CLASS TEST

SL.: 01 PT_ME_ABC_300522

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FLUID MECHANICS

MECHANICAL ENGINEERING

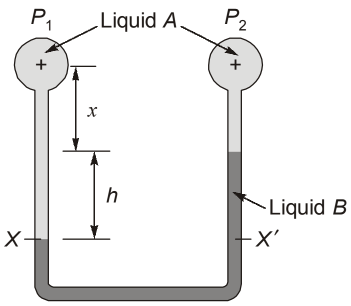
Date of Test : 08/06/2022

ANSWER KEY

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

DETAILED EXPLANATIONS

1. (c)



Taking point X and X' and equating the pressure on both sides

$$P_1 + (h + x) \times 0.88 \times 9.81 \times 10^3 = P_2 + x \times 0.88 \times 9.81 \times 10^3 + h \times 2.95 \times 9.81 \times 10^3$$

$$\Rightarrow P_1 + h \times 0.88 \times 9.81 \times 10^3 + x \times 0.88 \times 9.81 = x \times 0.88 \times 9.81 + P_2 + h \times 2.95 \times 9.81 \times 10^3$$

$$\Rightarrow P_1 - P_2 = h(2.95 \times 9.81 - 0.88 \times 9.81) \times 10^3$$

$$860 = h(2.3067 \times 10^3)$$

$$42.35 \times 10^{-3} = h$$

$$h = 42.35 \text{ mm}$$

2. (b)

For geometrically similar model and prototype

$$\left(\frac{P}{N^3D^5}\right)_{\text{model}} = \left(\frac{P}{N^3D^5}\right)_{\text{prototype}}$$

Given, $N_m = N_p$

$$\Rightarrow \frac{P_m}{N_m^3 D_m^5} = \frac{P_p}{N_p^3 D_p^5}$$

$$\frac{P_m}{P_p} = \frac{N_m^3 D_m^5}{N_p^3 D_p^5}$$

$$\frac{P_m}{P_p} = \frac{2^3 N_p^3}{N_p^3} \times \frac{D_m^5}{16^5 D_m^5}$$

$$P_m = \frac{10 \times 10^6 \times 2^3}{16^5} W = 76.29 \text{ W}$$

3. (a)

$$P_A - H \times 9.81 \times 1 - 0.18 \times 9.81 \times 0.827 = P_B - 13.6 \times 9.81 \times (H + 0.53)$$

$$-H \times 9.81 - 1.4603 = 97 - 13.6 \times 9.81 \times H - 13.6 \times 9.81 \times 0.53$$

$$\Rightarrow H = 0.2245 \text{ m}$$

$$\therefore H = 22.45 \text{ cm}$$

4. (c)

$$\therefore \quad \bar{V} = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4}d^2} \Rightarrow \frac{4Q}{\pi d^2} = \frac{4 \times 880 \times 10^{-9}}{\pi \times 0.50^2 \times 10^{-6}} = 4.48 \text{ m/s}$$

We know,
$$Q = \frac{\pi \Delta p D^4}{128 \mu L}$$

$$\Rightarrow \quad \mu = \frac{\pi \Delta p D^4}{128 Q L} = \frac{\pi \times 10^6 \times (0.5)^4 \times 10^{-12}}{128 \times 880 \times 10^{-9} \times 1}$$

$$\mu = 1.74 \times 10^{-3}$$

5. (c)

$$Re_{critical} = 2000 = \frac{VD}{\nu} = \frac{\rho VD}{\mu}$$

$$2000 = \frac{950 \times V \times 0.15}{8 \times 10^{-2}}$$

$$V = 1.123 \text{ m/s}$$

$$\text{Head loss} = \frac{32\mu VL}{\rho g D^2} = \frac{32 \times 8 \times 10^{-2} \times 1.123 \times 300}{950 \times 9.81 \times 0.15^2}$$

$= 4.113. \Rightarrow$ Maximum difference in oil elevations.

