Problems of chapter One

Properties of Fluids **Dr.Abdulkareem A.Wahab**

Problem 1.1 /

Calculate the mass density (ρ) , specific weight (weight density γ) , specific gravity (relative density S) of one liter of a liquid which weighs 7 N ?

Solution :

One liter = 1000 cm^3 = 10^3 cm^3

1 m^3 = 10^6 cm^3

One liter = $\frac{1\times10^3}{10^6}$ = 10^{-3} m^3

w = m g (Newton second law , F = ma)

$$m = \frac{w}{g} = \frac{7}{9.8} = 0.714 \text{ kg.}$$

$$\rho = \frac{m}{v} = \frac{0.714}{10^{-3}} = 714 \text{ kg / m}^3$$ (mass density)

$$\gamma = \frac{w}{v} = \frac{7}{10^{-3}} = 7000 \text{ N/ m}^3$$ (specific weight or weight density)

$$S_l = \frac{\rho_l}{\rho_w} = \frac{714}{1000} = 0.714$$ (specific gravity or relative density)

Problem 1.2 /

Calculate the mass density , specific weight and weight of one liter of petrol of specific gravity 0.7 ?

Solution :

One liter = 10^{-3} m^3

$$S_L = \frac{\rho_l}{\rho_w}$$

$$\rho_L = S_L\rho_w = 0.7 \times 1000 = 700 \text{ kg / m}^3$$ (mass density)

$\gamma_L = \rho_l\, g = 700 \times 9.8 = 6860 \ \text{N/ m}^3$ **(specific weight)**

$$\gamma = \frac{w}{v}$$

$$w = \gamma \ v = 6860 \times 10^{-3} = 6.86 \ \text{N}$$

<u>Problem 1.3</u> /

A distance between the moving plate and fixed plate is 0.025 mm , the velocity of moving plate is 60 cm /s , requires a force of 2 N /m^2 (shear stress). Determine the fluid viscosity between the plates ?

<u>Solution</u> :

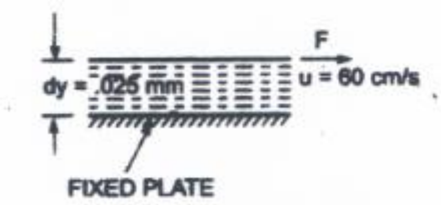


Fig. 1.3

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

du = change of velocity = u - 0 = 60 cm /s = 0.6 m /s

dy = change of distance = 0.025 mm = 0.025 × 10^{-3} m

$$\tau = 2 \ \text{N / m}^2$$

$$\mu = \frac{\tau}{\frac{du}{dy}} = \frac{2\times10^{-3}}{0.6/0.025} = 8.33 \times 10^{-5} \ \text{N.s / m}^2$$

$$= 8.33\times 10^{-5} \times 10 = 8.33 \times 10^{-4} \ \text{poise}$$

<u>Problems 1.4</u> /

A flat plate of area 1.5 × 10^6 mm^{2}is pulled with a speed of 0.4 m/s relative to another plate located at a distance of 0.15 mm from it. Find the force and power required to maintain this speed , if the fluid separated them is having viscosity as 1 poise.

Solution :

$$A = 1.5 \times 10^6 \text{ mm}^2 = 1.5 \text{ m}^2$$

$$\mu = 1 \text{ poise} = 0.1 \text{ N.s / m}^2$$

$$\tau = \mu \frac{du}{dy} = 0.1 \times \frac{0.4}{0.15 \times 10^{-3}} = 266.66 \text{ N / m}^2$$

$$\tau = \frac{F}{A}$$

$$F = \tau A = 266.66 \times 1.5 = 400 \text{ N}$$

P = F u (P is power)

$$P = 400 \times 0.4 = 160 \text{ watt}$$

Problem 1.5 /

Determine the intensity of shear stress of an oil having viscosity (μ) is 1 poise . The oil is used for lubricating the clearance between a shaft of diameter 10 cm and its journal bearing. The clearance is 1.5 mm and the shaft rotates at 150 rpm .

