CE6303 - MECHANICS OF FLUIDS

(FOR III – SEMESTER)

UNIT – I

PREPARED BY

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TWO MARK QUESTIONS AND ANSWERS

1. Define fluid mechanics.

It is the branch of science, which deals with the behavior of the fluids (liquids or gases) at rest as well as in motion.

2. Define Mass Density.

Mass Density or Density is defined as ratio of mass of the fluid to its volume (V)

Density of water = 1 gm/cm^3 or 1000 kg / m^3.

$$\boxed{p = \frac{Mass\ \ of\ \ fluid}{Volume of\ \ fluid}}$$

3. Define Specific Weight.

It is the ratio between weight of a fluid to its volume.

$$w = \frac{Weight\ \ of\ \ fluid}{Volume\ of\ \ fluid} = \left(\frac{Mass\ of\ \ fluid}{Volume\ of\ \ fluid}\right) \times g = p \times g$$

$$\boxed{w = p \times g}$$

Unit: N / m^3

4. Define Viscosity.

Viscosity is defined as the property of fluid, which offers resistance to the movement of one layer of fluid over another adjacent layer of fluid.

When two layers move one over the other at different velocities, say u and u+ du, the viscosity together with relative velocity causes a shear stress acting between the fluid layers. The top layer causes a shear stress on the adjacent lower layer while the lower layer causes a shear stress on the adjacent top layer.

This shear stress is proportional to the rate of change of velocity.

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

$\mu \Rightarrow$ Coefficient of dynamic viscosity (or) only viscosity
du / dy = rate of shear strain

5. Define Specific Volume.

Volume per unit mass of a fluid is called specific volume

$$Sp. volume = \left(\frac{Volume\ of\ a\ fluid}{Mass\ of\ fluid}\right) = \frac{1}{p} = \frac{1}{\left(\frac{mass\ of\ fluid}{volume}\right)}$$

Unit: m^3 / kg.

6. Define Specific Gravity.

Specific gravity is the ratio of the weight density or density of a fluid to the weight density or density of standard fluid. It is also called as relative density.

Unit : Dimension less. Denoted as: ‘S’

$$S(for liquid) = \frac{Weight\ density\ of\ liquid}{Weight\ density\ of\ water}$$

$$S(for\ gases) = \frac{Weight\ density\ of\ gas}{Weight\ density\ of\ air}$$

7. Calculate the specific weight, density and specific gravity of 1 litre of liquid which weighs 7 N.

Solution:

Given $V = 1ltre = \frac{1}{1000}\ m^3$

W = 7 N

i. Sp. Weight (w) $= \frac{weight}{volume} = \frac{7N}{\left(\frac{1}{1000}\right)m^3} = 7000\ N/m^3$

ii Density (p) $= \frac{w}{g} = \frac{7000 \ N}{9.81 m^3} kg/m^3 = 713..5 \ Kg/m^3$

iii. Sp. Gravity (S) $= \frac{Density \ of \ liquid}{Density \ of \ water} = \frac{713.5}{1000}$ (Density of water = 1000 kg / m$^{3)}$

S = 0.7135

8. State Newton's Law of Viscosity.

It states that the shear stress (τ) on a fluid element layer is directly proportional to the rate of shear strain. The constant of proportionality is called the co-efficient of viscosity

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

9. Name the Types of fluids.

1. Ideal fluid
2. Real fluid
3. Newtonian fluid
4. Non-Newtonian fluid.
5. Ideal plastic fluid

10. Define Kinematic Viscosity.

It is defined as the ratio between the dynamic viscosity and density of fluid.

Represented as γ ; $\upsilon = \frac{Viscosity}{Density} = \frac{\mu}{p}$

Unit: m^2 / sec.

$$1 \ Stoke = \frac{Cm^2}{S} = \left(\frac{1}{100}\right)^2 \frac{m^2}{S} = 10^{-4} m^2 / s.$$

Centistoke means $= \frac{1}{100}$ *stoke*

11. Find the Kinematic viscosity of an oil having density 981 kg/m. The shear stress at a point in oil is 0.2452 N/m^2 and velocity gradient at that point is 0.2 /sec.

