CLASS TEST

Sl. : 01SKME_JKLMNOP_100925

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HYDRAULIC MACHINE

MECHANICAL ENGINEERING

Date of Test : 10/09/2025

ANSWER KEY

1.	(b)	7.	(c)	13.	(b)	19.	(c)	25.	(a)
2.	(a)	8.	(d)	14.	(c)	20.	(a)	26.	(b)
3.	(a)	9.	(b)	15.	(d)	21.	(a)	27.	(b)
4.	(d)	10.	(b)	16.	(b)	22.	(d)	28	(c)
5.	(c)	11.	(b)	17.	(a)	23.	(a)	29.	(b)
6.	(a)	12.	(a)	18.	(a)	24.	(d)	30.	(b)

DETAILED EXPLANATIONS

1. (b)

$$\left(\frac{H}{D^2N^2}\right)_m = \left(\frac{H}{D^2N^2}\right)_p$$

$$\Rightarrow \quad \frac{30}{(1)^2 \times N^2} = \frac{20}{(3)^2 \times (600)^2}$$

$$N^2 = \frac{30 \times 3^2 \times 600^2}{20}$$

$$N = 2204.54 \text{ rpm}$$

2. (a)

$$\text{Maximum height attained} = \frac{u^2 \sin^2 \alpha}{2g} = \frac{18^2 \times (\sin 60)^2}{2 \times 9.81} = 12.38 \text{ m}$$

3. (a)

$$(F_r)_m = (F_r)_p$$

$$\left(\frac{V^2}{Lg}\right)_m = \left(\frac{V^2}{Lg}\right)_p$$

$$V_m = V_p\sqrt{\frac{L_m}{L_p}}$$

$$V_m = \frac{1}{\sqrt{36}} = \frac{1}{6} = 0.16 \text{ m/s}$$

4. (d)

Work done by ject on series of plates per second,

$$= F_x \times u$$

$$= \rho AV(V - u) \cdot u \qquad [\text{Where } F_x = \text{Force in } x \text{ direction}]$$

Kinetic energy of jet per second,

$$= \frac{1}{2}\text{mV}^2 = \frac{1}{2}\rho AV \cdot V^2 = \frac{1}{2}\rho AV^3$$

$$\text{Efficiency of jet} = \frac{\rho AV(V-u)\cdot u}{\frac{1}{2}\rho AV^3} = \frac{2(V-u)\cdot u}{V^2}$$

5. (c)

- Specific speed of turbine, $N_s = \dfrac{N\sqrt{P}}{H^{5/4}}$
- Specific speed of pump, $N_s = \dfrac{N\sqrt{Q}}{H^{3/4}}$

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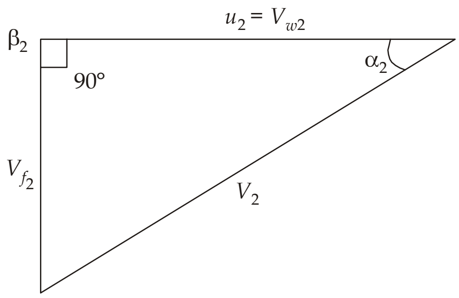
S.No.	Turbine	Specific speed
1.	Pelton - Single jet - Multijet jet	Upto 30 30 - 60
2.	Francis	60 - 300
3.	Propellar	300 - 600
4.	Kaplan	600 - 1000

- Draft tube is required at the exit of reaction turbine.
- Screw pump is used for pumping viscous oil.

6. (a)



From the outlet velocity triangle

$$V_{w_2} = V_2 \cos \alpha_2 = u_2$$
$$u_2 = \pi D_2 N/60 = \pi \times 0.3 \times 1450/60 = 22.78 \text{ m/s}$$

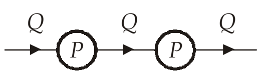
Manometric efficiency,

$$\eta_H = \frac{gH}{u_2 V_{w_2}} = \frac{gH}{u_2^2} \qquad [H = \text{net head developed}]$$

$$0.82 = \frac{9.81 \times H}{(22.78)^2}$$

$$H = 43.36 \text{ m}$$

7. (c)



Pumps in series

$$Q = Q_1 = Q_2 ...$$
$$\text{and } H = H_1 + H_2 ...$$

8. (d)

