CLASS TEST

SL. : 01SP_ME_HIJKLMN_230824

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FLUID MECHANICS

MECHANICAL ENGINEERING

Date of Test : 23/08/2024

ANSWER KEY

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

DETAILED EXPLANATIONS

1. (c)

Vorticity, $\Omega = 2\omega_z = \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) = \frac{\partial}{\partial x}(4xy) - \frac{\partial}{\partial y}(xy^2)$

$\Omega = 4y - 2xy$

At (1, 2), $\Omega_{(1,2)} = 4 \times 2 - 2 \times 1 \times 2 = 8 - 4 = 4\text{s}^{-1}$

2. (c)

As per given data,

Gauge pressure = 350 kPa

Barometric reading = 740 mm Hg

$\rho_{Hg} = 13590 \text{ kg/m}^3$

The atmospheric (or barometric) pressure can be expressed,

$P_{atm} = \rho g h = 13590 \times 9.81 \times 740 \times 10^{-3}$

$= 98.655$ kPa

Then the absolute pressure in the tank is

$P_{abs} = P_{gauge} + P_{atm} = 350 \text{ kPa} + 98.655 \text{ kPa}$

$P_{abs} = 448.655$ kPa

3. (d)

Continuity equation, $Q_1 = Q_2 + Q_3$

Now, $Q_2 = A_2V_2 = 0.008V_2$

$Q_3 = A_3V_3 = 0.004V_3 = 0.004 \times 2V_2$ [Given, $V_3 = 2V_2$]

$= 0.008V_2$

Now, $Q_2 = Q_3$

$\therefore$ Discharge at point 3, $Q_3 = \frac{Q_1}{2} = \frac{0.3}{2} = 0.15 \text{ m}^3/\text{s}$

4. (d)

By Newton's law of viscosity,

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

$$0.5 = \mu \times \frac{1-0}{(0.010-0)}$$

$$\mu = 0.005 = 5 \times 10^{-3} \text{ Ns/m}^2.$$

5. (d)

Total energy of a flowing fluid can be represented in terms of head which is given by

$$\left(\frac{P}{\rho g} + \frac{V^2}{2g} + Z = \text{Constant}\right).$$

Piezometric head is the sum of pressure head and datum head and it is given by $\left(\frac{P}{\rho g}+Z\right)$.

The pressure at any point in a static fluid is obtained by hydrostatic law which is given by $P = -\rho g h$, where h is the height of the point from the free surface. As we go down h is negative so the pressure gets increased and datum gets decreased.
Therefore, Piezometric head remains constant at all points in the liquid.

6. **(b)**
As for laminar flow,

Boundary layer thickness $(\delta) \propto \frac{1}{\sqrt{\text{Re}}}$

As the free stream velocity, $\uparrow\uparrow$, $\delta\downarrow\downarrow$ $\quad \because \text{Re} = \frac{\rho VD}{\mu}$

For turbulent flow,

Boundary layer thickness $(\delta) \propto \frac{1}{(\text{Re})^{1/5}}$

As the free stream velocity $\uparrow\uparrow$, $\delta\downarrow\downarrow$ and it also depending on the kinematic viscosity $\delta\uparrow\uparrow$ as kinematic viscosity $(\nu)\uparrow$.

7. **(c)**
We know,

$$C_d = C_C \times C_V$$
$$= 0.95\times\left[\frac{0.180}{0.200}\right]^2 = 0.769$$

8. **(c)**
As we know, the average velocity in fully developed laminar pipe flow is

$$V_{\text{avg}} = \frac{1}{2}V_{\max}$$
$$V_{\max} = 2V_{\text{avg}} = 2 \times 2 = 4.0 \text{ m/s}$$

9. **(c)**

10. **(a)**

11. **(a)**
Applying Bernoulli's equation between the two reservoirs, we get

$$12.5 = 0.5\frac{V^2}{2g}+\frac{fLV^2}{2gD}+\frac{V^2}{2g}$$

$$\Rightarrow \quad 12.5 = \frac{V^2}{2g}\left[1.5+\frac{fL}{D}\right]$$

$$\Rightarrow \quad 12.5 = \frac{V^2}{2\times 10}\left[1.5+\frac{0.04\times 1000}{0.5}\right]$$

$$\Rightarrow \quad 12.5 = \frac{V^2}{20} \times 81.5$$

$$\Rightarrow \quad V = 1.75 \text{ m/s}$$

12. (d)