Mass density p = 981 kg/m^3, Shear stress $\tau = 0.2452 N / m^2$

Velocity gradient $\frac{du}{dy} = 0.2$

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

$$0.2452 = \mu \times 0.2 \quad \Rightarrow \mu = \frac{0.2452}{0.2} = 1.226 Ns/m^2.$$

$$kinematic viscosity(\upsilon) = \frac{\mu}{p} = \frac{1.226}{981}$$

$$= 0.125 \times 10^{-2} m^2 / s.$$

$$= 0.125 \times 10^{-2} \times 10^4 cm^2 / S$$

$$= 12.5 stoke.$$

12. Determine the specific gravity of a fluid having viscosity 0.05 poise and Kinematic viscosity 0.035 stokes.

Given: Viscosity, μ = 0.05 poise = (0.05 / 10) Ns / m^2.

Kinematic viscosity ν = 0.035 stokes = 0.035 cm^2 / s

= 0.035 x 10^{-4} m^2 / s

$$\boxed{\upsilon = \frac{\mu}{p}}$$

$$0.035 \times 10^{-4} = \frac{0.05}{10} \times \frac{1}{p} \Rightarrow p = 1428.5 kg / m^3$$

Specific gravity of liquid = $\frac{\text{Density of liquid}}{\text{Density of water}} = \frac{1428.5}{1000}$ = 1.428 = 1.43

13. Define Compressibility.

Compressibility is the reciprocal of the bulk modulus of elasticity, K which is defined as the ratio of compressive stress to volumetric strain.

Consider a cylinder filled with a piston as shown

V → Volume of gas enclosed in the cylinder
P → Pressure of gas when volume is $\forall$

Increase in pressure = dp kgf / m^2

Decrease of volume = $d\forall$

$\therefore$ Volumetric strain $= \frac{-d\forall}{\forall}$

- Ve sign → Volume decreases with increase in pressure

$$\therefore \quad \text{Bulk modulus } K = \frac{Increase\ of\ \text{Pr}essure}{Volumetric\ strain} = \frac{d_p}{\frac{-d\forall}{\forall}} = \boxed{-\frac{d_p}{d\forall}\forall}$$

$$\boxed{Compressibility = \frac{1}{K}}$$

14. Define Surface Tension.

Surface tension is defined as the tensile force acting on the surface of a liquid in contact with a gas or on the surface between two immiscible liquids such that the contact surface behaves like a membrance under tension.

Unit: N / m.

15. Define Capillarity:

Capillary is defined as a phenomenon of rise of a liquid surface is a small tube relative to adjacent general level of liquid when the tube is held vertically in the liquid. The resistance of liquid surface is known as capillary rise while the fall of the liquid surface is known as capillary depression. It is expressed in terms of cm or mm of liquid.

16. The Capillary rise in the glass tube is not to exceed 0.2 mm of water. Determine its minimum size, given that surface tension of water in contact with air = 0.0725 N/m

Solution:

Capillary rise, h = 0.2 mm = 0.2 x 10^3 m

Surface tension $\sigma = 0.0725\ N/m$

Let, Diameter of tube = d

Angel θ for water = 0

Density for water = 1000 kg / m^2

$$h = \frac{4\sigma}{p \times g \times d} \Rightarrow 0.2 \times 10^{-3} = \frac{4 \times 0.0725}{1000 \times 9.81 \times d}$$

$$d = \frac{4 \times 0.0725}{1000 \times 9.81 \times 0.2 \times 10^{-3}} = 0.148m = 14.8cm$$

Minimum ϕ of the tube = 14.8 cm.

17. Find out the minimum size of glass tube that can be used to measure water level if the capillary rise in the tube is to be restricted to 2mm. Consider surface tension of water in contact with air as 0.073575 N/m.

