RPSC AEn-2024 Main Test Series

MECHANICAL ENGINEERING

Test 6

Test Mode : • Offline • Online

Subjects : Fluid Mechanics and Fluid Machines

DETAILED EXPLANATIONS

1. Solution:

It is defined as the ratio of the dynamic viscosity to the density of the fluid. Its S.I. unit is m^2/s.

i.e.,
$$\nu = \frac{\mu}{\rho}\left(m^2/s\right)$$

2. Solution:

Surface tension is defined as the tensile force acting on the surface of the liquid in contact with a gas or on the surface between two immiscible liquids such that the contact surface behaves like a membrane under tension. Its S.I. unit is N/m.

$$\text{Surface tension, } \sigma = \frac{\text{Force}}{\text{Length}}(\text{N/m})$$

3. Solution:

Capillarity is defined as the phenomenon of rise or fall of a liquid surface in a small tube relative to the adjacent general level of liquid when the tube is held vertically in the liquid. The rise of liquid surface is known as capillary rise while the fall of liquid surface is known as capillary depression.

4. Solution:

Steady Flow: Fluid flow is said to be steady if at any point in the flowing fluid various characteristics such as velocity, density, pressure, etc. do not change with time.

$$\frac{\partial V}{\partial t} = 0;\ \frac{\partial p}{\partial t} = 0;\ \frac{\partial \rho}{\partial t} = 0$$

Unsteady Flow: Fluid flow is said to be unsteady if at any point in the flowing fluid any one or all characteristics which describe the behaviour of the fluid in motion change with time.

$$\frac{\partial V}{\partial t} \neq 0;\ \frac{\partial p}{\partial t} \neq 0;\ \frac{\partial \rho}{\partial t} \neq 0$$

5. Solution:

A submerged body floats in equilibrium when the upward buoyant force equals the downward weight of the body.

i.e., Buoyant force = Weight of the body

6. Solution:

It is defined as the ratio of momentum of the flow per second based on actual velocity to the momentum of the flow per second based on average velocity across the section.

7. Solution:

The energy thickness (δ^{**}) is defined as the distance by which the boundary should be displaced to compensate for the reduction in kinetic energy of the flowing fluid on account of boundary layer formation.

8. Solution:

Diameter of bubble, $d = 40\text{ mm} = 40 \times 10^{-3}\text{ m}$

Pressure in excess of outside, $p = 2.5\text{ N/m}^2$

For a soap bubble, using equation, we get

$$p = \frac{8\sigma}{d}$$

$$2.5 = \frac{8 \times \sigma}{40 \times 10^{-3}}$$

$$\sigma = \frac{2.5 \times 40 \times 10^{-3}}{8}\text{ N/m} = 0.0125\text{ N/m}$$

9. Solution:

It is defined as the phenomenon of formation of vapor bubbles of a flowing liquid in a region where the pressure of the liquid falls below its vapor pressure and the sudden collapsing of theses vapor bubbles in a region of high pressure.

10. Solution:

Nozzle converts pressure energy of water into kinetic energy by producing a high-velocity jet, while the spear regulates discharge by varying jet area to control turbine power output.

11. Solution:

Given: $$\frac{u}{U_0} = \sin\left(\frac{\pi \cdot y}{2\delta}\right)$$

Displacement thickness (δ^*)

$$\delta^* = \int_0^\delta \left(1 - \frac{u}{U_0}\right)dy = \int_0^\delta \left(1 - \sin\left(\frac{\pi}{2}\frac{y}{\delta}\right)\right)dy$$

$$= y\Big|_0^\delta - \int_0^\delta \sin\left(\frac{\pi}{2}\frac{y}{\delta}\right)dy = \delta - \left[-\cos\left(\frac{\pi}{2}\frac{y}{\delta}\right)\cdot\frac{2\delta}{\pi}\right]_0^\delta$$

$$= \delta - [-(0-(1)]\frac{2\delta}{\pi} = \delta - \frac{2\delta}{\pi} = \left(\frac{\pi - 2}{\pi}\right)\delta$$