6. (a)

Shear stress at boundary

$$\tau_0 = \left(\frac{-\partial P}{\partial x}\right)\left(\frac{B}{2}\right)$$

Here, $B = 2 \times 1.5 \times 10^{-3} = 3 \times 10^{-3}$ m

$$\tau_0 = 1.25 \times 10^3 \times 1.5 \times 10^{-3}$$

$$\tau_0 = 1.875 \text{ Pa}$$

$$\bar{U} = \left(\frac{-\partial P}{\partial x}\right) \times \frac{B^2}{12\mu} = 1.25 \times 10^3 \times \frac{(2 \times 1.5 \times 10^{-3})^2}{12 \times 0.5}$$

$$\bar{U} = 1.875 \times 10^{-3}$$

$$\frac{Q}{W} = \bar{U} \times B = 1.875 \times 10^{-3} \times 3 \times 10^{-3} = 5.625 \times 10^{-3} \text{ m}^2/\text{s}$$

7. (c)

8. (b)

$$\text{Sensitivity} = \frac{1}{\sin\theta} = \frac{1}{\sin 30°} = 2$$

9. (b)
Surface tension is due to cohesion between liquid particles at the surface.

10. (d)

$$P = \rho_{Hg} \times g \times H$$
$$6.8 \times 10^4 = 13.6 \times 10^3 \times 9.81 \times H$$
$$H_{Hg} = 0.5096 \text{ m}$$
$$H_{water} = \frac{13.6}{1} \times 0.5096$$
$$H_{water} = 6.931 \text{ m}$$

11. (b)
For just equilbrium condition,

$$\dot{m}[V\cos\theta] = \mu Mg$$
$$1000 \times \pi \times 0.25 \times 0.05^2 \times V^2 \times 0.5 = 0.55 \times M \times 9.81$$
$$1000 \times \pi \times 0.25 \times 0.05^2 \times 2 \times 9.81 \times 2 \times 0.5 = 0.55 \times M \times 9.81$$
$$\Rightarrow \quad = 7.1399 \text{ kg}$$

12. (d)

$$\text{Volume of cube} = a^3$$
$$a^3 = 125 \times 10^{-3} \times 10^{-3} \text{ m}^3$$
$$\Rightarrow a = 5 \times 10^{-2}$$
$$\Rightarrow a = 0.05 \text{ m}$$
$$F = p \times A$$
$$P_{bottom} = p_{atm} + h_1 g \rho_{oil} + h_2 \rho_{water}\, g$$
$$= 101325 + 0.5 \times 0.8 \times 1000 \times 9.81 + 0.3 \times 1000 \times 9.81$$
$$P_{bottom} = 108192$$
$$F = P_{bottom} \times A = 108192 \times 0.05^2 = 270.48 \text{ N}$$
$$T = \text{Upthrust} - W$$
$$= 125 \times 10^{-6} \times 1000 \times 9.81 - 125 \times 10^{-6} \times 0.77 \times 1000 \times 9.81$$
$$= 0.282 \text{ N}$$

13. (c)

$$u = \frac{\partial \psi}{\partial y}$$
$$u = 2x^2 + (x + t)\, 2y$$
$\therefore$ for face OB, $\quad x \Rightarrow 0$
$$u_{OB} = 2ty$$
Discharge through AB

$\therefore \quad Q_{AB} = \int_0^2 u_{OB} \cdot 5dy = \int_0^2 2ty \cdot 5dy$

At $\quad t = 1$

$Q_{OB} = 20$ units

$\therefore \quad V = -\frac{\partial \psi}{\partial x} = -\left[4xy + y^2\right]$

At $\quad y = 0$

$V = 0$

$\therefore \quad Q_{AO} = 0$

$\therefore \quad Q_{AB} = Q_{OB} + Q_{OA}$

$= 20 + 0$

$= 20$ units

14. (d)

$$V_2 = \frac{Q}{A_2} = \frac{1.13 \times 10^{-6}}{\frac{\pi}{4} \times (0.0012)^2} \simeq 1 \text{ m/s}$$

$$\frac{P_1}{\rho g} + \frac{\alpha_1 V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \alpha_2 \frac{V_2^2}{2g} + z_2 + h_f$$

$$h_f = z_1 - z_2 - \frac{\alpha_2 V_2^2}{2g}$$

$$\Rightarrow \quad h_f = 0.6 - 0 - \frac{(2)(1)^2}{2 \times 9.81} = 0.5 \text{ m}$$

$$h_f = \frac{32 \mu VL}{\rho g D^2}$$

$$\Rightarrow \quad 0.5 = \frac{32 \times \mu \times 0.3 \times 1}{9000 \times 0.0012}$$

$$\Rightarrow \quad \mu = 6.75 \times 10^{-4} \text{ Pa-s}$$

15. (c)

