

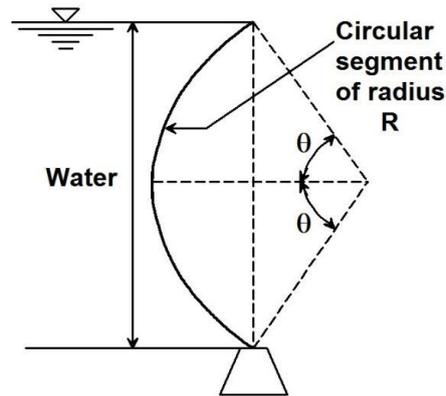
B : FLUID MECHANICS

Q. 1 – Q. 9 carry one mark each.

Q.1 The gap δ between two concentric cylinders, each of height h , is filled with an oil. The torque required to rotate the inner cylinder at an angular velocity of ω against the fixed outer cylinder is T . The diameter of the inner cylinder is d and $\delta \ll d$. The dynamic viscosity of the oil is given by

- (A) $\frac{4\pi\delta T}{d^3\omega h}$ (B) $\frac{4\delta T}{\pi d^3\omega h}$ (C) $\frac{4\pi\delta T}{d^2\omega h^2}$ (D) $\frac{4\delta T}{\pi d\omega h^3}$

Q.2 Water is retained against a sluice gate in the form of a circular segment as shown in the figure. If ρ and g are the density of water and gravitational acceleration respectively, the upward force exerted by the gate on the water per unit depth perpendicular to the plane of the figure is



- (A) $\rho R^2 \left(\theta - \frac{1}{2} \sin 2\theta \right) g$ (B) $\rho R^2 \left(\cos^2 \theta - \frac{1}{2} \sin \theta \right) g$
 (C) $\rho R^2 \left(\cos \theta - \frac{1}{2} \sin \theta \right) g$ (D) $\rho R^2 \left(\cos^2 \theta - \frac{1}{2} \sin^2 \theta \right) g$

Q.3 A two-dimensional velocity field is given by $\vec{V} = 10(y^3 - x^2y)\hat{i} + 2Cxy^2\hat{j}$, where \hat{i} and \hat{j} are the unit vectors in the directions of the rectangular Cartesian coordinates x and y , respectively. If the flow is incompressible, the constant C should be

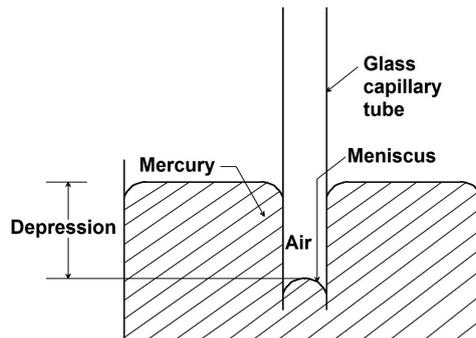
- (A) -10 (B) 0 (C) 5 (D) 10

Q.4 Let \vec{V} and T denote the velocity vector and temperature in a flow field. The rate of change of temperature experienced by a fluid particle as it passes through the point (x_1, y_1, z_1) at a time t_1 is 2.5°C/s . The rate of change of temperature at a time t_1 at the point (x_1, y_1, z_1) is 4.8°C/s . The quantity $\vec{V} \cdot \vec{\nabla} T$ at (x_1, y_1, z_1) and t_1 in $^\circ\text{C/s}$ is _____

Q.5 In a simple Couette flow apparatus, the gap h between the parallel plates is filled with a liquid of density ρ and dynamic viscosity μ , and one plate is dragged at a velocity of U parallel to itself, while the other plate is fixed. The magnitude of vorticity at any point in the flow is

- (A) $\frac{\mu}{\rho h^2}$ (B) 0 (C) $\frac{1}{h^2} \sqrt{\frac{\mu U h}{\rho}}$ (D) $\frac{U}{h}$

Q.6 An open glass capillary tube of 2 mm bore is lowered into a cistern containing mercury (density = 13600 kg/m^3) as shown in the figure. Given that the contact angle between mercury and glass = 140° , surface tension coefficient = 0.484 N/m and gravitational acceleration = 9.81 m/s^2 , the depression of mercury in the capillary tube below the free surface in the cistern, in mm, is _____