12. Solution:

Reciprocating Pump	Centrifugal Pump
• The discharge is fluctuating and pulsating.	• The discharge is continuous and smooth.
• Reciprocating pump handles a small quantity of liquids.	• The centrifugal pump handles a large quantity of liquids or fluids.
• This is used for small discharge (Q) and high head.	• Centrifugal pump used for high discharge (Q) through smaller heads.
• Reciprocating pump has low efficiency.	• Centrifugal pump has high efficiency.
• The reciprocating pump is complicated in operation and with much noise.	• The centrifugal pump is smooth in operation and without much noise.
• This pump runs at a low speed because of cavitation and separation.	• This pump runs at a high speed.
• Torque is not uniform here.	• In this torque is uniform

13. Solution:

Given: $u = x^3 + y^2 + 2z^2$, $v = -x^2y - yz - xy$

From continuity equation,

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad \text{... (i)}$$

$$\frac{\partial u}{\partial x} = \frac{\partial}{\partial x}(x^3 + y^2 + 2z^2) = 3x^2 + 0 + 0 = 3x^2$$

$$\frac{\partial v}{\partial y} = \frac{\partial}{\partial y}(-x^2y - yz - xy) = -x^2 - z - x$$

Putting the value of $\frac{\partial u}{\partial x}$ and $\frac{\partial v}{\partial y}$ in equation (i) we get

$$3x^2 + (-x^2 - z - x) + \frac{\partial w}{\partial z} = 0$$

$$2x^2 - z - x + \frac{\partial w}{\partial z} = 0$$

$$\frac{\partial w}{\partial z} = -2x^2 + z + x$$

Integrating, w.r.t.z, we get

$$w = -2x^2z + xz + \frac{z^2}{2} + f(x,y)$$

14. Solution:

Different heads used in Hydroelectric Power Plant are:

(i) Gross head: The difference between the head race level and tail race level when no water is flowing is known as gross head. It is denoted by H_g.

(ii) Net Head or Effective Head: It is the head available at the entrance to the turbine. It is obtained by subtracting all the losses of head from gross head.

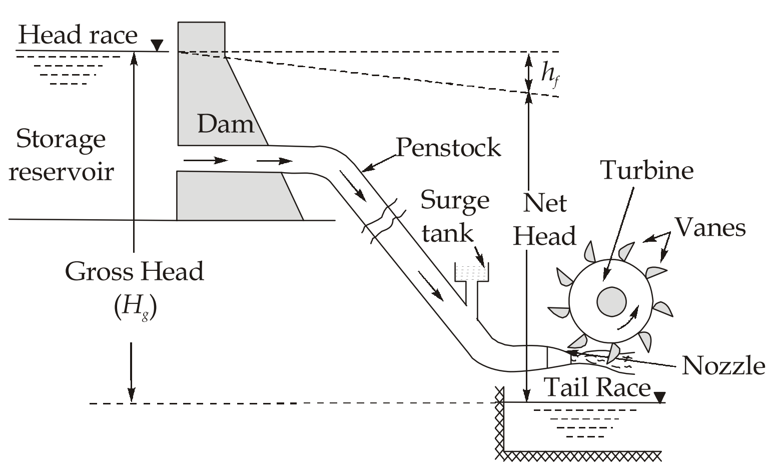
Net head is given by,

$$H = H_g - h_f$$

Where, H_g = Gross head, and

h_f = Total loss of head between the head race and the entrance of the turbine.

(iii) Layout of a Hydroelectric Power Plant



Layout of a hydroelectric power plant

15. Solution:

S.No.	Inward flow (Reaction turbine)	Outward flow (Reaction turbine)
1.	Water enters at the outer periphery, flows inward and discharge at the inner periphery.	Water enters at the inner periphery, flows outward and discharge at the outer periphery.
2.	Negative centrifugal head reduces the relative velocity of water at the outlet.	Positive centrifugal head increases the relative velocity of water at the outlet.
3.	Discharge does not increases.	The discharge increases.
4.	Easy and effective speed control.	Speed control is very difficult.
5.	The turbine adjusts the speed by itself.	The turbine cannot adjust the speed by itself.