As, Drag force, $F = \rho V^2 L^2$

$$\frac{F_m}{F_p} = \frac{\rho_m V_m^2 L_m^2}{\rho_p V_p^2 L_p^2} \quad \text{... (i)}$$

As, $Re_m = Re_p$

$$\frac{\rho_m V_m L_m}{\mu_m} = \frac{\rho_p V_p L_p}{\mu_p}$$

$$\frac{V_m}{V_p} = \frac{L_p}{L_m} \quad \text{... (ii)}$$

Using equation (i) and (ii)

$$\frac{F_m}{F_p} = 1$$

$$\Rightarrow \quad F_p = 300 \text{ N}$$

13. (b)

Volume of the cube, $V = 125$ mL

$$a^3 = 125 \times 10^{-3} \times 10^{-3} \text{ m}^3$$

$$a = 0.05 \text{ m}$$

Pressure at bottom surface,

$$P_{bottom} = P_{atm} + (\rho g h)_{oil} + [\rho g(h + a)]_{water}$$

$$= 101 \times 10^3 + (800 \times 9.81 \times 0.5) + [1000 \times 9.81 \times (0.3 + 0.05)]$$

$$P_{bottom} = 108357.5 \text{ Pa}$$

$$F_{bottom} = P_{bottom} \times A$$

$$= 108357.5 \times 0.05^2 = 270.89 \text{ N}$$

14. (a)

$$\tau = \mu \frac{du}{dx} = \mu(4 - 4x)$$

$$= 2(4 - 4 \times 1) = 0 \text{ N/m}^2$$

15. (a)

Pressure gradient $\left(\frac{\partial p}{\partial x}\right)$,

$$\therefore \quad U_{max} = \frac{-1}{8\mu}\left(\frac{\partial p}{\partial x}\right) \times t^2$$

$$\Rightarrow \quad 3 = \frac{-1}{8 \times 0.02}\left(\frac{\partial p}{\partial x}\right) \times (0.015)^2$$

$$\Rightarrow \qquad \left(\frac{\partial p}{\partial x}\right) = \frac{-3\times 8\times 0.02}{(0.015)^2} = -2133.33 \text{ N/m}^2/\text{m}$$

16. (c)

Given: $u = 2xy^2$, $v = 3\,xyt$

$$a_x = u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + \frac{\partial u}{\partial t} = 2xy^2 \times 2y^2 + 3xyt \times 4xy + 0$$

At (1, 1) and t = 1s, $\quad a_x = 2 \times 2 + 12 = 16 \text{ m/s}^2$

$$a_y = u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + \frac{\partial v}{\partial t} = 2xy^2 \times 3yt + 3xyt \times 3xt + 3xy$$

At (1, 1) and t = 1s, $\quad a_y = 6 + 9 + 3 = 18 \text{ m/s}^2$

$$a = \sqrt{a_x^2 + a_y^2} = \sqrt{16^2 + 18^2} = 24.08 \text{ m/s}^2 \simeq 24.1 \text{ m/s}^2$$

17. (a)

Radius: $\quad r = 10$ mm

$\therefore$ Diameter: $\quad d = 2r = 2 \times 10 = 20$ mm $= 0.02$ m

$$m = 72 \text{ kg/hr} = \frac{72}{3600} = 0.02 \text{ kg/s}$$

$$\mu = 0.002 \text{ kg/ms}$$

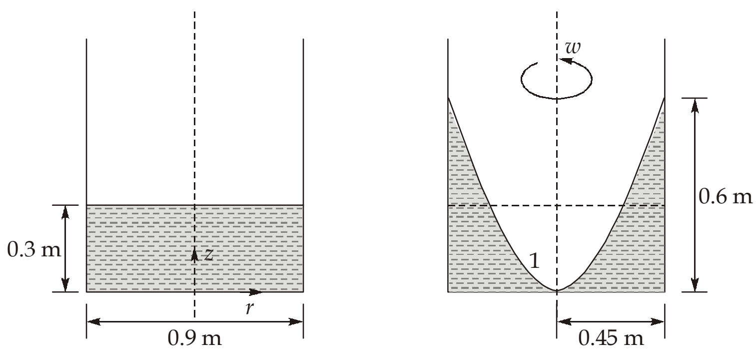
Reynolds number: $\text{Re} = \dfrac{\rho V d}{\mu}$