Depending upon the pump, a critical cavitation number of $\sigma < \sigma_c$ will result in cavitation and cause severe reduction in pump efficiency. Hence for operational purpose it should be seen that $\sigma \geq \sigma_c$

i.e NPSH $\geq \sigma_c H$

Hence minimum NPSH $= \sigma_c \times H$

9. (b)

Power required to run the pump = $P = \rho Q g h$

$$= 1000 \times (20 \times 10^{-3}) \times 9.81 \times 35 = 6.867 \text{ kW}$$

10. (b)

- Rotodynamics machines are those whose functioning depends on the principle of fluid dynamics.
- Positive displacement machines are those whose functioning depends on the change of volume of certain amount of fluid within the machine.

11. (b)

Applying energy equation,

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_j}{\rho g} + \frac{V_j^2}{2g} + Z_j + h_L$$

$$\Rightarrow \quad 0 + 0 + 1670 = 0 + \frac{V_j^2}{2g} + 1000 + h_L$$

$$A_{\text{penstock}} \times V_{\text{penstock}} = A_{\text{jet}} \times V_j$$

$$\Rightarrow \quad \frac{\pi}{4} D^2 \times V_P = \frac{\pi}{4} d_j^2 \times V_j$$

$$\Rightarrow \quad V_p = \left(\frac{d_j}{D}\right)^2 \times V_j = \left(\frac{0.18}{1}\right)^2 V_j = 0.0324 V_j$$

$$h_L = \frac{f L V_P^2}{D \times 2g} = \frac{0.015 \times 6000 \times (0.0324)^2 \times V_j^2}{1 \times 2 \times 9.81}$$

$$= 4.815 \times 10^{-3} \; V_j^2$$

From energy equation,

$$1670 = \frac{V_j^2}{2g} + 1000 + 4.815 \times 10^{-3} V_j^2$$

$$670 = 0.0557 V_j^2$$

$$V_j = 109.675 \text{ m/s}$$

$$V_{\text{bucket}} = \frac{V_j}{2} = \frac{109.675}{2} = 54.8 \text{ m/s}$$

$$V_{\text{bucket}} = 54.8 = \frac{\pi D N}{60}$$

$$N = \frac{54.8 \times 60}{\pi \times 3}$$

$$= 348.86 \text{ rpm} \simeq 349 \text{ rpm}$$

12. (a)

Given: Weight flow rate = 230 N/s

Mass flow rate, $\dot{m} = \frac{w}{g} = \frac{230}{9.81} = 23.445 \text{ kg/s}$

So, discharge, $\dot{Q} = \frac{w}{\rho g} = \frac{230}{10^3 \times 9.81} = 0.02345 \text{ m}^3/\text{s}$

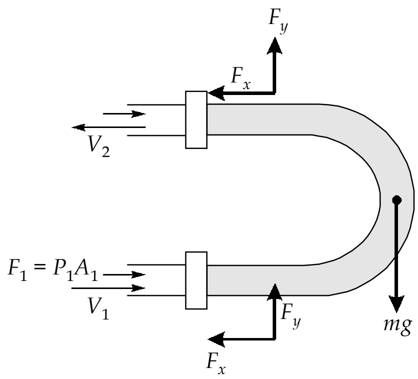
So, average velocity through pipe of water,

$$\Rightarrow \quad V = \frac{Q}{A} = \frac{0.02345}{\frac{\pi}{4}(0.05)^2} = 11.94 \text{ m/s}$$

As per second law of motion

$$\Rightarrow \quad \Sigma F_{ext} = \dot{m}\left(V_f - V_i\right)$$

Along x-direction:



$$-F_x + \left(P_1 - P_a\right) \times A_1 + \left(P_2 - P_a\right) \times A_2 = m_2V_2 - m_1V_1$$

$$-F_x = 23.44 \times (-11.94 - 11.94) - \left[(165 - 101) \times 10^3 + (134 - 101) \times 10^3\right] \times \frac{\pi}{4} \times 0.05^2$$