$\mu = 0.97$ poise $= 0.097$ Ns/m^2

$\rho = 0.9 \times 998 = 898.2$ kg/m^3

$\dot{m}$ = mass rate of flow $= \frac{100}{30} = 3.333$ kg/s

Q = Volume rate of flow

$= \frac{3.333}{988.2}$

$\Rightarrow \quad 3.711 \times 10^{-3}$ m^3/s $= 3.711$ L/s

Area of flow $= A = \frac{\pi}{4}(0.1)^2 = 0.007854$ m^2.

$$\bar{U} = \frac{3.711\times10^{-3}}{0.007854} = 0.4725 \text{ m/s}$$

$$-\Delta P = \frac{32\mu\bar{U}L}{D^2} = \frac{32\times0.097\times0.4725\times10.0}{(0.1)^2}$$

$$-\Delta P = 1467 \text{ Pa}$$

16. (b)

$$Re_L = \frac{UL}{v} = \frac{1.75\times5}{1.475\times10^5}$$

$$Re_L = 5.932\times10^5$$

$$C_f = \frac{0.074}{Re_L^{1/5}} = \frac{0.074}{(5.932\times10^5)^{1/5}} = 5.183\times10^{-3}$$

Drag force on one side of the plate,

$$F_d = C_f \times \text{area}\times\frac{1}{2}\rho U^2$$

$$= 5.183\times10^{-3}\times(1.8\times5)\times1.22\times\frac{(1.75)^2}{2}$$

$$F_d = 0.0871 \text{ N}$$

17. (d)

$\because$ Continuity equation holds,

$$\therefore \quad \frac{\pi}{4}\times(5)^2\times2 = \frac{\pi}{4}\times3^2\times x$$

$$x = 5.55 \text{ m/s}$$

Mars flow rate

$$\Rightarrow \quad \dot{m} = \int_{\dot{m}} A_1V_1 = 100\times\frac{\pi}{4}\times0.05^2\times2 = 3.9269 \text{ kg/s}$$

Let f_x and f_y be the force in Right and vertically upward diversion respectively to hold the box in position.

$\therefore$ Now, $\Sigma f_x = 0$ [Box is stationary after applying force]

$$-\dot{m}\times V_1\cos65^\circ + f_x = -\dot{m}\times V_2\cos0^\circ$$

$$-3.9269\times2\times\cos65^\circ + f_x = -3.9269\times5.55\times1$$

$$f_x = -18.475 \text{ N.}$$

f_x must be in left as f_x comes out to be negative.

Similarly for vertical direction $\Sigma f_y = 0$

$$f_y - 3.9269\times2\times\sin65^\circ = 0$$

$$f_y = 7.11 \text{ N}$$

$\therefore$ It is towards vertically upward direction.

18. (a)

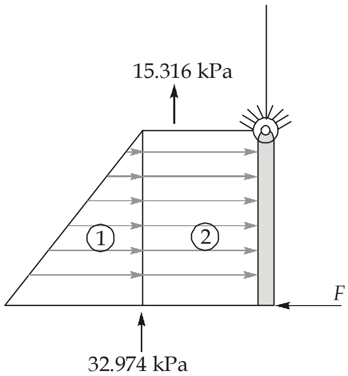
Gauge pressure at the upper end of the gate

$$= 80 + 0.9\times9.81\times4 - 100$$

$$= 15.316 \text{ kPa}$$

Gauge pressure at the lower end of the gate

$$= 80 + 0.9 \times 9.81 \times 6 - 100 = 32.974 \text{ kPa}$$



Using pressure diagram

For equilibrium,

Net moment about the hinge = 0

$$M_1 + M_2 = F \times 2$$

$$\frac{1}{2} \times (32.974 - 15.316) \times 2 \times 4 \times \left(\frac{2}{3} \times 2\right) + 15.316 \times 2 \times 4 \times \frac{2}{2} = F \times 2$$

