Manometers:

Manometer is an instrument for measuring the pressure of a fluid, consisting of a tube filled with a heavier gauging liquid, the level of the liquid being determined by the fluid pressure and the height of the liquid being indicated on a scale. A U-tube manometer consists of a glass tube bent in U-Shape, one end of which is connected to gauge point and the other end is exposed to atmosphere.

Manometric liquids:

1. Manometric liquids should neither mix nor have any chemical reaction with the liquid whose pressure intensity is to be measured.
2. It should not undergo any thermal variation.
3. Manometric liquid should have very low vapour pressure.
4. Manometric liquid should have pressure sensitivity depending upon the magnitude of pressure to be measured and accuracy requirement.

Convert all vertical columns of liquids to meters of water by multiplying them by corresponding specify gravity.

To write the manometric equation:

1. Convert all given pressure to meters of water and assume unknown pressure in meters of waters.
2. Proceeding from one end towards the other the following points must be considered.

- Any horizontal movement inside the same liquid will not cause change in pressure.
- Vertically downward movement causes increase in pressure and upward motion cause decrease in pressure.
- Convert all vertical columns of liquids to meters of water by multiplying them by corresponding specify gravity.
- Take atmospheric pressure as zero (gauge pressure computation).

Simple U-Tube Manometer: It consist of glass tube in U shape one end of which is connected to a point at which pressure is to be measured and other end remains open to the atmosphere as shown in fig. The tube generally contains mercury or any other liquid whose specific gravity is greater than the specific gravity of the liquid whose pressure is to be measured.

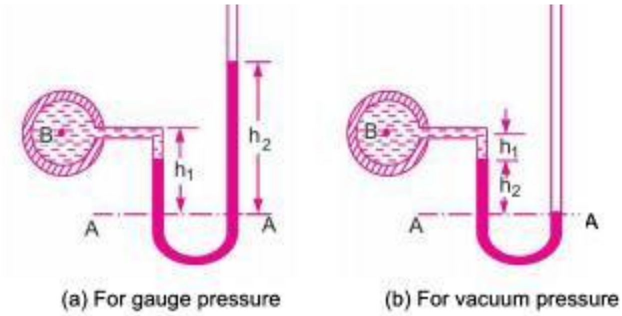


Fig: 12. Simple U tube Manometer

For Gauge Pressure. Let B is the point at which pressure is to be measured, whose value is p. The datum line is A-A Let, H_1 = Height of light liquid above the datum line

H_2 = Height of heavier liquid above the datum line

S_1 = Specific gravity of light liquid

ρ_1 = Density of light liquid = 1000 x S_1

S_2 = Specific gravity of heavy liquid

ρ_2 = Density of heavy liquid = 1000 x S_2

As the pressure is the same for the horizontal surface. Hence pressure above the horizontal datum line *A-A* in the left column and in the right column of U-tube manometer should be same.

Pressure above *A-A* in the left column $= p + \rho_1 \times g \times h_1$

Pressure above *A-A* in the right column $= \rho_2 \times g \times h_2$

Hence equating the two pressures $p + \rho_1 g h_1 = \rho_2 g h_2$

$\therefore \quad p = (\rho_2 g h_2 - \rho_1 \times g \times h_1).$

(*b*) **For Vacuum Pressure.** For measuring vacuum pressure, the level of the heavy liquid in the manometer will be as shown in Fig. 2.9 (*b*). Then

Pressure above *A-A* in the left column $= \rho_2 g h_2 + \rho_1 g h_1 + p$

Pressure head in the right column above *A-A* $= 0$

$\therefore \quad \rho_2 g h_2 + \rho_1 g h_1 + p = 0$

$\therefore \quad p = -(\rho_2 g h_2 + \rho_1 g h_1).$

Differential U-tube manometer

Let, A and B are the two pipes carrying liquids of specific gravity s_1 and s_3 & s_2 = specific gravity of manometer liquid.