$F_x = 750.206 \text{ N } (\leftarrow)$

Along y-direction

$$\Sigma F_y = \dot{m}\left(V_{2y} - V_{1y}\right)$$

$$\Rightarrow \quad F_y - m_{\text{fluid}} \times g = 0$$

$$F_y = m_{\text{fluid}} \times g$$

$$= \frac{\pi}{4} \times (0.05)^2 \times (7.5) \times 1000 \times 9.81$$

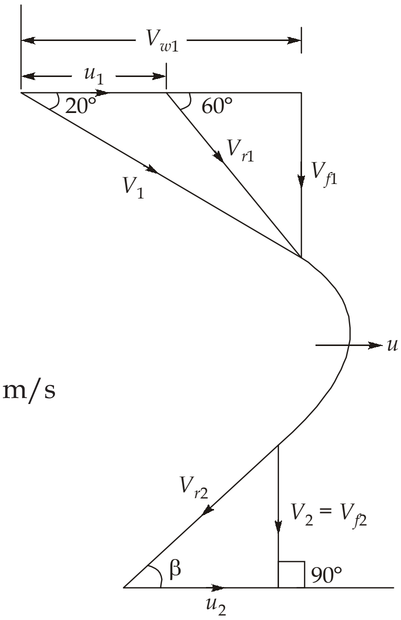
$$F_y = 144.46 \text{ N } (\uparrow)$$

So, total force that flange has to withstand is

$$F = \sqrt{F_x^2 + F_y^2} = \sqrt{(750)^2 + (144.46)^2}$$

$$= 763.78 \text{ N} \simeq 764 \text{ N}$$

13. (b)



$$u_1 = \frac{\pi DN}{60} = \frac{\pi \times 1.2 \times 450}{60} = 9\pi \text{ m/s}$$

From inlet velocity triangle,

$$\frac{V_1}{\sin 120°} = \frac{u_1}{\sin 40°}$$

$$V_1 = 9\pi \times \frac{\sin 120°}{\sin 40°} = 38 \text{ m/s}$$

$$V_u = V_1 \cos 20° = 35.7 \text{ m/s};$$

$$V_{w2} = 0 \text{ (Radial exit)}$$

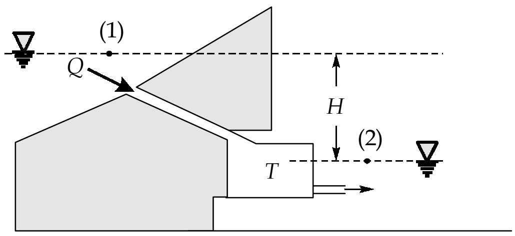
$$V_{f1} = V_1 \sin 20° = 38 \times \sin 20° = 12.99 \approx 13 \text{ m/s}$$

So, Power developed $= \rho Q(u_1 V_{w1} - u_2 V_{w2})$

$= 10^3 \times (0.4 \times 13) \times (9\pi) \times 35.7$

$= 5250$ kW

14. (c)



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

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + H = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + 0 + h_f + h_{turbine}$$

$$P_1 = P_2 = P_{atm}$$

$$V_1 \simeq V_2 \simeq 0$$

Now, $h_{turbine} = H - h_f = H - CQ^3$

So, Power, $P = \rho g Q h_{turbine} = \rho g Q(H - CQ^3)$

For maximum power,

$$\frac{\partial P}{\partial Q} = \rho g H - 4\rho g Q^3 C = 0$$

$$Q = \sqrt[3]{\frac{H}{4C}} \text{ or } \left(\frac{H}{4C}\right)^{1/3}$$

and

$$P_{max} = \rho g Q\left(H - C\left\{\left(\frac{H}{4C}\right)^{1/3}\right\}^3\right)$$

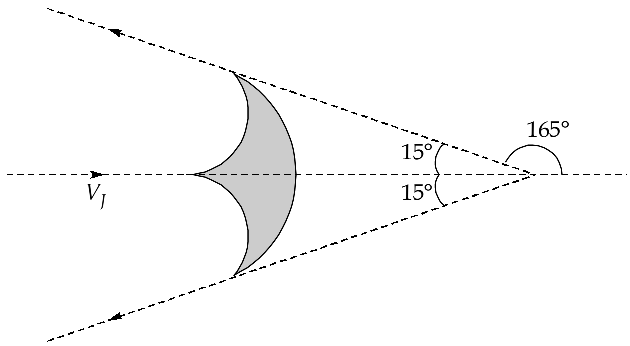
$$P_{max} = \rho g Q\left(H - \frac{H}{4}\right) = \frac{3}{4}\rho g Q H$$

15. (d)

