- Thus, efficiency of a volute pump fitted with vortex chamber is more than simple volute pump.

(c) Casing with guide blades

- Here, casing impeller is surrounded by a series of guide blades (vanes) mounted on a ring, known as diffuser.

- The liquid leaving the impeller passes through a passage having gradually increasing area between guide vanes. Due to this, velocity of flow decreases and kinetic energy is converted into pressure energy.
- The water from guide vanes (diffuser) passes through a surrounding casing, which is mostly concentric as shown in figure 1(c).

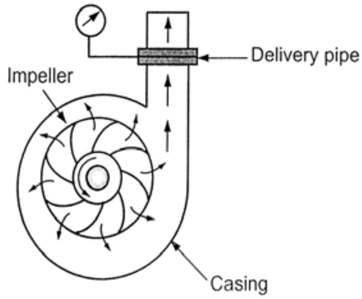


Fig. 1(a): Volute casing.

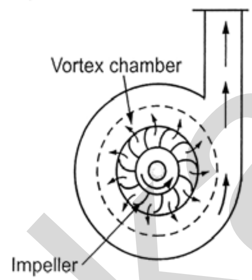


Fig. 1(b) : Vortex casing.

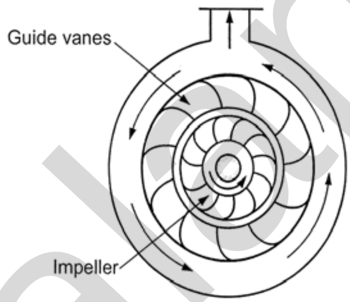


Fig. 1(c) : Casing with guide blades.

5. (e) Single Stage and Multistage Pumps

	Single stage pump	Multistage pump
1)	It has a single impeller.	It has two or more number of identical impellers mounted on some or differential shafts.
2)	It can develop a head upto 40 metres.	It is used to develop head higher than 40 m.
3)	Frictional losses and stresses are more.	For some discharge, frictional losses and stresses are less due to reduced head on each impeller requiring lower speeds.
4)	Due to higher specific speed, suction lift is limited.	Due to lower specific speed, higher suction lift is possible.

5. (f) Negative Slip

- In most of the cases, Q_{act} is less than Q_{th} and hence value of C_d is less than unity and slip is positive.
- However, in some cases, Q_{act} may be more than Q_{th}. In such cases, value of C_d is more than unity and slip will be negative. This happens, when there is

direct connection between suction and delivery sides before the end of suction stroke.

- This happens, if the momentum of liquid in suction pipe is large enough to open the delivery valve before the beginning of delivery stroke, or before the end of suction stoke. Therefore, negative slip is found in case of reciprocating pumps.
- Negative slip occurs in case of reciprocating pumps having long suction pipe and short delivery pipe, especially, when they are operating at high speeds.

6. (a) Functions of Air Vessel

(a) To obtain continuous supply of water at a uniform rate.
(b) To save considerable amount of work in overcoming the frictional resistance in the suction and delivery pipes.
(c) To run the pump at a high speed without separation.

- Air vessel is a closed chamber containing compressed air in the top portion and water at the bottom of chamber.
- The water may flow in or out of vessel through an opening provided at the base of chamber.
- When the water enters the air vessel, the air gets compressed further and when the liquid flows out of the vessel, the air will expand in the chamber.
- The air vessel is fitted to the suction pipe and to the delivery pipe at a point close to the cylinder of single acting reciprocating pump.
- Figure shows the single acting reciprocating pump, to which, air vessels are fitted to the suction and delivery pipe.
- The air vessel acts like an intermediate reservoir.

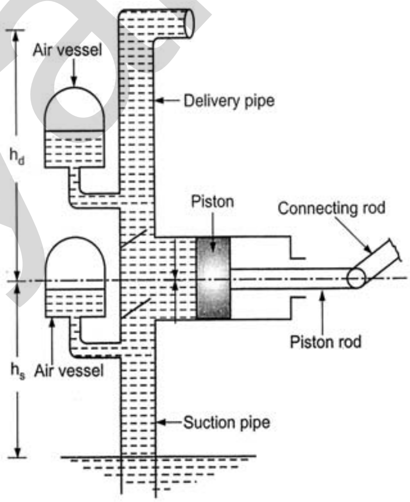


Fig. : Air vessels fitted to reciprocating pump

(a) Air vessel fitted to suction pipe:

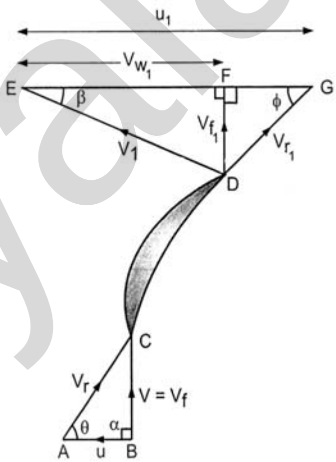
- During first half of the suction stroke, the piston moves with acceleration, which means the velocity of water in the suction pipe is more than the mean velocity and hence the discharge of water entering the cylinder will be more than the mean discharge.

- This excess quantity of water will be supplied from the air vessel to the cylinder, in such a way that, the velocity of flow in suction pipe below the air vessel is equal to mean velocity of flow.
- During second half of suction stroke, the piston moves with retardation and hence velocity of flow in the suction pipe is less than mean velocity of flow.
- Thus, the discharge entering the cylinder will be less than mean discharge. And the excess water flowing in the suction pipe will be stored into air vessel, which will be supplied during first half of next suction stroke.

(b) Air vessel fitted to delivery pipe:

- When the air vessel is fitted to the delivery pipe, during the first half of the delivery stroke, the piston moves with acceleration and forces the water into the delivery pipe with a velocity more than mean velocity.
- The quantity of water in excess of mean discharge will flow into air vessel. This will compress air inside the vessel.
- During the second half of delivery stroke, the piston moves with retardation and the velocity of water in the delivery pipe will be less than the mean velocity. The water already stored into air vessel will start flowing in to the delivery pipe and velocity of flow in the delivery pipe beyond the point, to which, air vessel is fitted, will become equal to mean velocity. Hence, the rate of flow of water in the delivery pipe will be uniform.

6. (b) Given data: $D_1 = 70$ cm = 0.7 m, D = 35 cm = 0.35 m, $\theta = 40°$, $\phi = 25°$,
N = 1440 rpm, B = 7 cm = 0.07 m, $B_1 = 3$ cm = 0.03 m.



Procedure: As water enters radially, $\alpha = 90°$. Therefore, $V_w = 0$.
We have,

Tangentially velocity at inlet and outlet as,

$$u = \frac{\pi DN}{60} = \frac{\pi \times 0.35 \times 1440}{60} = 26.39 \text{ m/s}$$

and $$u_1 = \frac{\pi D_1 N}{60} = \frac{\pi \times 0.7 \times 1440}{60} = 52.77 \text{ m/s}$$

From the inlet velocity triangle, Δ ABC

$$\tan\theta = \frac{V_f}{u}$$

$\therefore$ $V_f = u \cdot \tan\theta = 26.38 \times \tan(40) = 22.135$ m/s

(1) Discharge:
We have, $Q = \pi DB \cdot V_f = \pi \times 0.35 \times 0.07 \times 22.135 = 1.703$ m^3/sec

(2) Work done or power required:
Also, $Q = \pi D_1 \cdot B_1 \cdot V_{f1}$

$$\therefore V_{f_1} = \frac{Q}{\pi D_1 B_1} = \frac{1.703}{\pi \times 0.7 \times 0.03} = 25.81 \text{ m/sec}$$

From outlet velocity Δ GFD,

$$\tan\phi = \frac{V_{f_1}}{u_1 - V_{w_1}}$$

$$\therefore \tan(25) = \frac{22.81}{52.77 - V_{w_1}}$$

$$\therefore V_{w_1} = -2.58 \text{ m/sec}$$

As V_{w_1} is coming out to be negative, therefore outlet velocity triangle will change.

From the formula, $\tan\phi = \frac{V_{f_1}}{u_1 - V_{w_1}}$, it can be said that, if $V_{w_1} < u_1$, then the difference $\left(u_1 - V_{w_1}\right)$ is positive and hence V_{w_1} will come positive.

But here, V_{w_1} is negative, therefore, we can say, $V_{w_1} > u_1$.