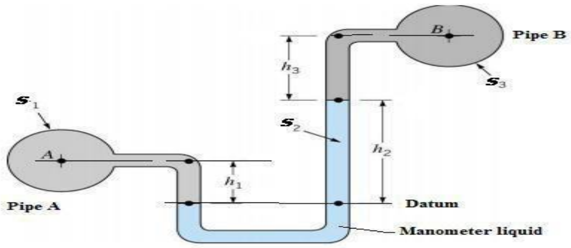


Fig:13. Differential U-tube Manometer

Let two point A & B are at different level and also contains liquids of different sp.gr. These points are connected to the U-tube differential manometer. Let the pressure at A and B are P_A and P_B

Let h = Difference of mercury level in the U-tube.

y = Distance of the centre of B, from the mercury level in the right limb.

x = Distance of the centre of A, from the mercury level in the right limb.

ρ_1 = Density of liquid at A.

ρ_2 = Density of liquid at B.

ρ_g = Density of heavy liquid or mercury.

Taking datum line at X-X.

Pressure above X-X in the left limb $= \rho_1 g(h + x) + p_A$

where p_A = pressure at A.

Pressure above X-X in the right limb $= \rho_g \times g \times h + \rho_2 \times g \times y + p_B$

where p_B = Pressure at B.

Equating the two pressure, we have

$$\rho_1 g(h + x) + p_A = \rho_g \times g \times h + \rho_2 gy + p_B$$

$$\therefore \quad p_A - p_B = \rho_g \times g \times h + \rho_2 gy - \rho_1 g(h + x)$$

$$= h \times g(\rho_g - \rho_1) + \rho_2 gy - \rho_1 gx$$

$\therefore$ Difference of pressure at A and $B = h \times g(\rho_g - \rho_1) + \rho_2 gy - \rho_1 gx$

In Fig. 2.18 (*b*), the two points A and B are at the same level and contains the same liquid of density ρ_1. Then

Pressure above X-X in right limb $= \rho_g \times g \times h + \rho_1 \times g \times x + p_B$

Pressure above X-X in left limb $= \rho_1 \times g \times (h + x) + p_A$

Equating the two pressure

$$\rho_g \times g \times h + \rho_1 gx + p_B = \rho_1 \times g \times (h + x) + p_A$$

$$\therefore \quad p_A - p_B = \rho_g \times g \times h + \rho_1 gx - \rho_1 g(h + x)$$

$$= g \times h(\rho_g - \rho_1).$$

Problems:

1. Calculate the sp.weight, density and sp.gravity of one litre of liquid which weights 7N.

Sol:

$$\text{Volume} = 1 \text{ litre} = \frac{1}{1000}\,\text{m}^3 \quad \left(\because\ 1 \text{ litre} = \frac{1}{1000}\,\text{m}^3 \text{ or } 1 \text{ litre} = 1000\,\text{cm}^3\right)$$

$$\text{Weight} = 7\text{ N}$$

(*i*) Specific weight (w) $= \dfrac{\text{Weight}}{\text{Volume}} = \dfrac{7\text{ N}}{\left(\frac{1}{1000}\right)\text{m}^3} =$ **7000 N/m³. Ans.**

(*ii*) Density (ρ) $= \dfrac{w}{g} = \dfrac{7000}{9.81}\ \text{kg/m}^3 =$ **713.5 kg/m³. Ans.**

(*iii*) Specific gravity $= \dfrac{\text{Density of liquid}}{\text{Density of water}} = \dfrac{713.5}{1000} \quad \{\because\ \text{Density of water} = 1000\ \text{kg/m}^3\}$

$=$ **0.7135. Ans.**

2. Calculate the density, sp.weight and weight of one litre of petrol of specific gravity = 0.7

Solution. Given : Volume = 1 litre = $1 \times 1000 \text{ cm}^3 = \frac{1000}{10^6} \text{ m}^3 = 0.001 \text{ m}^3$

Sp. gravity $S = 0.7$

(*i*) *Density* (ρ)

Using equation (1.1*A*),

Density (ρ) $= S \times 1000 \text{ kg/m}^3 = 0.7 \times 1000 =$ **700 kg/m³. Ans.**

(*ii*) *Specific weight* (*w*)