Discharge from jet (Q) $= \dfrac{6.116}{3600} = 1.6989 \times 10^{-3} \text{ m}^3/\text{s}$

Now, velocity of jet $= \dfrac{Q}{\text{Area of jet}}$

$$V_J = \frac{1.6989 \times 10^{-3}}{\frac{\pi}{4}(20 \times 10^{-3})^2} = 5.40 \text{ m/s}$$



For theoretical force it is assumed that velocity is not reduced as water passes around each cup,

$$\therefore \quad F_{\text{theoretical}} = \dot{m}(\Delta V) = (\rho \dot{Q})(V_J(1 - \cos 165°))$$

$$= 1000 \times 1.6989 \times 10^{-3}(5.40(1 - \cos 165°)) = 18.035 \text{ N}$$

$$\therefore \quad \frac{\text{Actual force}}{\text{Theoretical force}} = \frac{15}{18.035} = 0.8316$$

If V_1 is the actual velocity at outlet,

Now, $$\text{Actual force} = \dot{m}(\Delta V_a)$$

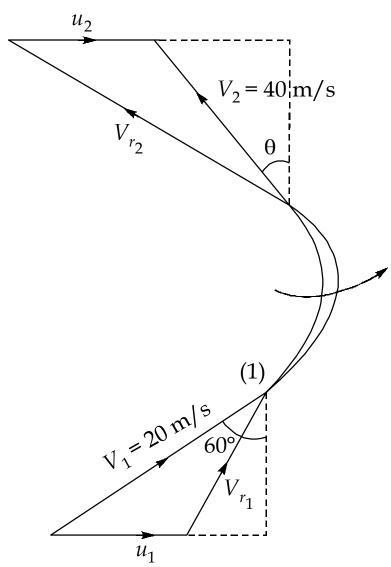
$$15 = \rho\dot{Q}(V_j - V_1 \cos(165°))$$

$$15 = 1000 \times 1.6989 \times 10^{-3}(5.40 - V_1(\cos 165°))$$

$$V_1 = 3.55 \text{ m/s}$$

$$\therefore \quad \frac{\text{Outlet velocity}}{\text{Inlet velocity}} = \frac{3.55}{5.40} = 0.6574$$

16. (b)



$$R_1 = 2 \text{ m}, R_2 = 1 \text{ m}$$

$\because$ Torque = 0

$$\Rightarrow \quad T = \dot{m}(V_{w_2}R_2 - V_{w_1}R_1) = 0$$

$$\Rightarrow \quad V_{w_2}R_2 = V_{w_1}R_1 \quad \text{...(i)}$$

Now, from velocity triangles,

$$V_{w_1} = V_1 \sin 60° = 20\left(\frac{\sqrt{3}}{2}\right) = 10\sqrt{3}$$

and $$V_{w_2} = V_2 \sin\theta = 40\sin\theta$$

Putting values of V_{w_1} and V_{w_2} in equation (i), we get

$$(40\sin\theta)(1) = 10\sqrt{3}(2)$$

$$\sin\theta = \frac{20\sqrt{3}}{40} = \frac{\sqrt{3}}{2}$$

$$\theta = \sin^{-1}\left(\frac{\sqrt{3}}{2}\right) = 60°$$

17. (a)

Given: $Q = 0.05\ m^3/s$, $H = 30$ m, $d = 15$ cm = 0.15 m, $l = 150$ m, $f' = 0.014$, $\eta_o = 0.75$.

$$\therefore \quad Q = A \times V$$

$$\Rightarrow \quad V = 2.83\ m/s$$

Manometric head,

$$H_m = H + \frac{4fLV^2}{2gD} + \frac{V^2}{2g} = 30 + \frac{4 \times 0.014 \times 150 \times (2.83)^2}{2 \times 9.81 \times 0.15} + \frac{(2.83)^2}{2 \times 9.81}$$

$$= 53.267\ m$$

$$\therefore \quad \eta_o = \frac{\text{Water power}}{\text{Shaft power}}$$

$$\text{or,} \quad 0.75 = \frac{\rho g Q H_m}{SP}$$

$$SP = \frac{1000 \times 9.81 \times 0.05 \times 53.267}{0.75} = 34.84\ kW$$

18. (a)