From continuity equation, $m = \rho A V$

or $\quad V = \dfrac{m}{\rho A} = \dfrac{m}{\frac{\rho \pi d^2}{4}} = \dfrac{4m}{\rho \pi d^2}$

$$\therefore \qquad \text{Re} = \frac{\rho d}{\mu} \times \frac{4m}{\rho \pi d^2} = \frac{4m}{\pi \mu d} = \frac{4 \times 0.02}{\pi \times 0.002 \times 0.02} = 636.62$$

18. (a)



Initial conditions

Final condition when bottom starts exposing

Apply forced vortex motion equation at points (1) and (2)

$$\frac{P_1}{\rho g} - \frac{(V_1)^2}{2g} + z_1 = \frac{P_2}{\rho g} - \frac{(V_2)^2}{2g} + z_2$$

At point 1, $P_1 = P_{atm} \Rightarrow P_{gauge} = 0$

$V_1 = \omega R_1 = 0$

$z_1 = 0$

At point, $P_2 = P_{atm} \Rightarrow P_{gauge} = 0$

$z_2 = 0.6$

Therefore, $$0 - 0 + 0 = 0 - \frac{(\omega R_2)^2}{2g} + 0.6$$

$$\Rightarrow \quad \frac{\omega^2 (0.45)^2}{2 \times (9.81)} = 0.6$$

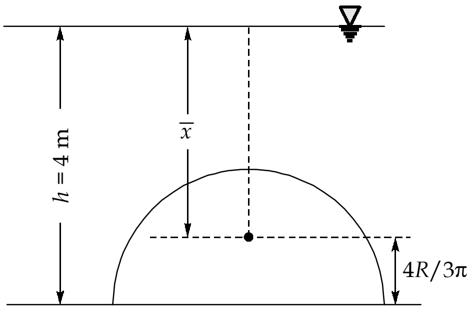
$$\Rightarrow \quad \omega = 7.62 \text{ rad/s}$$

19. (d)

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

20. (c)

Refer figure,



Depth of centre of gravity,

$$\bar{x} = h - \frac{4R}{3\pi} = 4 - \frac{4 \times 1}{3 \times \frac{22}{7}} = 3.576 \text{ m}$$

21. (c)

As

In x-direction, $$u = \frac{-x}{x^2 + y^2}$$

$$\frac{\partial u}{\partial x} = \frac{-(x^2 + y^2) + 2x^2}{(x^2 + y^2)^2} = \frac{x^2 - y^2}{(x^2 + y^2)^2}$$

and,

In y-direction, $$v = \frac{-y}{x^2 + y^2}$$

$$\frac{\partial v}{\partial y} = \frac{-(x^2 + y^2) + 2y^2}{(x^2 + y^2)^2} = \frac{(y^2 - x^2)}{(x^2 + y^2)^2}$$

Continuity equation

$$\Rightarrow \quad \frac{\partial u}{\partial y} + \frac{\partial v}{\partial y} = 0$$

22. (b)

A velocity potential is a scalar function used in potential flow theory.

23. (b)

$$F_v = \gamma \times \frac{1}{2} \times \frac{\pi D^2}{4} \times 1$$

$$F_v = 10 \times \frac{1}{2} \times \frac{\pi (2)^2}{4} \times 1 = 15.7 \text{ kN/m}$$

24. (b)

$$D_i = 6 \times 10^{-2} \text{ m}$$
$$D_f = 6.9 \times 10^{-2} \text{ m}$$

As soap bubble has two surfaces,

Therefore total change in surface area $= 2\left[4\pi\left(R_f^2 - R_i^2\right)\right] = 2\left[\pi\left(D_f^2 - D_i^2\right)\right]$