16. Solution:

(i) Suction head (h_g): It is the vertical height of the centre line of the centrifugal pump above the water surface in sump from which water is to be lifted.

(ii) Delivery head (h_d): It is the vertical height between the centre line of the pump and the water surface in the tank to which water is delivered.

(iii) Static head (H_g): It is total vertical height through which water has to be lifted. It is given as,

$$H_s = h_s + h_d$$

(iv) Manometric head (H_m): It is defined as the head against which a centrifugal pump has to work.

17. Solution:

Following are the three types of similarities that exist between model and prototype :

1. **Geometric Similarity :** The geometric similarity is said to exist between the model and the prototype if the ratio of all corresponding linear dimension in the model and prototype are equal.
2. **Kinematic Similarity :** It means the similarity of motion between model and prototype. If at the corresponding points in the model and in the prototype, the velocity or acceleration ratios are same (both in magnitude and direction), the two flows are said to be kinematically similar.
3. **Dynamic Similarity :** Dynamic similarity means the similarity of force (both in magnitude and in direction) in model and prototype. Dynamic similarity is said to exist between the model and the prototype if the ratios of the corresponding forces acting at the corresponding points are equal.

18. Solution:

Let 'V' be the total volume of the iceberg

visible volume of the iceberg above the water level is 600 m^3 and volume of ice in sea water = $(V - 600)$ m^3

Density of sea water, ρ_s = 1025 kg/m^3, density of iceberg, ρ_i = 915 kg/m^3

We know that

Weight of iceberg = Weight of water displaced by ice.

$$\rho_i \times V \times g = \rho_s \times (V - 600) \times g$$

$$915\, V = 1025\,(V - 600)$$

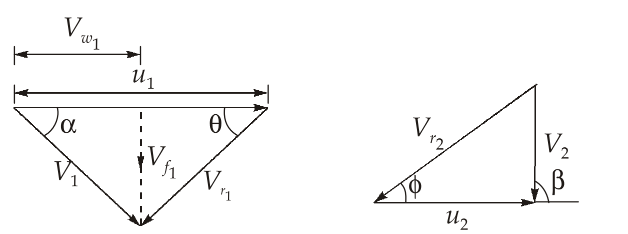
$$V = 5590.9 \text{ m}^3 \text{ i.e. total volume}$$

$\therefore$ Weight of iceberg $= \rho_i \times V \times g = 915 \times 5590.9 \times 9.81 = \mathbf{50.184 \times 10^6\ N.}$

19. Solution:

Given: P = 12 MW, H = 20 m, α = 30°, D = 6 m, D_h = 4 m, η_h = 80%, η_0 = 75%

For keeping absolute velocity at outlet minimum $V_{w_2} = 0$, i.e. discharge at outlet is axial.



Inlet velocity diagram   Outlet velocity diagram

$$\text{Power, } P = \eta_0 \times \rho \times g \times Q \times H$$

where, Q = Discharge (m^3/s)

$$12 \times 10^6 = 0.75 \times 1000 \times 9.81 \times Q \times 20$$

$$Q = 81.55 \text{ m}^3/\text{s}$$

$$Q = \frac{\pi}{4} \times \left(D^2 - D_h^2\right) \times V_{f_1} \quad \left[\text{where, } V_{f_1} = \text{flow velocity}\right]$$

$$81.55 = \frac{\pi}{4} \times \left(6^2 - 4^2\right) \times V_{f_1}$$

$$V_{f_1} = 5.19 \text{ m/s}$$

Hydraulic efficiency, $$\eta_H = \frac{V_{w_1} u_1}{gH}$$

$$0.8 = \frac{V_{w_1} \times u_1}{9.81 \times 20}$$

$$V_{w_1} \times u_1 = 156.96 \quad \text{...(i)}$$

$$\tan\alpha = \frac{V_{f_1}}{V_{w_1}}$$

$$V_{w_1} = 8.99 \text{ m/s}$$

Put in equation (i)