$$\text{Power} = T_1 \omega_1$$

$$75000 = T_1 \times \frac{2\pi \times 210}{60}$$

$$T_1 = 3410.463\ Nm$$

As we know,

$$\text{Unit torque, } T_u = \frac{T}{H}$$

$$\Rightarrow \quad \frac{T_2}{T_1} = \frac{H_2}{H_1}$$

$$\frac{T_2}{3410.463} = \frac{10}{5}$$

$$T_2 = 6820.926\ Nm$$

19. (c)

$$\text{Manometric efficiency, } \eta_m = \frac{gH_m}{V_{w2}u_2}$$

$$\Rightarrow \quad 0.75 = \frac{g \times 30}{V_{w2}u_2}$$

$$\text{Total head, } \frac{V_{w2}u_2}{g} = \frac{30}{0.75} = 40\ m$$

Pressure rise through the impeller $\left(\frac{p_2 - p_1}{\rho g}\right)$ is 65% of the total head developed by the pump.

$$\text{Thus, } \frac{p_2 - p_1}{\rho g} = 0.65 \times \frac{V_{w2}u_2}{g} = 0.65 \times 40 = 26\ m$$

Energy equation between the inlet and outlet tip of the impeller,

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + \frac{V_{w2}u_2}{g} + z_1 = \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

$$\Rightarrow \quad \frac{p_2 - p_1}{\rho g} = \frac{V_f^2}{2g} + \frac{V_{w2}u_2}{g} - \frac{V_2^2}{2g} \qquad (\because z_1 = z_2;\ V_1 = V_f)$$

$$\Rightarrow \quad 26 = \frac{3^2}{2 \times 9.81} + 40 - \frac{V_2^2}{2g}$$

$$\Rightarrow \quad \frac{V_2^2}{2g} = \frac{3^2}{2 \times 9.81} + 40 - 26$$

$$V_2 = 16.8428 \text{ m/s} = \sqrt{V_{f2}^2 + V_{w2}^2} = \sqrt{3^2 + V_{w2}^2}$$

$$V_{\omega 2} = 16.5735 \text{ m/s}$$

20. (a)

Given,
$H = 24.5$ m
$Q = 10.1\ \text{m}^3/\text{s}$
$N = 4$ rev/sec $= 4 \times 60 = 240$ rpm
$\eta_0 = 0.90$

Power generated

$= \rho g H \times 0.9 \times Q$
$= 1000 \times 9.81 \times 10.1 \times 24.5 \times 0.9 = 2184.74$ kW

$$N_S = \frac{N\sqrt{P}}{H^{5/4}} = \frac{240\sqrt{2184.7}}{(24.5)^{5/4}} = 205.80$$

Types of turbine	**Specific speed (S.I.)**
Pelton wheel with single jet	8.5 to 30
Pelton wheel with two or more jets	30 to 51
Francis turbine	51 to 225
Kaplan or propeller turbine	255 to 860

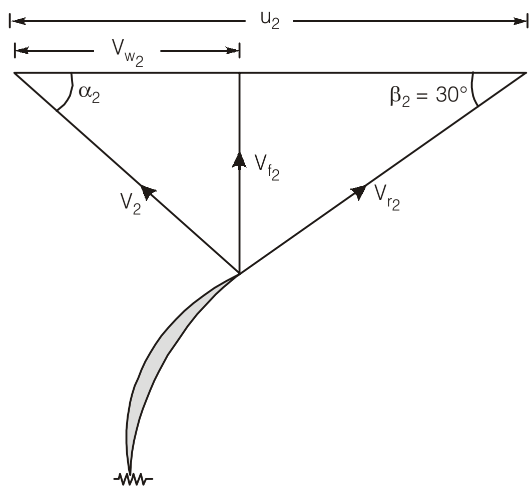
Hence, turbine is Francis.

21. (a)

At the outlet
$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.30 \times 1200}{60} = 18.85 \text{ m/s}$$

$V_{f2} = 2.0$ m/s and $\beta_2 = 30°$

From the outlet velocity triangle,



$$\tan \beta_2 = \frac{V_{f_2}}{u_2 - V_{w_2}}$$

$$\tan 30° = \frac{2.0}{18.85 - V_{w_2}}$$

$$18.85 - V_{w_2} = 3.464; \text{ and hence } V_{w_2} = 15.386 \text{ m/s}$$

Manometric efficiency

$$\eta_m = \frac{gH}{u_2 V_{w_2}}$$

Head developed, $$H = \eta_m \frac{u_2 V_{w_2}}{g} = \frac{0.85 \times 18.85 \times 15.386}{9.81} = 25.13 \text{ m}$$