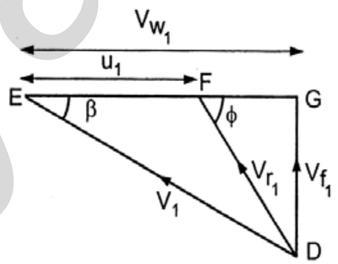


Fig. : changed outlet velocity triangle

$$\therefore \text{From the } \Delta \text{ DFG}, \tan\phi = \frac{V_{f_1}}{V_{w_1} - u_1}$$

$$\therefore \tan(25) = \frac{25.81}{V_{w_1} - 52.77}$$

$$\therefore V_{w_1} - 52.77 = 55.34$$

$$\therefore V_{w_1} = 108.11 \text{ m/s}$$

Work done per second of water

$$= \frac{W}{g} \cdot V_{w_1} \cdot u_1 \qquad = \frac{pgQ}{g} \cdot V_{w_1} \cdot u_1$$

$$= pQ\ V_{w_1} \cdot u_1 \qquad = 1000 \times 1.703 \times 108.11 \times 52.77$$

$$= 9715.55 \times 10^3 \text{ Watt} \qquad = 9.715 \text{ kW}$$

6. (c) The following types of draft tubes are commonly used:

(a) Conical type

- The conical type draft tube is generally used on low powered units for all specific speeds, frequently, on large-head units.
- The side angle ranges from 4 to 6°, the length from 3 to 4 times the diameter and the discharge area from four to five times the throat area.
- It is fabricated from mild steel plates.
- It has efficiency upto 90% and it is employed for vertical shaft turbines.

(b) Simple Elbow draft tube

- Elbow type draft tubes are used for Kaplan turbines. These tubes reduce the depth and cost of excavation.
- It has circular cross-section throughout from inlet to outlet as shown in figure 1, which is turned through 90°. This type of draft tube is designed to turn the water from the vertical to the horizontal direction with a minimum depth of excavation and at the same time, having a high efficiency.
- It is made of concrete with steel lining at inlet to resist cavitation.
- The horizontal portion of the draft tube is generally inclined upwards to lead the water gradually to the level of the tail race and to prevent entry of air from the exit end. The exit end of the draft tube must be totally immersed in water.

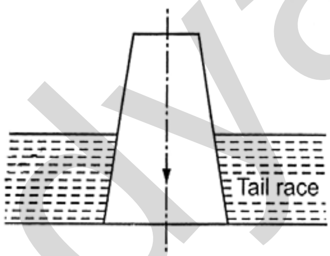


Fig. 1: Straight conical draft tube.

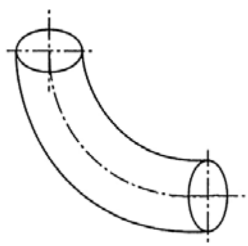


Fig. 2: Simple Elbow draft tube.

(c) Elbow draft tube

- It is circular in cross-section at inlet in its vertical leg, which turns into rectangular cross-section in horizontal portion of tube up to outlet.
- The horizontal portion of tube is gradually inclined upwards, so that, the water leaves the tube almost at tail race level.
- In this case also, the cost and depth of excavation is reduced.
- The efficiency of these tubes is in the range of 60% to 80%.
- It is also made of concrete with steel lining near the runner.

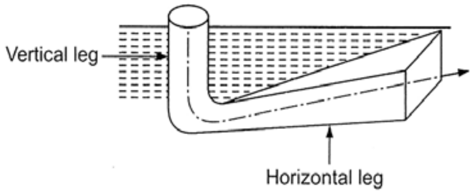


Fig. 3: Elbow type draft tube

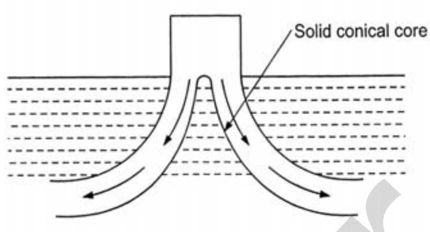


Fig. 4: Moody's spreading draft tube of 'Hydrocone'

(d) Moody spreading draft tube

- Figure 4 shows a Moody's spreading draft tube.
- It is provided with a solid central core of conical shape, which reduces whirling action of discharged water.
- The efficiency of such a draft tube is about 85%.
- It is used for vertical shaft turbines having large whirl component at exit of their runner.

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