

* UNIT - 1 : FLUID STATICS *

Physical properties:

Density:

The density (ρ) of a fluid is defined as its mass per unit volume.

→ Its units are kg/m^3 .

→ ρ for water is generally taken as 1000 kg/m^3 .

Specific volume:

The specific volume (v) is the volume per unit mass. Its units are m^3/kg .

→ It is the reciprocal of the density.

specific Gravity:

specific gravity (or) relative density is the ratio of density of a fluid to the density of a standard fluid.

→ The standard fluid is water at 4°C . For gases

→ The standard fluid is Hydrogen at 0°C .

→ Specific gravity is dimensionless.

specific weight:

The specific weight of a fluid is its weight per unit volume.

→ Its units are N/m^3 .

→ Evidently $w = \rho g$.

→ For water the usual value of w is 9810 N/m^3 .

viscosity:

The viscosity of a fluid is considered to be a measure of its resistance to shear or angular deformation.

→ Viscosity is no role in static fluid.

DEFINITION OF FLUID

when a fluid is made to move, the cohesiveness between the fluid molecules tends to resist the motion, and greater the resistance greater the viscosity.

units of viscosity:

The dimensions of μ may be found as follows.

$$\mu = \frac{\tau}{\frac{du}{dx}} = \frac{\text{stress}}{\text{velocity} \div \text{distance}}$$

$$\begin{aligned}\text{stress} &= \frac{\text{Force}}{\text{Area}} \times \frac{\text{Distance}}{\text{Velocity}} \\ &= \frac{FL}{L^2} = \frac{FT}{L^2} \\ &= \text{mass} \times \text{Acceleration} \times \frac{T}{L^2} = m \frac{L}{T^2} \times \frac{T}{L^2} = \frac{M}{LT}\end{aligned}$$

Since $\mu = \frac{FT}{L^2}$ its units are Ns/m^2
 → It can be expressed in kg/m

Kinematic viscosity:

The kinematic viscosity ν of a fluid is defined as the ratio of dynamic viscosity to density.

$$\begin{aligned}\text{Dimensions of } \nu &= \frac{\mu}{\rho} \\ &= \frac{ML^{-1}T^{-1}}{ML^{-3}} = L^2T^{-1}\end{aligned}$$

→ units of ν are m^2

→ The CGS units of ν are $cm^2/(1 cm^2) = 1 \text{ stroke}$.

Surface tension:

There is always a surface of contact between a liquid and a gas or between two immiscible liquids like the water surface exposed to atmospheric pressure.

Weight density (ω):

weight density is the ratio of weight of fluid to volume of fluid.

$$\text{Weight density} (\omega) = \rho \cdot g$$

$$\omega = \frac{\text{Weight of fluid}}{\text{Volume of fluid}}$$

$$= \frac{N}{m^3}$$

$$g = 9.81 \text{ m/s}^2$$

$$s = \omega / g$$

Problem:

- i) The mass density of oil is 1.0 kg/m^3 . What is the weight density of oil? Specific gravity of oil? Specific volume of fluid.

Ans: Given that mass density of oil is (ρ) = 1.0 kg/m^3

$$\text{Weight density of oil} (\omega) = \rho \cdot g$$

$$\omega = 1.0 \times 9.81$$

$$\boxed{\omega = 9.81 \text{ N/m}^3}$$

Specific gravity of oil = $\frac{\rho_{\text{oil}}}{\rho_{\text{water}}}$

$$= \frac{1.0}{1000}$$

$$\boxed{s = 0.001 \text{ m/s}}$$

Newton's law of viscosity:

In a fluid the shear stress is proportional to shear strain.

$$\tau \propto \left(\frac{du}{dy} \right)$$

$$\boxed{\tau = \eta \cdot \frac{du}{dy}}$$

unit - 1 , pg - 3 / 16

problems

1) A plate 0.025 mm distance from a fluid, plate moves with 60 cm/s and required force of 2 N/unit area to maintain that speed determine the viscosity of the fluid.