22. (d)

Net available head, $H = 500\ (1 - 0.05) = 475$ m

$$\text{Power per jet} = \frac{1500}{2} = 750 \text{ kW}$$

$$\text{Specific speed } (N_s) = \frac{N\sqrt{P}}{H^{5/4}}$$

$$\Rightarrow \quad 15 = \frac{N\sqrt{750}}{(475)^{5/4}}$$

$$\Rightarrow \quad N = 1214.58 \text{ rpm}$$

23. (a)

$$\sigma_c = \frac{(\text{NPSH})_{\text{min}}}{H}$$

$$0.12 = \frac{(\text{NPSH})_{\text{min}}}{30}$$

$$\text{Minimum NPSH} = 3.6 \text{ m}$$

$$\text{NPSH} = \frac{(P_{\text{atm}})_{\text{abs}}}{\gamma} - \frac{P_v}{\gamma} - z_s - h_L$$

where, z_s = Elevation of the pump above the rump water surface, $(z_s)_{\max}$ corresponds to σ_c.

Hence, $$(z_s)_{\max} = \frac{(P_{\text{atm}})}{\gamma} - \frac{P_v}{\gamma} - h_L - (\text{NPSH})_{\text{min}}$$

$$= \frac{96.0}{9.79} - \frac{3.0}{9.79} - 0.3 - 3.6 = 5.6 \text{m}$$

24. (d)

$$N_S = \frac{N\sqrt{P}}{(H)^{5/4}} = \frac{100\sqrt{6400}}{(10)^{5/4}} = 450$$

$$N_S(450) > 250$$

Turbine is Kaplan.

25. (a)

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

$$0+0+95 = 0+\frac{(1.5)^2}{2\times 10}+0+20+h_T$$

$$h_T = 95 - 0.1125 - 20 = 74.8875 \text{ m}$$

The work done by the fluid on a turbine is positive. The power extracted is

$$P = \rho g Q h_T = 1000 \times 10 \times 25 \times 74.8875$$
$$= 18.72185 \text{ MW}$$

26. (b)

The force on the jet is upward and to the left. The leftward component is supplied by the compression spring.

$$F_x = \rho Q[(V_x)_2 - (V_x)_1]$$
$$= 1000\times\left(\frac{\pi}{4}\times(0.035)^2\times 20\right)\times(20\cos 45^\circ - 20)$$
$$= -112.7185 \text{ N}$$

By Hooke's law, $F_x = -k\Delta x$

$$-112.7185 = -1.8\times 1000\,(\Delta x)$$
$$\Delta x = 62.62 \text{ mm} = 6.262 \text{ cm}$$

27. (b)

Hydraulic efficiency, $\eta_h = \dfrac{v_{\omega 1}u_1 - v_{\omega 2}u_2}{gH}$ [1, 2 → Inlet and outlet respectively]

$$0.83 = \frac{4.25\sqrt{H}u_1 - 0.35\sqrt{H}u_2}{9.81H}$$

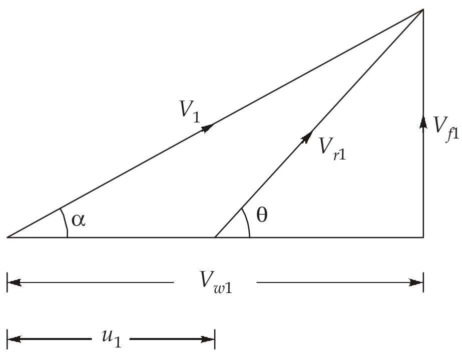
$$u_1 = u$$

⇒ $u_2 = 0.7u$

$$0.83 = \frac{4.25\sqrt{H}u - 0.35\sqrt{H}(0.7)u}{9.81H}$$

$$u = \frac{0.83\times 9.81\sqrt{H}}{4.25-0.35\times 0.7} = 2.03\sqrt{H} = u_1$$

$$u_2 = 1.423\sqrt{H}$$



From inlet velocity triangle, we have

$$\tan\theta = \frac{V_{f1}}{(V_{w1}-u_1)} = \frac{1.05\sqrt{H}}{4.25\sqrt{H}-2.03\sqrt{H}} = 0.47297$$