Q.7 Consider a combined forced-free vortex. The central region with radius R and angular velocity ω is the forced vortex and the rest is the free vortex. The pressure at the edge of the combined vortex is p_0 . If the density of the fluid is ρ , the pressure at the center of the combined vortex is

- (A) $p_0 - \rho\omega^2 R^2$ (B) $p_0 - \frac{1}{2} \rho\omega^2 R^2$ (C) $p_0 + \frac{1}{2} \rho\omega^2 R^2$ (D) $p_0 + \rho\omega^2 R^2$

Q.8 The following is true at the point of separation of a boundary layer:

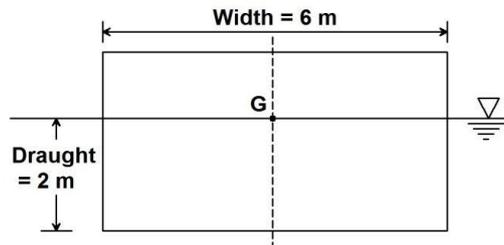
- (A) Transition occurs from laminar to turbulent flow
 (B) The flow relaminarizes from turbulent regime
 (C) The shear stress vanishes
 (D) The relation between stress and rate of strain ceases to be linear

Q.9 A certain fluid flow phenomenon is described by Reynolds, Weber and Ohnesorge numbers. The Weber and Ohnesorge numbers are defined as $We = \frac{\rho U^2 L}{\sigma}$, and $Oh = \frac{\mu}{\sqrt{\rho \sigma L}}$, respectively, where σ is the surface tension, ρ is the density, μ is the dynamic viscosity, U is the velocity and L is the characteristic dimension. If Re denotes the Reynolds number, which of the following relations is true?

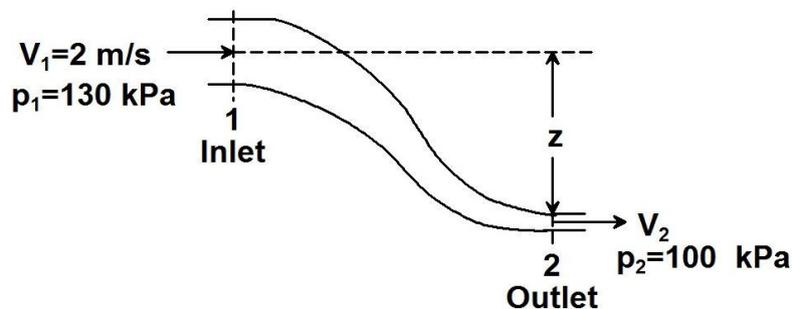
- (A) $We = Oh Re^2$ (B) $We = Oh^2 Re^2$ (C) $We = Oh^2 Re$ (D) $We = Oh Re$

Q. 10 – Q. 22 carry two marks each.

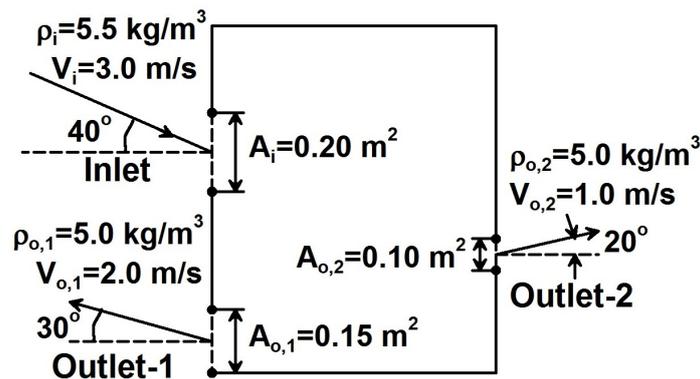
- Q.10 A rectangular boat 6 m wide and 15 m long (dimension perpendicular to the plane of the figure) has a draught of 2 m. The side view of the boat is as shown in the figure. The centre of gravity G of the boat is at the free surface level. The metacentric height of the boat in m is