Solution :

$$\mu = 1 \text{ poise} = 0.1 \text{ N.s / m}^2$$

$$D = 1.5 \text{ cm} = 0.1 \text{ m}$$

$$u = \frac{\pi D N}{60} = \frac{\pi \times 0.1 \times 150}{60} = 0.785 \text{ m/ s}$$

$$\tau = \mu \frac{du}{dy} = 0.1 \times \frac{0.785}{1.5 \times 10^{-3}} = 52.33 \text{ N/ m}^2$$

Problem 1.6 /

Determine the dynamic viscosity of an oil , which is used for lubrication between a square plate of size 0.8 m × 0.8 m and an inclined plane with angle of inclination 30^0 as shown in Fig.(1.4) . The weight of the plate is 300 N and it slides down the inclined plane with a uniform velocity of 0.3 m /s . The thickness of oil film is 1.5 mm .

Solution :

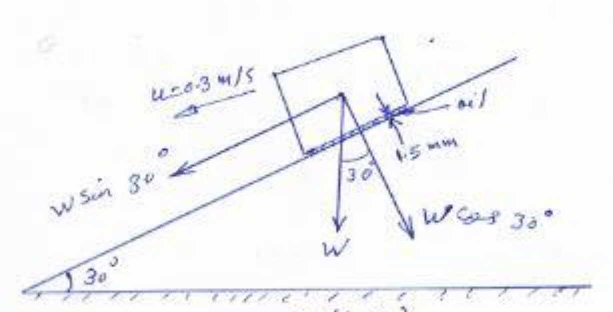


Fig.(1.4)

A = 0.8 × 0.8 = 0.64 m^2

Thickness of oil film = t = dy = 1.5 mm = 1.5 × 10^{-3} m

Component of weight W , along the plane = W Sin 30^o

= 300 × 0.5 = 150 N

$$\tau = \frac{F}{A} = \frac{150}{0.64} = 234.37 \text{ N/m}^2$$

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

$$\mu = \frac{\tau}{\frac{du}{dy}} = \frac{234.37}{\frac{0.3}{1.5 \times 10^{-3}}} = 1.17 \text{ N.s /m}^2 = 1.17 \times 10 = 11.7 \text{ poise}$$

Problem 1.7 /

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

Solution :

t = dy = 1.25 cm = 0.0125 m

μ = 14 poise = 1.4 N.s / m^2

$$\tau = \mu \frac{du}{dy} = 1.4 \times \frac{2.5}{0.0125} = 280 \text{ N / m}^2$$

Problem 1.8 /

The space between two square flat parallel plate is filled with oil . Each side of the plate is 60 cm . The thickness of the oil film is 12.5 mm. The upper plate , which moves at 2.5 m/s are requires a force of 98.1 N to maintain the speed.Determine : (1) the dynamic viscosity of the oil in poise .

(2) the kinematic viscosity of the oil in stokes , if the specific gravity(S) of the oil is 0.95 .

Solution :

Area (A) = $0.6 \times 0.6 = 0.36 \ m^2$

$dy = 12.5 \times 10^{-3}$ m

du = 2.5 m/s

$$\tau = \frac{F}{A} = \frac{98.1}{0.36} = 272.5 \ N/m^2$$

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

(1) $$\mu = \frac{\tau}{\frac{du}{dy}} = \frac{272.5}{\frac{2.5}{12.5 \times 10^{-3}}} = 1.36 \ N/m^2 = 13.6 \text{ poise}$$

(2) $\rho_{oil} = 0.95 \times 1000 = 950 \ kg/m^3$

$$\nu = \frac{\mu}{\rho} = \frac{1.36}{950} = 0.00143 \ m^2/s$$

$$\nu = 0.00143 \times 10^4 \ cm^2/s$$

$$= 14.3 \ cm^2/s = 14.3 \text{ stokes}$$

Problem 1.9 /

Find the kinematic viscosity of an oil having density 981 kg/m^3. The shear stress a point in oil is 0.2452 N/m^2 and velocity gradient (du / dy) at the point is 0.2 per second .

Solution :

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

$$\mu = \frac{\tau}{\frac{du}{dy}} = \frac{0.2452}{0.2} = 1.226 \ \text{N.s / m}^2$$

$$\nu = \frac{\mu}{\rho} = \frac{1.226}{981} = 0.0012 \ \text{m}^2\text{/s} = 0.0012 \times 10^4 \ \text{cm}^2\text{/s} = 12 \ \text{stokes} .$$

Problem 1.10 /

Determine the specific gravity (S) of a fluid having a dynamic viscosity (μ) is 0.05 poise and kinematic viscosity 0.035 stokes ?