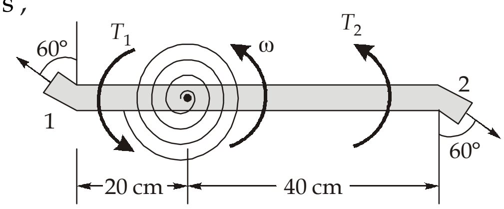
$$\theta = 25.31^\circ$$

28 (c)

$$\text{Torque, } T_1 = -\rho Q_n\, r_1(u_1 + v_1\cos\beta), \qquad u_1 = \omega r_1$$

$$Q_n = \frac{1.2\times10^{-3}}{2} = 0.6\times10^{-3}\ \text{m}^3/\text{s},$$

$$r_1 = 0.2\ \text{m},$$



$$V_1 \Rightarrow V_2 = \frac{1.2\times10^{-3}\times\frac{1}{2}}{\frac{\pi}{4}\times0.008^2} = 11.94\ \text{m/s}$$

$$\beta_1 = 120°$$

$$T_1 = -10^3\times0.6\times10^{-3}\times0.2\times[\omega\times0.2 + 11.94\cos120°]$$

$$T_1 = -0.12\,[0.2\omega - 5.97]$$

and
$$T_2 = -\rho Q_n r_2[u_2 + V_2\cos\beta_2]$$

$$= -10^3\times0.6\times10^{-3}\times0.4\,[\omega\times0.4 + 11.94\cos120°]$$

$$= -0.24[0.4\omega - 5.97]$$

$$\text{Total torque, } T = T_1 + T_2 = -\{0.12(0.2\omega - 5.97) + 0.24(0.4\omega - 5.97)\}$$

$$= -(0.024\omega - 0.7164 + 0.096\omega - 1.4328)$$

$$T = -(0.12\omega - 2.1492)$$

Now,
$$\omega = \frac{2\pi\times100}{60} = 10.47\ \text{rad/s}$$

$$T = 2.1492 - 0.12\times10.47 \Rightarrow 0.8926\ \text{N-m}$$

$$\theta = \frac{0.8926\ (\text{N}-\text{m})}{2(\text{N}-\text{m/rad})} = 0.4463\ \text{rad/s} = 25.57°$$

29. (b)

Power developed $P \propto Q \propto d^2$ where, d = diameter of the jet

Required jet diameter,

$$\frac{P_1}{P_2} = \frac{d_1^2}{d_2^2}$$

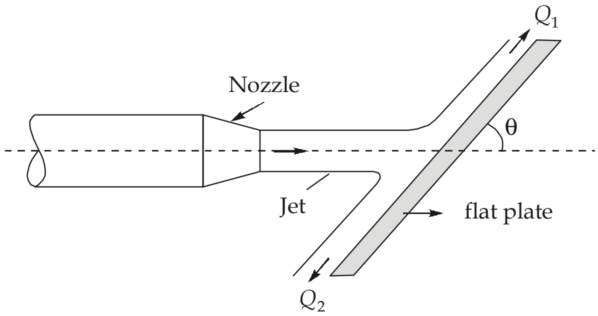
$$\frac{P}{(1-0.64)P} = \frac{(150)^2}{d_2^2}$$

$$\frac{1}{0.36} = \left(\frac{150}{d_2}\right)^2$$

$$d_2 = 150\sqrt{0.36}$$

$$d_2 = 90\ \text{mm}$$

30. (b)



Since the plate surface is smooth, there can be no force exerted by the plate on the fluid jet in the tangential direction.

$$F_t = \rho Q_1 v - \rho Q_2 v - \rho Q v \times \cos\theta = 0$$

$$Q_1 - Q_2 = Q\cos\theta \quad \text{...(1)}$$

$$Q = Q_1 + Q_2 \quad \text{...(2)}$$

Solving eq. (1) and (2), one jets

$$Q_1 = \frac{Q}{2}(1+\cos\theta)$$

$$Q_2 = \frac{Q}{2}(1-\cos\theta)$$

$$\frac{Q_1}{Q_2} = \frac{1+\cos\theta}{1-\cos\theta}$$

if θ = 26°

$$= \frac{1+\cos 26°}{1-\cos 26°}$$

$$\frac{Q_1}{Q_2} = 18.76$$

■■■■