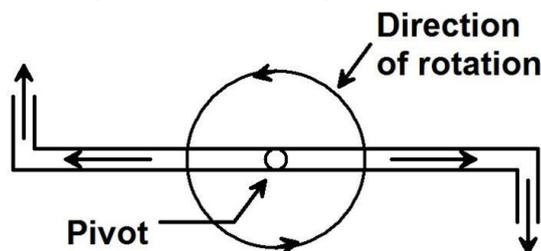
- (A) -1.0 (B) 0.5 (C) 1.5 (D) 2.0
- Q.11 Water drains out into atmosphere from a small orifice located at the bottom of a large open tank. If the initial height of the water column is H , the time taken to empty the tank is proportional to
- (A) $H^{1/2}$ (B) H (C) $H^{3/2}$ (D) H^2
- Q.12 Consider a two-dimensional velocity field given by $\vec{V} = \pi y \hat{i} - \pi x \hat{j}$, where \hat{i} and \hat{j} are the unit vectors in the directions of the rectangular Cartesian coordinates x and y , respectively. A fluid particle is located initially at the point $(-1, 1)$. Its position after unit time is
- (A) $(-2, -2)$ (B) $(1, -1)$ (C) $(1, 1)$ (D) $(3, -1)$
- Q.13 The figure shows a reducing area conduit carrying water. The pressure p and velocity V are uniform across sections 1 and 2. The density of water is 1000 kg/m^3 . If the total loss of head due to friction is just equal to the loss of potential head between the inlet and the outlet, then V_2 in m/s will be _____



- Q.14 A fluid enters a control volume through an inlet port (denoted with subscript 'i') and leaves through two outlet ports (denoted with subscripts 'o,1' and 'o,2') as shown in the figure. The velocities may be assumed to be uniform across the ports. The rate of change of mass in the control volume in kg/s, at the instant shown in the figure, is _____



- Q.15 The total discharge of water through a lawn sprinkler shown in the figure is one liter per minute. The velocity of the jet at each end, relative to the arm, is $2\pi/30$ m/s. The density of water is 1000 kg/m^3 and the length of each arm is 0.1 m. If the frictional torque of the pivot is $\pi/36$ mN.m, the rotational speed, in revolutions per minute, of the sprinkler is _____



- Q.16 Consider a two-dimensional potential flow field with the radial and tangential velocity components, $v_r = \frac{m}{2\pi r}$ and $v_\theta = \frac{k}{2\pi r}$, respectively, where m and k are constants. The stream function is such that it increases along the direction of traverse of a line in the flow field if the flow is from left to right across that line. The stream function ψ for this flow field, with $\psi = 0$ at $r = a$ and $\theta = 0$, is

- (A) $\frac{m\pi\theta}{2} + \frac{k\pi}{2} \ln \frac{r}{a}$ (B) $\frac{m\pi\theta}{2} - \frac{k\pi}{2} \ln \frac{r}{a}$
 (C) $\frac{m\theta}{2\pi} + \frac{k}{2\pi} \ln \frac{r}{a}$ (D) $\frac{m\theta}{2\pi} - \frac{k}{2\pi} \ln \frac{r}{a}$

Q.17 A steady, two-dimensional, inviscid and incompressible flow field is described in rectangular Cartesian coordinates as $u = ax$ and $v = -ay$, where u and v are the components of the velocity vector in the x and y directions, respectively. Gravity acts along the negative y -direction. The pressure distribution, with the reference pressure taken as zero at the origin, with usual notation, is given by

(A) $-\frac{1}{2}\rho a^2(x^2 + xy + y^2) - \rho gy$ (B) $-\frac{1}{2}\rho a^2(x^2 - xy + y^2) - \rho gy$

(C) $-\frac{1}{2}\rho a^2(x^2 + y^2) - \rho gy$ (D) $-\frac{1}{2}\rho a^2(x^2 - y^2) - \rho gy$