Using equation (1.1), $w = \rho \times g = 700 \times 9.81 \text{ N/m}^3 =$ **6867 N/m³. Ans.**

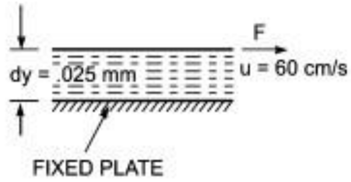
(*iii*) *Weight* (*W*)

We know that specific weight $= \frac{\text{Weight}}{\text{Volume}}$

or $w = \frac{W}{0.001}$ or $6867 = \frac{W}{0.001}$

$\therefore$ $W = 6867 \times 0.001 =$ **6.867 N. Ans.**

3. A plate 0.023 mm distant from a fixed plate moves at 60 cm/s and requires a force of 2N per unit area i.e 2 N/m^2 to maintain this speed. Determine the fluid viscosity between the plates.



Solution. Given :

Distance between plates, $dy = .025 \text{ mm} = .025 \times 10^{-3} \text{ m}$

Velocity of upper plate, $u = 60 \text{ cm/s} = 0.6 \text{ m/s}$

Force on upper plate, $F = 2.0 \frac{\text{N}}{\text{m}^2}$.

This is the value of shear stress *i.e.*, τ

Let the fluid viscosity between the plates is μ.

Using the equation (1.2), we have $\tau = \mu \frac{du}{dy}$.

where du = Change of velocity $= u - 0 = u = 0.60$ m/s

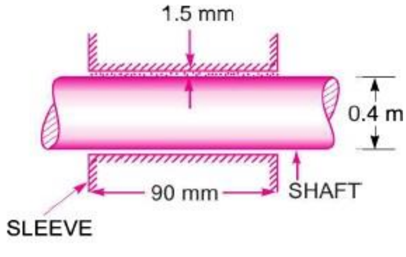
dy = Change of distance $= .025 \times 10^{-3}$ m

τ = Force per unit area $= 2.0 \frac{\text{N}}{\text{m}^2}$

$$\therefore \quad 2.0 = \mu \frac{0.60}{.025 \times 10^{-3}} \quad \therefore \quad \mu = \frac{2.0 \times .025 \times 10^{-3}}{0.60} = 8.33 \times 10^{-5} \frac{\text{Ns}}{\text{m}^2}$$

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

4. 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 90mm. The thickness of the oil film is 1.5mm.



Solution. Given :

Viscosity $\mu = 6$ poise $= \frac{6}{10} \frac{\text{N s}}{\text{m}^2} = 0.6 \frac{\text{N s}}{\text{m}^2}$

Dia. of shaft, $D = 0.4$ m

Speed of shaft, $N = 190$ r.p.m

Sleeve length, $L = 90 \text{ mm} = 90 \times 10^{-3}$ m

Thickness of oil film, $t = 1.5 \text{ mm} = 1.5 \times 10^{-3}$ m

Tangential velocity of shaft, $u = \dfrac{\pi D N}{60} = \dfrac{\pi \times 0.4 \times 190}{60} = 3.98$ m/s

Using the relation $\tau = \mu \dfrac{du}{dy}$

where du = Change of velocity = $u - 0 = u = 3.98$ m/s

dy = Change of distance = $t = 1.5 \times 10^{-3}$ m

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

This is shear stress on shaft

$\therefore$ Shear force on the shaft, F = Shear stress × Area

$$= 1592 \times \pi D \times L = 1592 \times \pi \times .4 \times 90 \times 10^{-3} = 180.05 \text{ N}$$

Torque on the shaft, $T = \text{Force} \times \dfrac{D}{2} = 180.05 \times \dfrac{0.4}{2} = 36.01$ Nm

$\therefore$ *Power lost $= \dfrac{2\pi NT}{60} = \dfrac{2\pi \times 190 \times 36.01}{60} =$ **716.48 W. Ans.**

5. The surface tension of water in contact with air at 20°C is 0.0725N/m. The pressure inside a droplet of water is to be 0.02 N/cm² greater then the outside pressure. Calculate the diameter of the droplet of water.