Solution:

Capillary rise h = 2.0 mm = $2.0 \times 10^{-3} m$

Let, diameter = d

Density of water = 1000 kg / m^3

$\sigma = 0.073575 \ N/m$

Angle for water $\theta = 0$

$$h = \frac{4\sigma}{p \times g \times d} \quad \Rightarrow 2.0 \times 10^{-3} = \frac{4 \times 0.073575}{1000 \times 9.81 \times d}$$

d = 0.015 m = 1.5 cm.

Thus the minimum diameter of the tube should be 1.5 cm.

18. Define Real fluid and Ideal fluid.

Real Fluid:

A fluid, which possesses viscosity, is known as real fluid. All fluids, in actual practice, are real fluids.

Ideal Fluid:

A fluid, which is incompressible and is having no viscosity, is known as an ideal fluid. Ideal fluid is only an imaginary fluid as all the fluids, which exist, have some viscosity.

19. Write down the expression for capillary fall.

Height of depression in tube $h = \frac{4\sigma Cos\theta}{p \times g \times d}$

Where,

h = height of depression in tube.

d = diameter of the

σ = surface tension

ρ = density of the liquid.

θ = Angle of contact between liquid and gas.

20. Two horizontal plates are placed 1.25 cm apart. The space between them being filled with oil of viscosity 14 poises. Calculate the shear stress in oil if upper plate is moved with a velocity of 2.5 m/s.

Solution:

Given:

Distance between the plates, dy = 1.25 cm = 0.0125m.

Viscosity μ = 14 poise = 14 / 10 Ns / m^2

Velocity of upper plate, u = 2.5 m/Sec.

Shear stress is given by equation as $\tau = \mu$ (du / dy).

Where du = change of velocity between the plates = u – 0 = u = 2.5 m/sec.

dy = 0.0125m.

τ = (14 /10) X (2.5 / 0.0125) = 280 N/m^2.

16 MARKS QUESTIONS AND ANSWERS

1. Calculate the capillary effect in millimeters a glass tube of 4mm diameter, when immersed in (a) water (b) mercury. The temperature of the liquid is 20^0 C and the values of the surface tension of water and mercury at 20^0 C in contact with air are 0.073575 and 0.51 N/m respectively. The angle of contact for water is zero that for mercury 130^0. Take specific weight of water as 9790 N / m^3

Given:

Diameter of tube $\Rightarrow$ d = 4 mm = $4 \times 10^{-3} m$

Capillary effect (rise or depression) $\Rightarrow h = \dfrac{4\sigma \cos\theta}{p \times g \times d}$

$\sigma =$ Surface tension in kg f/m

$\theta =$ Angle of contact and p = density

i. **Capillary effect for water**

$$\sigma = 0.073575 \ N/m, \quad \theta = 0^0$$

$$p = 998 \ kg/m^3 \ @ \ 20^0 c$$

$$h = \frac{4 \times 0.73575 \times Cos 0^0}{998 \times 9.81 \times 4 \times 10^{-3}} = 7.51 \times 10^{-3} m$$

= 7.51 mm.

Capillary effect for mercury:

$$\sigma = 0.51 N/m, \qquad \theta = 130^0$$

$$p = sp \ gr \times 1000 = 13.6 \times 1000 = 13600 \ kg/m^3$$

$$h = \frac{4 \times 0.51 \times Cos 130^0}{13600 \times 9.81 \times 4 \times 10^{-3}}$$

$$= -2.46 \times 10^{-3} \text{ m}$$

= - 2.46 mm.

-Ve indicates capillary depression.