Ans: Given that

$$\text{distance of fluid } dy = 0.025 \text{ mm} = 2.5 \times 10^{-5} \text{ m}$$

$$\text{viscosity } \mu = 60 \text{ cm/s} \Rightarrow 60 \times 10^{-2} \text{ m/s} = \frac{60}{100} \text{ m/s}$$

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

$$\text{viscosity } \mu = ?$$

w.k.t

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

$$2 = \mu \cdot \frac{0.6}{2.5 \times 10^{-5}}$$

$$\mu = 8.33 \times 10^{-5} \text{ N.s/m}^2$$

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

$$12 \times 10^6 \text{ Pa} = 120$$

2) The dynamic viscosity of oil used for lubrication between shaft and sleeve is 6 poise the shaft diameter is 0.4 m and rotates at 190 RPM. calculate the power lost in bearing for a speed length 90 mm. the thickness of oil film is 1.5 mm

Ans: Viscosity $\mu = 6 \text{ poise}$

$$\text{diameter } d = 0.4 \text{ m}$$

$$N = 190 \text{ RPM}$$

$$\text{Speed } L = 90 \text{ mm} \Rightarrow 90 \times 10^{-3} \text{ m}$$

$$\text{Thickness of film } (dy) = 1.5 \text{ mm} = 1.5 \times 10^{-3} \text{ m}$$

$$V = \frac{\pi d \omega}{160}$$

Unit-1, Pg-4/16

$$= \frac{3.14 \times 0.4 \times 190}{60}$$

$$= 3979.350 \text{ mm/s}$$

$$d u = 3.97 \text{ m/s}$$

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

$$\text{Surface contact area } A = \pi d L$$

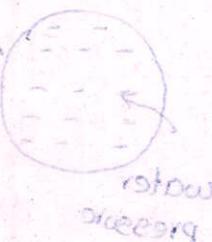
$$A = 3.14 \times 0.4 \times 90 \times 10^{-3}$$

$$\therefore A \approx 0.11 \text{ m}^2$$

From

$$\frac{F}{A} = \mu \cdot \frac{du}{dy}$$

$$\frac{F}{0.11} = 6 \cdot \frac{3.97}{1.5 \times 10^{-3}}$$



$$\therefore F = \frac{6 \times 3.97 \times 0.11}{1.5 \times 10^{-3}}$$

$$\therefore F = 1751.2 \times 10^3 \text{ N}$$

$$\text{Torque } \tau = F \times \perp \text{er distance}$$

$$= 1751.2 \times 0.2$$

$$= 350.24 \text{ N.m}$$

$$\text{Power } P = \frac{2\pi f T}{60}$$

$$= \frac{2 \times 3.14 \times 190 \times 350.24}{60}$$

$$\therefore P = 6968.63 \text{ W}$$

Surface tension (σ):

The force act (per unit length) in fluid surface is called

Surface tension. $Kg/m = N/m$

unit -1, pg - 5/16

of fluid

$$\sigma = \frac{F}{L} \times \mu_0 \times \mu_0 \epsilon =$$

$$\sigma = \frac{F}{L}$$

units are N/m

$$1 \text{ mm} / 0.028 \cdot \rho F P E =$$

$$1 \text{ mm} \cdot F P \cdot \epsilon = 96$$

In surface tension there are three types

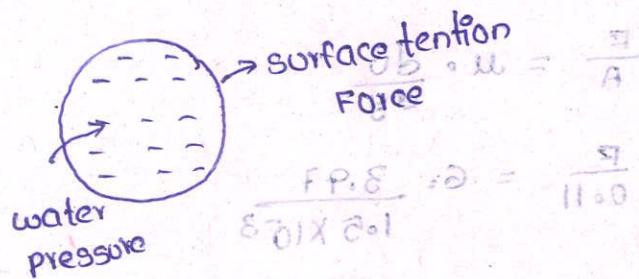
1) soap bubble

2) water droplet

3) water jet.

$$8 \cdot 01 \times 0^9 \times \mu_0 \times \mu_0 \epsilon = A$$

1) surface tension in liquid droplet:



more?