Solution :

$$\mu = 0.05 \ \text{poise} = 0.005 \ \text{N.s / m}^2$$

$$\nu = 0.035 \ \text{stokes} = 0.035 \ \text{cm}^2\text{ / s} = 0.035 \times 10^{-4} \ \text{m}^2\text{ / s}$$

$$\nu = \frac{\mu}{\rho} \quad , \quad \rho_f = \frac{\mu}{\nu} = \frac{0.005}{0.035 \times 10^{-4}} = 1428.5 \ \text{kg / m}^3$$

$$S_f = \frac{\rho_f}{\rho_w} = \frac{1428.5}{1000} = 1.4285$$

Problem 1.11 /

Determine the viscosity of a liquid having kinematic viscosity 6 stokes and specific gravity 1.9 ?

Solution :

$$\nu = 6 \ \text{stokes} = 6 \ \text{cm}^2\text{/ s} = 6 \times 10^{-4} \ \text{m}^2 \text{/s}$$

$$S_f = \frac{\rho_f}{\rho_w} \quad , \quad \rho_f = S_f \times \rho_w = 1.9 \times 1000 = 1900 \ \text{kg / m}^3$$

$$\nu = \frac{\mu}{\rho_f} \quad , \quad \mu = \nu \times \rho_f = 6 \times 10^{-4} \times 199 = 1.14 \ \text{N.s / m}^2$$

$$= 11.4 \ \text{poise} .$$

Problem 1.12 /

The velocity distribution for flow over a flat plate is given by equation : $u = \frac{3}{4} y - y^2$ in which u is the velocity in m /s at a distance (y) m above the plate.

Determine the shear stress at y = 0.15 m . Take dynamic viscosity of fluid as 0.85 poise .

Solution :

$$u = \frac{3}{4}y - y^2 \quad , \quad \frac{du}{dy} = \frac{3}{4} - 2y$$

$$\text{At } y = 0.15 \text{ m} \quad , \quad \frac{du}{dy} = \frac{3}{4} - 2 \times 0.15 = 0.45$$

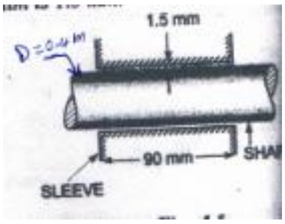
$$\text{If } \mu = 8.5 \text{ poise} = 0.85 \text{ N.s / m}^2$$

$$\tau = \mu \frac{du}{dy} = 0.85 \times 0.45 = 0.3825 \text{ N / m}^2$$

Problem 1.13 /

The dynamic viscosity of an 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 a bearing for a sleeve length of 90 mm. The thickness of the oil film is 1.5 mm.

Solution :



$\mu = 6$ **poise** $= 0.6$ **N.s / m²**

$$u = r\,\omega = \frac{D}{2} \times \frac{2\pi N}{60} = \frac{\pi D N}{60} = \frac{\pi \times 0.4 \times 190}{60} = 3.98 \text{ m/s}$$

$$\tau = \mu \frac{du}{dy} = 0.6 \frac{3.98}{1.5 \times 10^{-3}} = 1592 \text{ N / m}^2$$

$$\tau = \frac{F}{A} \qquad (\text{ A is surface area })$$

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

$$T = F \times \frac{D}{2} \qquad (\text{ T is Torque N.m })$$

$$= 180.05 \times \frac{0.4}{2} = 36.01 \text{ N.m}$$

$$\text{Power (lost)} = T\,\omega = 36.01 \times \frac{2\pi N}{60} = 716\ 48 \text{ watt .}$$

Problem 1.14 /

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 liquid whose viscosity is unknown . If a torque of 12 N.m is required to rotate the inner cylinder at 100 rpm., determine the viscosity of the fluid ?