2. A cylinder of 0.6 m^3 in volume contains air at 50^{0}C and 0.3 N/ mm^2 absolute pressure. The air is compressed to 0.3 m^3. Find (i) pressure inside the cylinder assuming isothermal process (ii) pressure and temperature assuming adiabatic process. Take K = 1.4

Given:

Initial volume $\forall_1 = 0.36 \, m^3$

Pressure P_1 = 0.3 N/mm^2

$$= 0.3 \times 10^6 \ N/m^2$$

Temperature, t_1 = 50^0 C

T_1 = 273 + 50 = 323 ^{0} K

Final volume, $\forall_2 = 0.3m^3$

K = 1.4

i. Isothermal Process:

$$\frac{P}{p} = Constant \quad (or) \; p\forall = Constant$$

$$p_1\forall_1 = p_2\forall_2$$

$$p_2 = \frac{p_1\forall_1}{\forall_2} = \frac{30\times10^4\times0.6}{0.3} = 0.6\times10^6 \; N/m^2$$

= 0.6 N / mm^2

ii. Adiabatic Process:

$$\frac{p}{p^K} = Constant \quad or \qquad \boxed{p\forall^K = constant}$$

$$p_1.\forall_1{}^K = p_2\forall_2{}^K$$

$$p_2 = p_1\frac{\forall_1 K}{\forall_2 K} = 30\times10^4\times\left(\frac{0.6}{0.3}\right)^{1.4} = 30\times10^4\times2^{1.4}$$

$$= 0.791\times10^6 \; N/m^2 = 0.791 N/mm^2$$

For temperature, $p\forall = RT$**,** $p\forall^k = constant$

$$p = \frac{RT}{\forall} \text{ and } \frac{RT}{\forall}\times\forall^k = constant$$

$$RT\forall^{k-1} = Constant$$

$$T\forall^{k-1} = Constant \qquad (\because R \text{ is also constant})$$

$$T_1 V_1^{k-1} = T_2 V_2^{k-1}$$

$$T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{k-1} = 323 \quad \left(\frac{0.6}{0.3} \right)^{1.4-1.0}$$

$$= 323 \times 2^{0.4} = 426.2^0 K$$

$$t_2 = 426.2 - 273 = 153.2^0 C$$

3. If the velocity profile of a fluid over a plate is a parabolic with the vertex 202 cm from the plate, where the velocity is 120 cm/sec. Calculate the velocity gradients and shear stress at a distance of 0,10 and 20 cm from the plate, if the viscosity of the fluid is 8.5 poise.

Given,

Distance of vertex from plate = 20 cm.

Velocity at vertex, u = 120 cm / sec.

Viscosity, $\mu = 8.5 poise = \frac{8.5}{10} \frac{Ns}{m^2} = 0.85$

Parabolic velocity profile equation, $u = ay^2 + by + C$ -------------- (1)

Where, a, b and c constants. Their values are determined from boundary conditions.

i) At y = 0, u = 0

ii) At y = 20cm, u = 120 cm/se.

iii) At y = 20 cm, $\frac{du}{dy} = 0$

Substituting (i) in equation (1), C = 0

Substituting (ii) in equation (1), $120 = a(20)^2 + b(2) = 400a + 20b$ -----------(2)

Substituting (iii) in equation (1), $\frac{du}{dy} = 2ay + b$

$$0 = 2 \times a \times 20 + b = 40a + b \quad \text{-----------(3)}$$

solving 1 and 2, we get,

$$400\,a + 20\,b = 0$$

$$(-)$$

$$800\,a + 20\,b = 0$$

40 a + b = 0

b = - 40 a

$$120 = 400\,a + 20\,b(-40\,a) = 400\,a - 800\,a = -400\,a$$

$$a = \frac{120}{-400} = -\frac{3}{10} = -\,0.3$$

$$b = -40 \times (-0.3) = 1.2$$

Substituting a, b and c in equation (i) $u = -0.3y^2 + 12y$

$$\frac{du}{dy} = -0.3 \times 2y + 12 = -0.6y + 12$$

Velocity gradient

at y = 0, Velocity gradient, $\left(\frac{du}{dy}\right)_{y=0} = -0.6 \times 0 + 12 = 12/s.$

at y =10 cm, Velocity gradient, $\left(\frac{du}{dy}\right)_{y=10} = -0.6 \times 10 + 12 = -6 + 12 = 6/s.$

at y = 20 cm, Velocity gradient, $\left(\frac{du}{dy}\right)_{y=20} = -0.6 \times 20 + 12 = -12 + 12 = 0$