$= 2\ (0.003647) = 7.294 \times 10^{-3}\ \text{m}^2$

Work input required, $W = \sigma \times \Delta A = 0.039 \times 7.294 \times 10^{-3}$

$= 2.845 \times 10^{-4}$ Joule

25. (b)

Velocity of air in pitot tube is

$$V = c\sqrt{2gh}$$

$$h = x\left(\frac{S_m}{S} - 1\right) = 12 \times 10^{-3}\left(\frac{1}{1.2 \times 10^{-3}} - 1\right)$$

$$h = 9.988 \text{ m}$$

$$V = \sqrt{2 \times 9.81 \times 9.988} \simeq 14 \text{ m/s}$$

26. (b)

Conservation of mass,

$$\dot{m}_{in} - m_{out} = \left.\frac{d\dot{m}}{dt}\right|_{\text{tank}}$$

$$\Rightarrow \quad \rho A V_1 - \rho A V_2 = \rho \times \frac{\pi}{4} D^2 \times \frac{dh}{dt}$$

$$\Rightarrow \quad (0.12)^2 \times [2.5 - 1.9] = (0.75)^2 \times \frac{dh}{dt}$$

$$\Rightarrow \quad \frac{dh}{dt} = 0.01536 \text{ m/s}$$

So, time required to fill remaining tank,

$$t = \frac{1-0.3}{0.01536}s$$

$\Rightarrow$ $$t = 45.57\text{s}$$

27. (c)

Minor loss due to sudden expansion from 6 cm diameter pipe to 12 cm is given by

$$(h_f)_{\text{expansion}} = \frac{V_1^2}{2g}\left[1-\frac{A_1}{A_2}\right]^2$$

$$= \frac{V_1^2}{2g}\times\left[1-\frac{d_1^2}{d_2^2}\right]^2 = \frac{V_1^2}{2g}\times\left(1-\left(\frac{1}{2}\right)^2\right)^2 = \frac{9}{16}\left(\frac{V_1^2}{2g}\right)$$

28. (d)

Projected area $(A_p) = l \times d$

$= 1 \times 0.05 = 0.05\ \text{m}^2$

Total drag, $F_D = C_d \times \frac{1}{2}\rho u_0^2 \times A_p$

$$= 1.25\times\left[\frac{1}{2}\times 1.2\times 0.2^2\right]\times 0.05$$

$= 1.5 \times 10^{-3}$ N

Shear drag $= 0.18\times\left[\frac{1}{2}\times 1.2\times 0.2^2\right]\times 0.05$

$= 0.216 \times 10^{-3}$ N

Total drag = Shear drag + Pressure drag

$1.5 \times 10^{-3} = 0.216 \times 10^{-3}$ + Pressure drag

Pressure drag $= 1.284 \times 10^{-3}$ N

29. (b)

The frontal area of a sphere is $A = \frac{\pi D^2}{4}$.

The drag force acting on the balloon is

$$F_D = C_D A\frac{\rho V^2}{2} = (0.2)\left[\frac{\pi(7)^2}{4}\right]\frac{(1.20)\left(\frac{40\times 5}{18}\right)^2}{2} = 570.14\text{ N}$$

Acceleration in the direction of the winds

$$a = \frac{F_D}{m} = \frac{570.14}{350} = 1.63\text{ m/s}^2$$

30. (c)

As per given data:

$$u^* = \frac{u}{U} \text{ and } y^* = \frac{y}{\delta}$$

$$dy^* = \delta^{-1}\, dy$$

The given parabolic velocity distribution and the expression for the displacement thickness can then be expressed as

$$u^* = 2y^* - y^{*2}, \text{ and } \delta^* = \delta\int_0^1 (1-u^*)\,dy^*$$

Combining these equations gives,

$$\delta^* = \delta\int_0^1 \left(1-2y^*+y^{*2}\right)dy^*$$

$$\delta^* = \delta\left[y^* - y^{*2} + \frac{1}{3}y^{*3}\right]_0^1$$

$$\delta^* = \frac{1}{3}\delta$$

$$\frac{\delta^*}{\delta} = \frac{1}{3}$$

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