On solving $\quad F = 108.352 \text{ kN}$

19. (b)

$$H_m = H + \frac{fLV_d^2}{2gd} + 1.3 \times \frac{V_d^2}{2g} + \frac{V_d^2}{2g}$$

H_m = Net head required

$$H_m = 30 + \frac{4f'LV_d^2}{2gd} + 1.3 \times \frac{V_d^2}{2g} + \frac{V_d^2}{2g}$$

$f' = 0.02 \qquad A_dV_d = 50 \times 10^{-3} \text{ m}^3/\text{s}$

$d = 200 \text{ mm}$

$$\frac{\pi}{4} \times 0.2^2 \times V_d = 50 \times 10^{-3}$$

$$V_d = 1.59 \text{ m/s}$$

$$\Rightarrow \quad H_m = 30 + \frac{4 \times 0.02 \times 100 \times 1.59^2}{2 \times 9.81 \times 0.2} + \frac{1.3 \times 1.59^2}{2 \times 9.81} + \frac{1.59^2}{2 \times 9.81}$$

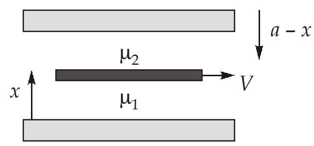
$$= 35.45 \text{ m}$$

$$\Rightarrow \quad \text{Power} = \rho Qg\, H_m = 17388.225 \text{ W} = 17.388 \text{ kW}$$

20. (d)

$$\tau_1 = \text{shear stress at bottom}$$

$$= \mu_1 \times \frac{V}{x}$$



$$\tau_2 = \text{shear stress at top} = \mu_2 \frac{V}{a - x}$$

$$\text{drag force} = (\tau_1 + \tau_2) \times A = F_D$$

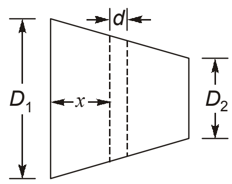
$$= F_D = A \times \left[\frac{\mu_1 V}{x} + \frac{\mu_2 V}{a - x}\right]$$

$$\frac{dF_D}{dx} = 0 = \frac{-\mu_1 V}{x^2} + \frac{\mu_2 V}{(a-x)^2} \Rightarrow \frac{\mu_1}{x^2} = \frac{\mu_2}{(a-x)^2}$$

$$a - x = \sqrt{\frac{\mu_2}{\mu_1}} x$$

$$\Rightarrow \qquad \frac{a\sqrt{\mu_1}}{\sqrt{\mu_1} + \sqrt{\mu_2}} = x$$

21. (a)



$$\therefore \qquad D = D_1 - \frac{(D_1 - D_2)x}{L}$$

By Hagen–Poiseuille equation,

$$Q = \frac{\pi D^4}{-128\mu} \frac{\partial P}{\partial x}$$

For a differential length dx, the differential pressure drop is,

$$d(\Delta_p) = \frac{128\mu Q}{\pi D^4}.dx$$

$$\therefore \qquad dD = -(D_1 - D_2)dx / L$$

$$\therefore \qquad d(\Delta_p) = \frac{128\mu Q - L}{\pi(D_1 - D_2)} \times \frac{1}{D^4}.dD$$

Integrating both sides to determine the pressure drop across the conical contraction,

$$\Delta_p = \frac{-128\mu Q}{3x} \times \frac{-L}{(D_1 - D_2)}\left[\frac{1}{D^4}\right]_{D_1}^{D_2}$$

$$\Rightarrow \qquad \Delta_p = \frac{-128\mu Q}{3x} \times \frac{(D_1^2 + D_1 D_2 + D_2^2)}{(D_1^3 - D_2^3)}$$

22. (a)

(1) $$u = x^2 \cos y$$
$$v = -2x \sin y$$

Continuity equation

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

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

$$(2x)\cos y-(2x)\cos y = 0$$

hence satisfy the continuity equation.