Solution :

$$u = r\,\omega = \frac{D}{2} \times \frac{2\pi N}{60} = \frac{\pi D N}{60} = \frac{\pi \times 0.15 \times 100}{60} = 0.7854 \text{ m/s}$$

$$\text{Surface area (A)} = \pi D L = \pi \times 0.15 \times 0.25 = 0.1178 \text{ m}^2$$

$$dy = \frac{D_{outer} - D_{inner}}{2} = \frac{0.151 - 0.15}{2} = 0.0005 \text{ m}$$

$$\tau = \mu \frac{du}{dy} = \frac{\mu \times 0.7854}{0.0005} \qquad (1)$$

$$\tau = \frac{F}{A} \quad , \quad F = \tau \times A = \frac{\mu \times 0.7854 \times 0.1178}{0.0005} \qquad (2)$$

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

$$12 = \frac{\mu \times 0.7854 \times 0.1178}{0.0005} \times \frac{0.15}{2}$$

$$\mu = 0.864 \text{ N.s / m}^2 = 8.64 \text{ poise .}$$

Problem 1.15 /

The weight density of gas is 16 N/m^3 at $25^o c$ and at an absolute pressure of 0.25 N/mm^2. Determine the mass density of gas and gas constant ?

Solution:

$$T_{abs.} = 25 + 273 = 298^o \text{ K}$$

$P = 0.25 \times 10^6 = 25 \times 10^4$ N/m²

$\gamma = \rho\, g$

$\rho = \frac{\gamma}{g} = \frac{16}{9.81} = 1.63$ kg/ m³, $\frac{p}{\rho} = R\,T$, $R = \frac{p}{\rho T} = \frac{25\times10^4}{1.63\times298}$

= 532.5 N.m/kg.k

Problem 1.16 /

A cylinder of 0.6 m³ in volume contains air at 50°c and 0.3 N/mm² absolute pressure. The air is compressed to 0.3 m³. Find (1) pressure inside the cylinder , assuming isothermal process and (2) pressure and temperature, assuming adiabatic process.(Take 1.4).

Solution :

$V_1 = 0.6\ m^3$, $T_1 = 50 + 273 = 323^o\ k$, $P_1 = 30\times 10^4\ N/m^2$

$V_2 = 0.3\ m^3$, $k = 1.4$

(1) Isothermal process :

$\frac{P}{\rho}$ = constant , or $P\,V$ = constant

$P_1 V_1 = P_2 V_2$, $P_2 = \frac{p_1 V_1}{V_2} = \frac{30\times10^4\ \times0.6}{0.3} = 0.6 \times 10^6\ N/m^2$

(2) Adiabatic process :

$\frac{P}{\rho^k}$ = constant or $P\,V^k$ = constant

$P_1 V_1^k = P_2 V_2^k$

$P_2 = P_1 \frac{V_1^k}{V_2^k} = 30\times10^4 \times \left(\frac{0.6}{0.3}\right)^{1,4} = 30\times10^4 \times 2^{1.4}$

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

$\frac{R\,T}{V} \times V^k$ = constant , $R\,T\,V^{k-1}$ = constant

$T\,V^{k-1}$ = constant (R is constant)

$T_1 V_1^{k-1} = T_2 V_2^{k-1}$, $T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{1.4-1}$

$T_2 = 323\,(\frac{0.6}{0.3})^{0.4} = 323 \times 10^{0.4} = 426.2^{o}\ k$

$T_2 = 426.2 - 273 = 153.2^{o}c$

Problem 1.17 /

Determine the Bulk modulus of elasticity of a liquid. If the pressure of the liquid increased from 70 N/cm^2 to 130 N/cm^2. The volume of the liquid decreases by 0.15 per cent (15%) .

Solution :

Increase of pressure (dP) = 130 - 70 = 60 N/cm^2

Decrease of Volume (dV) = 15 %

$K = \frac{dp}{\frac{dV}{V}} = \frac{60}{\frac{15}{100}} = 4 \times 10^4\ N / cm^2$

Problem 1.18 /

What is the Bulk modulus of elasticity of a liquid which is compressed in a cylinder from a volume of 0.0125 m^3 at 80 N/cm^2 pressure to a volume of 0.0124 m^3 at 150 N/cm^2 pressure .