Shear Stresses:

Shear stresses is given by, $\tau = \mu \frac{du}{dy}$

i. Shear stress at y = 0 , $\tau = \mu\left(\frac{du}{dy}\right)_{y=0} = 0.85 \times 12.0 = 10.2 N/m^2$

ii. Shear stress at y = 10 , $\tau = \mu\left(\frac{du}{dy}\right)_{y=10} = 0.85 \times 6.0 = 5.1 N/m^2$

iii. Shear stress at y = 20 , $\tau = \mu\left(\frac{du}{dy}\right)_{y=20} = 0.85 \times 0 = 0$

4. A 15 cm diameter vertical cylinder rotates concentrically inside another cylinder of diameter 15.10 cm. Both cylinders are 25 cm high. The space between the cylinders is filled with a liquid whose viscosity is unknown. If a torque of 12.0 Nm is required to rotate the inner cylinder at 100 rpm determine the viscosity of the fluid.

Solution:

Diameter of cylinder = 15 cm = 0.15 m

Diameter of outer cylinder = 15.10 cm = 0.151 m

Length of cylinder ⇒ L = 25 cm = 0.25 m

Torque T= 12 Nm ; N = 100 rpm.

Viscosity = μ

Tangential velocity of cylinder $u = \frac{\pi DN}{60} = \frac{\pi \times 0.15 \times 100}{60} = 0.7854 \quad m/s$

Surface area of cylinder $A = \pi D \times L = \pi \times 0.15 \times 0.25$

= 0.1178 m^2

$\tau = \mu \frac{du}{dy}$ $\qquad du = u - 0 = u = 0.7854 \ m/s$

$$dy = \frac{0.151 - 0.150}{2} = 0.0005 \ m$$

$$\tau = \frac{\mu \times 0.7854}{0.0005}$$

Shear force, $F = Shear\ Stress \times Area = \frac{\mu \times 0.7854}{0.0005} \times 0.1178$

Torque $T = F \times \frac{D}{2}$

$$12.0 = \frac{\mu \times 0.7854}{0.0005} \times 0.1178 \times \frac{0.15}{2}$$

$$\mu = \frac{12.0 \times 0.0005 \times 2}{0.7854 \times 0.1178 \times 0.15} = 0.864 Ns/m^2$$

$$\mu = 0.864 \times 10 = 8.64\ poise.$$

5. The dynamic viscosity of oil, used for lubrication between a shaft and sleeve is 6 poise. The shaft is of diameter 0.4 m and rotates at 190 rpm. Calculate the power lost in the bearing for a sleeve length of 90 mm. The thickness of the oil film is 1.5 mm.

Given, $\mu = 6 poise = \frac{6}{10} \frac{Ns}{m^2} = 0.6 \frac{Ns}{m^2}$

D = 0.4 m $\quad L = 90mm = 90 \times 10^{-3} m$

N = 190 rpm. $\quad t = 1.5mm = 1.5 \times 10^{-3} m$

$$Power = \frac{2\pi NT}{60} W$$

$$T = force \times \frac{D}{2} Nm.$$

$$F = Shear\ stress \times Area \ = \tau \times \pi DL$$

$$\tau = \mu \frac{du}{dy} N/m^2$$

$$u = \frac{\pi\ DN}{60}\ m/s.$$

Tangential Velocity of shaft, $u = \frac{\pi\ DN}{60} = \frac{\pi \times 0.4 \times 190}{60} = 3.98\ m/s.$

du = change of velocity = u – 0 = u = 3.98 m/s.