(2) $u = x + 2$

$v = 1 - y$

Continuity equation

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

$$= \frac{\partial}{\partial x}(x+2)+\frac{\partial}{\partial y}(1-y) = 1 - 1 = 0$$

hence satisfy the continuity equation.

(3) $u = xyt$

$$v = x^3 - y^2\frac{t}{2}$$

Continuity equation

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

$$= \frac{\partial}{\partial x}(xyt)+\frac{\partial}{\partial y}\left(x^3-\frac{y^2t}{2}\right) = yt - yt = 0$$

(4) $u = ln(x + y)$

$$v = xy-\frac{y}{x}$$

Continuity equation

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

$$= \frac{\partial}{\partial x}ln(x+y)+\frac{\partial}{\partial y}\left(xy-\frac{y}{x}\right) = \frac{1}{x+y}+x-\frac{1}{x} \neq 0$$

Hence, does not satisfy continuity equation.

23. (a)

$$\text{Pressure head} = \frac{p}{\rho g} = \frac{19.62\times 10^3}{1000\times 9.81\times 0.8} = 2.5\text{m of oil}$$

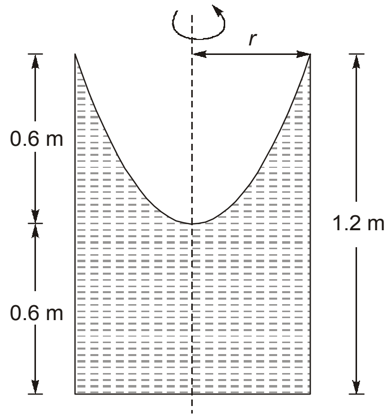
$$\text{Velocity head} = \frac{V^2}{2g} = \frac{Q^2}{2A^2g} = \frac{(0.12)^2}{2\times\left(\frac{\pi}{4}\times 0.25^2\right)^2\times 9.81} = 0.3 \text{ m of oil}$$

Datum head = 2.7 m

Total head = Pressure head + Velocity head + Datum head

= 2.5 + 0.3 + 2.7 = 5.5 m

24. (a)



Original volume of

$$\text{Cylinder} = \pi r^2 h$$

$$V_1 = \pi r^2 \times 1.2$$

Volume of liquid spilled out

$$= \frac{1}{2}\pi r^2 \times h$$

$$V_2 = \frac{1}{2}\pi r^2 \times 0.6$$

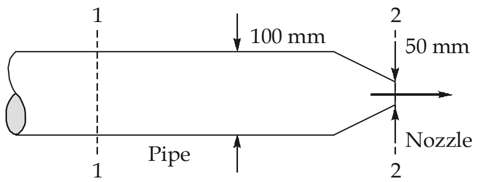
$$\therefore \quad \frac{V_2}{V_1} = \frac{\frac{1}{2}\times 0.6\pi r^2}{\pi r^2 \times 1.2} = \frac{1}{4}$$

25. (b)

$$V_1 A_1 = V_2 A_2$$

$$5\times\frac{\pi}{4}(0.1)^2 = V_2 \times \frac{\pi}{4}(0.05)^2$$

$$\Rightarrow \quad V_2 = 20 \text{ m/s}$$



From force balance in x-diagram

$$P_1A_1 + R_x - P_2A_2 = \rho Q(V_2 - V_1)$$

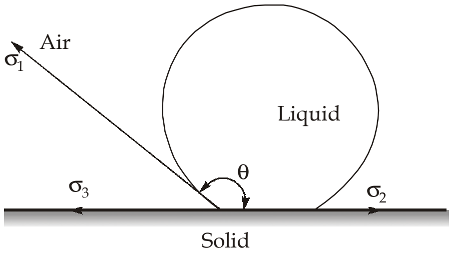
$$\Rightarrow \quad R_x = \rho Q(V_2 - V_1) + P_2A_2 - P_1A_1$$

$$= 1000\times\frac{\pi}{4}(0.1)^2\times 5(20-5) + 100\times 10^3\times\frac{\pi}{4}(0.05)^2 - 500\times 10^3\times\frac{\pi}{4}(0.1)^2$$