Solution :

$d\,V = 0.0125 - 0.0124 = 0.0001\ m^3$

$d\,P = 150 - 80 = 70\ N/cm^2$

$K = \frac{dP}{\frac{-dV}{V}} = \frac{70}{\frac{0.0001}{0.0125}} = 70 \times 125\ N/cm^2$

Problem 1.19 /

A surface tension of water in contact with air at 20^{o}c is 0.0725 N/m. The pressure inside a droplet of water is to be 0.02 N/cm^2 greater than the outside pressure. Calculate the diameter of the droplet of water .

Solution :

$P = 0.02 \times 10^4$ N/m^2

$$P = \frac{4\,\sigma}{d}\ ,\ d = \frac{4\sigma}{P} = \frac{4 \times 0.0725}{0.02 \times 10^4} = 0.00145 \text{ m} = 1.45 \text{ mm.}$$

Problem 1.20 /

Find the surface tension in a soap bubble of a 40 mm diameter , when the inside pressure is 2.5 N/m^2 above atmospheric pressure .

Solution :

$$P = \frac{8\,\sigma}{d} \quad , \quad \sigma = \frac{P\,d}{8} = \frac{2.5 \times 40 \times 10^{-3}}{8} = 0.0125 \text{ N/m}$$

Problem 1.21 /

The pressure outside the droplet of water of diameter 0.04 mm is 10.32 N/cm^2 (atmospheric pressure) . Calculate the pressure within the droplet , if surface tension is given as 0.0725 N/m of water .

Solution :

$$P_{inside} = \frac{4\,\sigma}{d} = \frac{4 \times 0.0725}{0.04 \times 10^{-3}} = 7250 \text{ N/ m}^2 = 0.725 \text{ N / cm}^2$$

$$P_{outside} = P_{inside} + P_{atm.} = 0.725 + 10.32 = 11.045 \text{ N / cm}^2$$

Problem 1.22 /

Calculate the capillary effect in millimeter in a glass tube of 4 mm diameter, when immersed in (1) water , and (2) mercury. The values of the surface tension of water and mercury are 0.073575 N/m and 0.51 N/m respectively. The angle of contact for mercury 1.30^o.

Solution :

$$h = \frac{4\,\sigma\cos\theta}{\rho\,g\,d}$$

(1) For water rise , $h = \frac{4 \times 0.073575}{1000 \times 9.81 \times 4 \times 10^{-3}}$ **(ϴ is zero)**

h = 7.51 ×10^{-3} m = 7.51 mm

(2) For mercury depression , h = $\frac{-4 \times 0.51 \times \cos 1.30^o}{13600 \times 9.81 \times 4 \times 10^{-3}}$

h = -2.46 × 10^{-3} m = - 2.46 mm

Problem 1.23 /

Find the diameter of glass tube (capillary tube) that can be used to measure surface tension of water in contact with air as 0.073575 N/m .

Solution :

$h = \frac{4\sigma}{\rho g d}$, $d = \frac{4\sigma}{\rho g h} = \frac{4 \times 0.073575}{1000 \times 9.81 \times 2 \times 10^{-3}}$

= 0.015 m = 1.5 cm.

Problem 1.24 /

An oil of viscosity 5 poise is used for lubrication between a shaft and sleeve. The diameter of the shaft is 0.5 m and it rotates at 200 rpm. Calculate the power lost in oil for a sleeve length of 100 mm . The thickness of oil film is 1 mm.

Solution :

$u = r\ \omega = \frac{D}{2} \times \frac{2\pi N}{60} = \frac{\pi D N}{60} = \frac{\pi \times 0.5 \times 200}{60}$ = 5.235 rad / s

$\mu = 5 \times 0.1 = 0.5$ N.s / m^2

$\tau = \mu \frac{du}{dy} = \frac{0.5 \times 5.235}{1 \times 10^{-3}} = 2617.5$ N / m^2

$\tau = \frac{F}{A}$, $F = \tau A = \tau . \pi D L = 2617.5 \times \pi \times 0.5 \times 1 \times 10^{-3}$

= 410.95 N

Torque (T) = $F . \frac{D}{2} = 410.95 \times \frac{0.5}{2} = 102.74$ N.m

Power (lost) = Torque . $\omega = 102.74 \times \frac{2\pi N}{60}$

= 2150 watt = 2.15 kw .