$$8 \cdot 01 \times 0^9 \times \mu_0 = \frac{\sigma}{A}$$

In liquid droplet Pressure Force (F_{pr}) is equal to the

surface tension force outer surface of liquid droplet

$$(F_{pr}) = (\sigma)$$

$$\text{so } \sigma = \frac{F_{pr}}{A} = \frac{P \cdot \pi \cdot d^2}{4 \cdot \pi \cdot d^2} = \frac{P}{4}$$

According to pressure

$$P = \frac{\text{Force}}{\text{Area}} = \frac{F_{pr}}{A}$$

$$\Rightarrow \frac{F_{pr}}{\frac{\pi}{4} d^2} = \frac{P}{\pi d^2} = \frac{P}{4}$$

$$\sigma = \frac{F_{pr}}{\frac{\pi}{4} d^2}$$

$$\text{liquid droplet pressure } F_{pr} = P \cdot \frac{\pi}{4} d^2 \quad \text{--- ①}$$

$$0.028 \cdot 0.01 \times 96 \times \frac{\pi}{4} d^2 = 9$$

$$\text{surface tension force } F_{\sigma} = \sigma \cdot \pi d^2 \quad \text{--- ②}$$

(σ) not yet known

so how to do it? by doing equation ① & equation ②

$$P \cdot \frac{\pi}{4} d^2 = \sigma \cdot \pi d^2$$

unit - 1, Pg - 6/16

$$P_0 \frac{d}{4} = 0$$

$$P = \frac{40}{d}$$

$$\textcircled{2} \rightarrow b \times d = 0$$

Q) Surface tension in soap bubble / Air bubble / water bubble

In soap bubble there are two surfaces are present outside of the bubble. Inside of the bubble is empty.



Air pressure
Surface pressure

$$F_{pr} = P_0 \frac{\pi}{4} d^2 \quad \text{--- ①}$$

$$\text{Surface tension force} = 2\sigma \pi d$$

$$m \times F_{pr} = m \times 2\sigma \pi d$$

$$F_{pr} = 2\sigma \pi d \quad \text{--- ②}$$

from equation ① and ② doing

$$\text{eqn ①} = \text{eqn ②}$$

$$\frac{m \times F_{pr} \frac{\pi}{4} d^2}{m \times 2\sigma \pi d} = 2\sigma \pi d$$

$$2\sigma \pi d \cdot \frac{d}{4} = 2\sigma$$

$$P = \frac{8\sigma}{d}$$

Surface tension in water jet:

Pressure force (F_{pr}) in liquid water jet = $P \cdot \pi d^2$

$$m \times F_{pr} = m \times P \cdot \pi d^2 = P \cdot \pi d^2 \quad \text{--- ①}$$

unit - 1, Pg - 7/16

Surface tension force (F_t) in liquid water jet

$$F_t = 2\sigma d \quad \text{--- (2)}$$

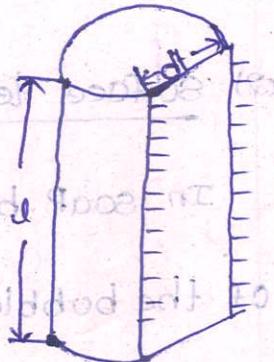
$$\frac{\Delta P}{d} = \sigma$$

doing equation (1) = equation (2)

$$Pd = 2\sigma d$$

$$Pd = 2\sigma$$

$$P = \frac{2\sigma}{d}$$



Problems:

1) The bubble diameter 2mm. calculate How much pressure of air in bubble. Assume the value of surface tension between air and water $72.7 \times 10^3 \text{ N/m}$

Ans: Given that

$$\text{diameter of the bubble} = 2\text{mm} = 2 \times 10^{-3} \text{ m}$$

$$\text{surface tension } \sigma = 72.7 \times 10^3 \text{ N/m}$$

$$\text{pressure } P = \frac{8\sigma}{d}$$

$$= \frac{8 \times 72.7 \times 10^3}{2 \times 10^{-3}}$$

$$P = 9290.8 \text{ Pa}$$

$$\frac{9290.8}{10} = 929.08$$

2) A Soap bubble 50 mm in diameter contains a pressure of 2 bar. Find the surface tension in soap film.