$$8.99 \times u_1 = 156.96$$

$$u_1 = 17.46 \text{ m/s}$$

(i) Runner vane angle at inlet (θ) and at outlet (ϕ)

$$\tan\theta = \frac{V_{f_1}}{u_1 - V_{w_1}} = \frac{5.19}{17.46 - 8.99} = 0.6127$$

$$\theta = 31.49°$$

$$\tan\phi = \frac{V_{f_2}}{u_2}$$

For Kaplan turbine, $V_{f_1} = V_{f_2}$ and $u_1 = u_2$

$$\tan\phi = \frac{5.19}{17.46} = 0.297$$

$$\phi = 16.55°$$

(ii) Guide vane angle at outlet (β) for minimum velocity at outlet $\left(V_{w_2} = 0\right)$

So, $\beta = 90°$

(iii) Speed of runner, N (rpm)

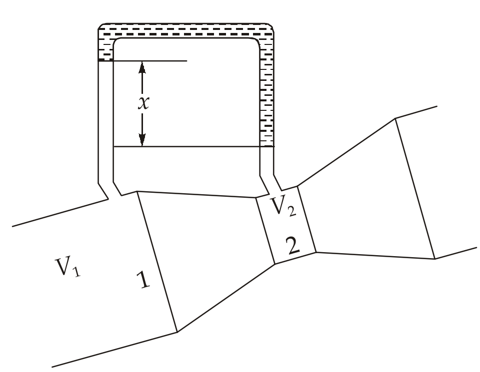
$$u = \frac{\pi D N}{60}$$

$$17.46 = \frac{\pi \times 6 \times N}{60}$$

$$N = 55.57 \text{ rpm}$$

20. Solution:

Given data: $d_1 = 30$ cm; $d_2 = 15$ cm; $S_m = 0.6$; $x = 30$ cm; $h_L = 0.2\dfrac{V_1^2}{2g}$



Applying energy equation between main and throat

$$\frac{p_1}{\rho g}+\frac{V_1^2}{2g}+z_1 = \frac{p_2}{\rho g}+\frac{V_2^2}{2g}+z_2+h_L$$

$$\left(\frac{p_1}{\rho g}+z_1\right)-\left(\frac{p_2}{\rho g}+z_2\right) = \frac{V_2^2}{2g}+h_L-\frac{V_1^2}{2g} \quad \text{...(i)}$$

The L.H.S. of this expression gives the reading of manometer

∴ Convert the reading of given liquid in terms of water.

$$h = x\left(1-\frac{S_m}{S_w}\right) = 30\left(1-\frac{0.6}{1}\right) = 30 \times 0.4 = 12 \text{ cm} = 0.12 \text{ m}$$

$$\therefore \quad \left(\frac{p_1}{\rho g}+z_1\right)-\left(\frac{p_2}{\rho g}+z_2\right) = 0.12$$

From equation (i)

$$0.12 = \frac{V_2^2}{2g}+0.2\frac{V_1^2}{2g}-\frac{V_1^2}{2g}$$

$$\therefore \quad V_2^2 - 0.8\, V_1^2 = 0.12 \times 2 \times 9.81 = 2.3544 \quad \text{...(ii)}$$

$$\therefore \quad A_1V_1 = A_2V_2$$

$$\frac{\pi}{4}(30)^2 \cdot V_1 = \frac{\pi}{4}(15)^2 \cdot V_2$$

$$4\, V_1 = V_2$$

substitute $4V_1 = V_2$ in equation (i)

$$(4\, V_1)^2 - 0.8\, V_1^2 = 2.3544$$

$$V_1 = 0.3936 \text{ m/s}$$

Discharge: $$Q = A_1V_1 = \frac{\pi}{4}(0.3)^2 \times 0.3936$$

$$= 0.02782 \text{ m}^3\text{/s} = \mathbf{27.82\ l/s}$$

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