Force required to hold the nozzle, $R_x = -3141.6$ N

26. (c)

From force balance at point of contact,



$$\sigma_1 \cos(180 - \theta) + \sigma_3 = \sigma_2$$

or $$\cos(180 - \theta) = \frac{\sigma_2 - \sigma_3}{\sigma_1} = -\cos\theta$$

$\therefore$ $\sigma_1 = 0.0720$ N/m (liquid and air)

$\sigma_2 = 0.0418$ N/m (liquid and solid)

$\sigma_3 = 0.0008$ N/m (air and solid)

$$\cos\theta = \frac{0.0008 - 0.0418}{0.072} = -0.56944$$

$$\theta = 124.7°$$

27. (b)

$$\therefore \quad \text{Re} = \frac{16}{f} = \frac{16}{0.04} = 400$$

$\therefore$ The flow is viscous.

The shear stress in case of viscous flow through a pipe is given by

$$\tau = \frac{-\partial p}{\partial x}\left(\frac{r}{2}\right)$$

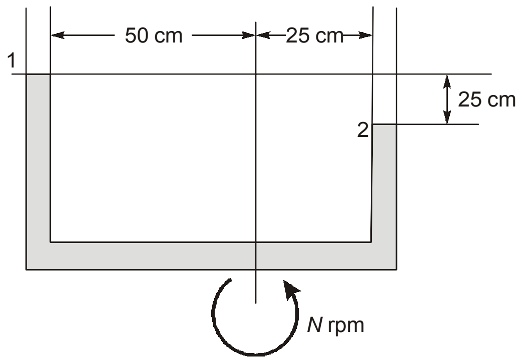
$\therefore$ $\frac{\partial p}{\partial x}$ is constant across a section.

$$\therefore \quad \tau \propto r$$

$$\therefore \quad \frac{\tau}{r} = \frac{\tau_0}{R} = \frac{0.00981}{40} = \frac{\tau_0}{100}$$

$$\therefore \quad \tau_0 = \frac{100 \times 0.00981}{40} = 0.0245 \text{ N/cm}^2$$

28. (c)



$$\frac{\overset{0}{\cancel{P_1}}}{\cancel{\rho g}} - \frac{V_1^2}{2g} + Z_1 = \frac{\overset{0}{\cancel{P_2}}}{\cancel{\rho g}} - \frac{V_2^2}{2g} + Z_2$$

$$Z_1 - Z_2 = \frac{V_1^2}{2g} - \frac{V_2^2}{2g}$$

$$0.25 = \frac{1}{2g}\left\{r_1^2\omega^2 - r_2^2\omega^2\right\}$$

$$0.25 \times 2 \times 9.81 = \omega^2\left\{\left(\frac{50}{100}\right)^2 - \left(\frac{25}{100}\right)^2\right\}$$

$$\omega = 5.115 \text{ rad/s}$$

$$N = \frac{60\omega}{2\pi} = \frac{60 \times 5.515}{2 \times \pi}$$

$$= 48.8 \text{ rpm}$$

29. (a)

$$Re_L \le 2000$$

$$\Rightarrow \quad \frac{\rho VD}{\mu} \le 2000$$

$$\Rightarrow \frac{(0.92 \times 1000) \times \frac{Q}{A} \times (10 \times 10^{-2})}{0.9 \times 10^{-1}} \le 2000$$

$$\Rightarrow \quad Q \le \frac{2000 \times 0.9 \times 10^{-1} \times A}{(0.92 \times 1000) \times (10 \times 10^{-2})}$$

$$\Rightarrow \quad Q \le 1.95652 \times \frac{\pi}{4} \times \left\{\frac{10}{100}\right\}^2$$

$$\Rightarrow \quad Q \le 0.015366 \text{ m}^3/\text{s}$$

$$\Rightarrow \quad Q \le 15.36 \simeq 15.4 \text{ L/s}$$

30. (c)

$$f = \frac{64}{\text{Re}}$$

$$Re = \frac{UD}{\nu} = \frac{0.1 \times 0.1}{10^{-5}} = 1000$$

$$f = \frac{64}{1000} = 0.064$$

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