$dy = t = 1.5 \times 10^{-3}\ m.$

$$\tau = \mu \frac{du}{dy} \Rightarrow \quad \tau = 10 \times \frac{3.98}{1.5 \times 10^{-3}} = 1592\,N/m^2$$

Shear force on the shaft F = Shear stress x Area

$$F = 1592 \times \pi D \times L = 1592 \times \pi \times 0.4 \times 90 \times 10^{-3} = 180.05N$$

Torque on the shaft, $T = Force \times \frac{D}{2} = 180.05 \times \frac{0.4}{2} = 36.01 \quad Ns.$

$$\text{Power lost} = \frac{2\pi \text{NT}}{60} = \frac{2\pi \times 190 \times 36.01}{60} = 716.48\,W$$

6.If the velocity distribution over a plate is given by $u = \frac{2}{3}y - y^2$ in which U is the velocity in m/s at a distance y meter above the plate, determine the shear stress at y = 0 and y = 0.15 m. Take dynamic viscosity of fluid as 8.63 poise.

Given:

$$u = \frac{2}{3}y - y^2$$

$$\frac{du}{dy} = \frac{2}{3} - 2y$$

$$\left(\frac{du}{dy}\right)_{y=0} = \frac{2}{3} - 2(0) = \frac{2}{3}$$

$$\left(\frac{du}{dy}\right)_{y=0.15} = \frac{2}{3} - 2\times(0.17) = 0.667 - 0.30$$

$$\mu = 8.63 poise = \frac{8.63}{10} \text{ SI units } = 0.863 \text{ Ns / m}^2$$

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

i. Shear stress at y = 0 is given by

$$\tau_0 = \mu\left(\frac{du}{dy}\right)_{y=0} = 0.863\times 0.667 = 0.5756 \; N/m^2$$

ii. Shear stress at y = 0.15 m is given by

$$(\tau)_{y=0.15} = \mu\left(\frac{du}{dy}\right)_{y=0.15} = 0.863\times 0.367 = 0.3167 \; N/m^2$$

7.The diameters of a small piston and a large piston of a hydraulic jack at3cm and 10 cm respectively. A force of 80 N is applied on the small piston Find the load lifted by the large piston when:

a. **The pistons are at the same level**
b. **Small piston in 40 cm above the large piston.**

The density of the liquid in the jack in given as 1000 kg/m^3

Given: Dia of small piston d = 3 cm.

$\therefore$ Area of small piston , $a = \frac{\pi}{4} d^2 = \frac{\pi}{4}\times(3)^2 = 7.068 cm^2$

Dia of large piston, D = 10 cm

$\therefore$ Area of larger piston, $A = \frac{P}{4} \times (10)^2 = 78.54 cm^2$

Force on small piston, F = 80 N

Let the load lifted = W

a. When the pistons are at the same level

Pressure intensity on small piston

$$P = \frac{F}{a} = \frac{80}{7.068} N/cm^2$$

This is transmitted equally on the large piston.

$\therefore$ Pressure intensity on the large piston $= \frac{80}{7.068}$

$\therefore$ Force on the large piston = Pressure x area

$$= = \frac{80}{7.068} \text{ x } 78.54 \text{ N} = 888.96 \text{ N.}$$

b. when the small piston is 40 cm above the large piston

Pressure intensity on the small piston

$$= \frac{F}{a} = \frac{80}{7.068} N/cm^2$$

$\therefore$ Pressure intensity of section A – A

$= \frac{F}{a} +$ pressure intensity due of height of 40 cm of liquid. P = pgh.

But pressure intensity due to 40cm. of liquid

$$= p \times g \times h = 1000 \times 9.81 \times 0.4 N/m^2$$

$$= \frac{1000 \times 9.81 \times 0.4}{10^4} N/cm^2 = 0.3924 N/cm^2$$

$\therefore$ Pressure intensity at section

$$A - A = \frac{80}{7.068} + 0.3924$$

$= 11.32 + 0.3924 = 11.71$ N/cm^2

Pressure intensity transmitted to the large piston = 11.71 N/cm^2

Force on the large piston = Pressure x Area of the large piston

$$= 11.71 \times A = 11.71 \times 78.54$$

= 919. 7 N.