Solution. Given :

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

Pressure intensity, p in excess of outside pressure is

$$p = 0.02 \text{ N/cm}^2 = 0.02 \times 10^4 \frac{\text{N}}{\text{m}^2}$$

Let d = dia. of the droplet

we get $p = \dfrac{4\sigma}{d}$ or $0.02 \times 10^4 = \dfrac{4 \times 0.0725}{d}$

$$d = \frac{4 \times 0.0725}{0.02 \times (10)^4} = .00145 \text{ m} = .00145 \times 1000 = \mathbf{1.45 \text{ mm. Ans.}}$$

6. Calculate the capillary rise in a glass tube of 2.5mm diameter when immersed vertically in a) water b) Mercury. Take surface tension of 2.5 mm diameter when immersed vertically in contact with air. The specific gravity for mercury is given as 13.6 and angle of contact = 130°

Solution. Given :

Dia. of tube, $d = 2.5 \text{ mm} = 2.5 \times 10^{-3}$ m

Surface tension, σ for water $= 0.0725$ N/m

σ for mercury $= 0.52$ N/m

Sp. gr. of mercury $= 13.6$

$\therefore$ Density $= 13.6 \times 1000 \text{ kg/m}^3$.

(*a*) Capillary rise for water ($\theta = 0°$)

Using equation (1.20), we get $h = \dfrac{4\sigma}{\rho \times g \times d} = \dfrac{4 \times 0.0725}{1000 \times 9.81 \times 2.5 \times 10^{-3}}$

$= .0118 \text{ m} = \mathbf{1.18 \text{ cm. Ans.}}$

(*b*) For mercury

Angle of contact between mercury and glass tube, $\theta = 130°$

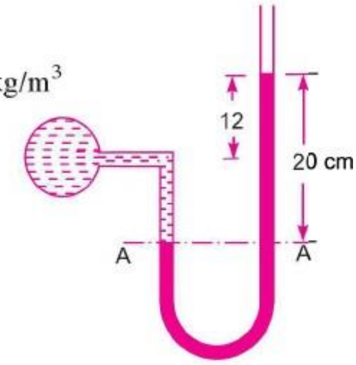
Using equation (1.21), we get $h = \dfrac{4\sigma \cos\theta}{\rho \times g \times d} = \dfrac{4 \times 0.52 \times \cos 130°}{13.6 \times 1000 \times 9.81 \times 2.5 \times 10^{-3}}$

$= -.004 \text{ m} = -\mathbf{0.4 \text{ cm. Ans.}}$

The negative sign indicates the capillary depression.

7. The right limb of a single U-tube manometer containing mercury is open to the atmosphere while the left limb is connected to a pipe in which a fluid of sp.gravity is 0.9 is flowing. The centre of the pipe is 12cm below the level of mercury in the right limb. Find the pressure of fluid in the pipe if the difference of mercury in the two limbs is 20cm.

Solution. Given :



Sp. gr. of fluid, $S_1 = 0.9$

$\therefore$ Density of fluid, $\rho_1 = S_1 \times 1000 = 0.9 \times 1000 = 900 \text{ kg/m}^3$

Sp. gr. of mercury, $S_2 = 13.6$

$\therefore$ Density of mercury, $\rho_2 = 13.6 \times 1000 \text{ kg/m}^3$

Difference of mercury level, $h_2 = 20 \text{ cm} = 0.2 \text{ m}$

Height of fluid from *A-A*, $h_1 = 20 - 12 = 8 \text{ cm} = 0.08 \text{ m}$

Let p = Pressure of fluid in pipe

Equating the pressure above *A-A*, we get

$$p + \rho_1 g h_1 = \rho_2 g h_2$$

$$p + 900 \times 9.81 \times 0.08 = 13.6 \times 1000 \times 9.81 \times .2$$

$$p = 13.6 \times 1000 \times 9.81 \times .2 - 900 \times 9.81 \times 0.08$$

$$= 26683 - 706 = 25977 \text{ N/m}^2 = \mathbf{2.597 \text{ N/cm}^2. \text{ Ans.}}$$