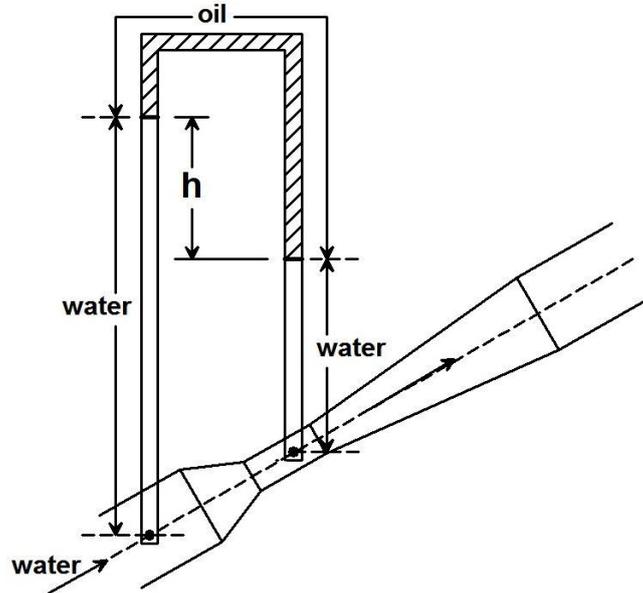
Q.18 A cylinder of radius 0.1 m rotating clockwise about its own axis at an angular velocity of $100/\pi$ radians per second is placed in a cross-stream of air flowing at a velocity of 10 m/s from left to right. The density of air is 1.2 kg/m^3 . The lift force per unit length of the cylinder in N/m is _____

Q.19 The velocity profile in turbulent flow through a pipe is approximated as $\frac{u}{u_{\max}} = \left(\frac{y}{R}\right)^{1/7}$, where u_{\max} is the maximum velocity, R is the radius and y is the distance measured normal to the pipe wall towards the centerline. If u_{av} denotes the average velocity, the ratio $\frac{u_{\text{av}}}{u_{\max}}$ is

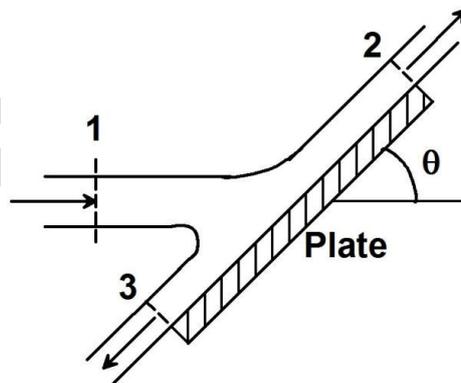
(A) $\frac{2}{15}$ (B) $\frac{1}{5}$ (C) $\frac{1}{3}$ (D) $\frac{49}{60}$

Q.20 A steel sphere (density = 7900 kg/m^3) of diameter 0.1 m is dropped from rest in water (density = 1000 kg/m^3). The gravitational acceleration is 9.81 m/s^2 . Assuming that the drag coefficient is constant and equal to 1.33, the terminal velocity attained by the sphere in m/s is _____

- Q.21 An inclined venturimeter connected to an inverted manometer is shown in the figure. The cross-sectional areas at the inlet and the throat are $2 \times 10^{-3} \text{ m}^2$ and $2 \times 10^{-4} \text{ m}^2$, respectively. The densities of water and oil are 1000 kg/m^3 and 800 kg/m^3 , respectively. The gravitational acceleration is 9.81 m/s^2 . If the discharge of water through the venturimeter is $5 \times 10^{-4} \text{ m}^3/\text{s}$, neglecting viscous effects and assuming uniform velocities across the inlet and the throat, the manometer reading h , in m, will be _____



- Q.22 A plane jet of water with volumetric flow rate $0.012 \text{ m}^3/\text{s}$ and cross-sectional area $6 \times 10^{-4} \text{ m}^2$ strikes a stationary plate inclined at angle θ and leaves as two streams, as shown in the figure. The ratio of the discharge through section 2 to that through section 3 is 3:1. The velocities may be considered uniform across the cross-sections and the effects of friction may be neglected. The density of water is 1000 kg/m^3 . Ignoring the effects of gravity, the magnitude of the normal force exerted on the plate, in N, is _____



END OF THE QUESTION PAPER