Ans: Given that

$$\text{diameter } d = 50 \text{ mm} = 50 \times 10^{-3} \text{ m}$$

$$\rho = 8 \times 10^3 \text{ N/m}^2$$

from soap bubble surface tension

$$P_{\text{hub}} = \frac{8\sigma}{d}$$

$$8\sigma = pd$$

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$$pd = \frac{\rho d}{8}$$

$$\sigma = \frac{\rho d}{8}$$

$$\sigma = \frac{1250 \times 10^{-3} \times 50 \times 10}{8}$$

$$\sigma = 1250 \text{ N/m}^2$$

Types of fluids

The fluids are classified based on newton's law of viscosity

1) Newtonian fluid

2) Non-newtonian fluid

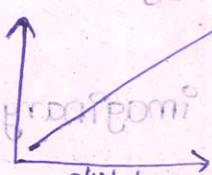
3) Ideal fluid

4) Real fluid

5) Ideal plastic

1) Newtonian fluids:

$$\tau = \mu \cdot \frac{du}{dx}$$



$$\frac{\partial \tau}{\partial u} = 0 = \eta$$

→ which fluids are obeying the newton's law of viscosity

Such type of fluids are called Newtonian fluids

2) Non-newtonian fluids:

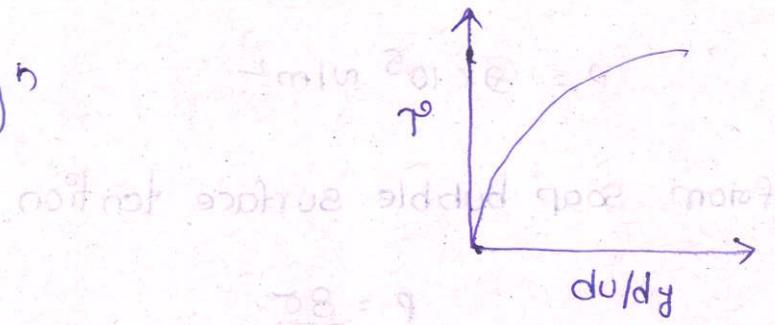
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The fluids which are disobey the newton's law of

viscosity such type of fluids are called as non-newtonian

fluids.

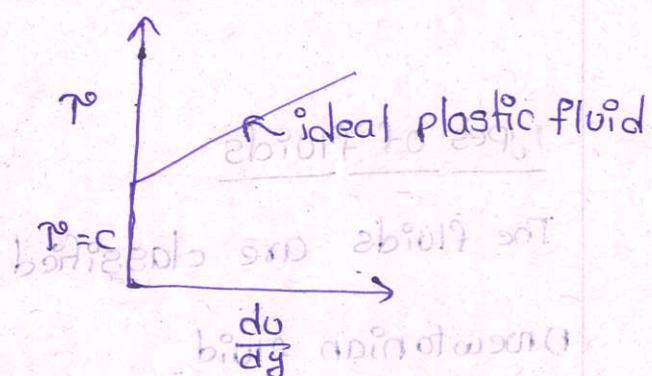
$$\tau = \mu \left(\frac{du}{dy} \right)^n$$



3) Ideal plastic fluids:

In this fluids these are mainly shear stress constant up to certain point then these fluids follows Newton's law of viscosity. Such type of fluids are called as Ideal plastic fluids.

$$\tau = c + \mu \cdot \frac{du}{dy}$$

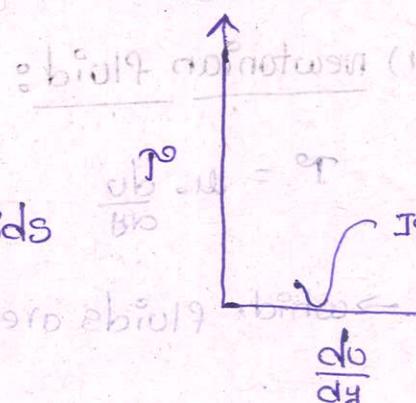


Ideal fluid:

In ideal fluids shear stress is zero

$$\tau = 0 = \mu \cdot \frac{du}{dy}$$

→ Ideal fluids are imaginary fluids



Real fluid:

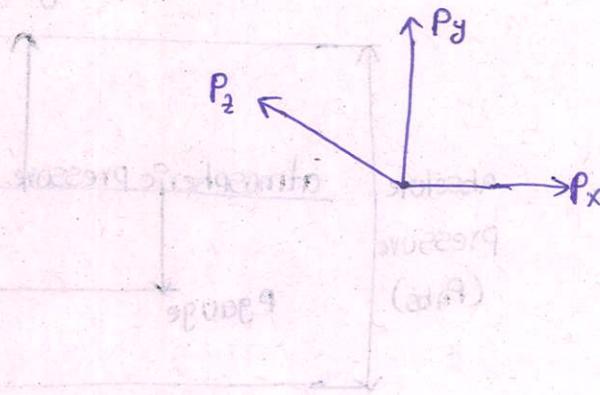
water is a real fluid

→ The fluids which obeys all the fluids laws are called as Real fluids.

Foucault's law of pressures:

The intensity of pressure at any point in a fluid is same in all directions

$$P = P_x = P_y = P_z$$



1) Absolute pressure:

→ which is defined as pressure, which is measured with reference of absolute volume / high pressure.

$$\text{Absolute pressure} = \text{Atmospheric pressure} + \text{gauge pressure}$$

2) Gauge pressure:

→ which is defined as the pressure measured with instrument / gauge is called gauge pressure.

3) Vacuum pressure / negative pressure / low pressure:

→ which is the pressure in fluid below of atmospheric pressure is called vacuum pressure.

4. High pressure:

which the pressure in fluid above of atmospheric pressure is called high pressure

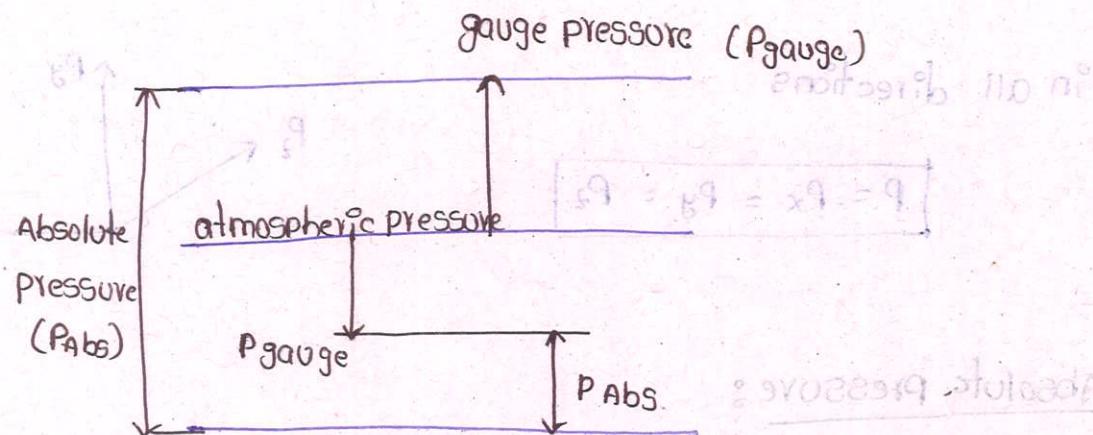
5) Atmospheric pressure:

The pressure in whether (or) atmosphere is called atmospheric pressure

$$1 \text{ atm} = 1013 \text{ bar}$$

$$1 \text{ bar} = 10^5 \text{ N/m}^2$$

pressure scale:

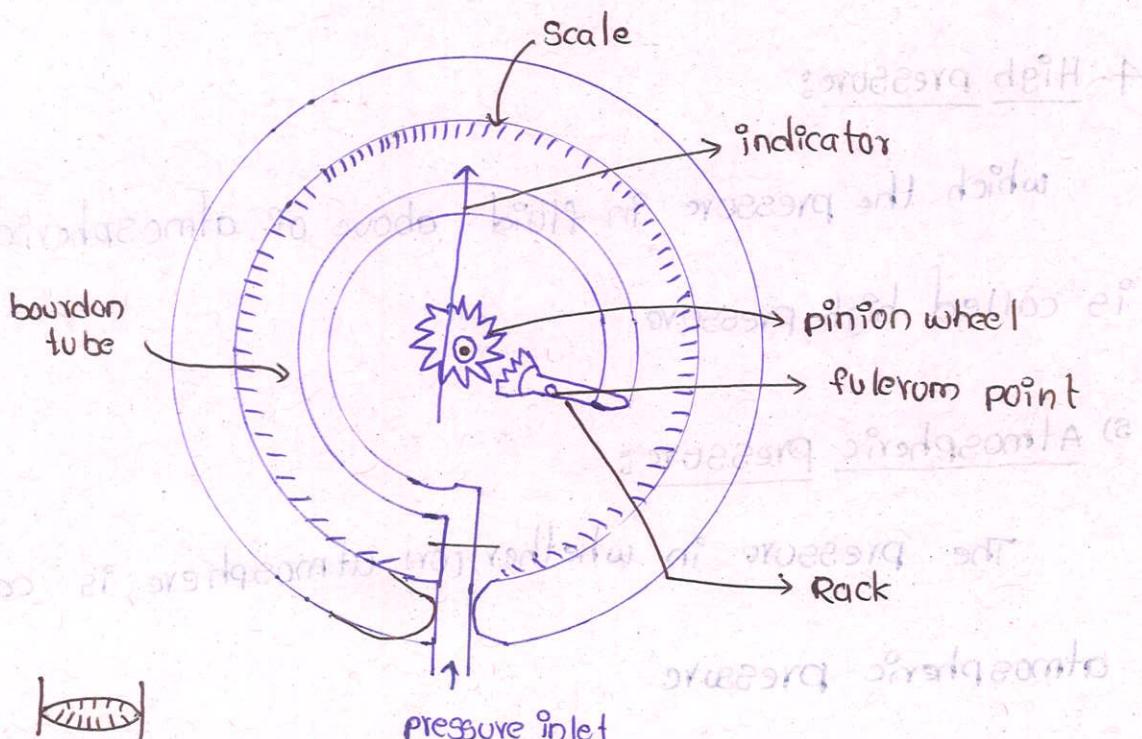


$$P_{\text{Abs}} = P_{\text{Atm}} \pm P_{\text{gauge}}$$

* pressure measuring devices:

- 1) manometer
- 2) mechanical pressure gauge
- 3) Bourdon tube pressure gauge

Bourdon tube pressure gauge



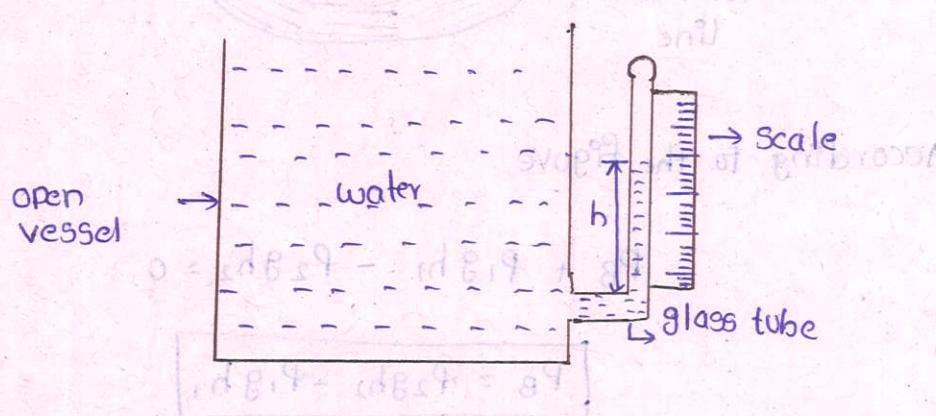
boudon tube cross section,

MANOMETERS

- 1) Piezo meters
- 2) U-tube manometer
- 3) differential manometer.

1) Piezo meter:

It is a simplest form of manometer and used for measuring average pressure of liquid.



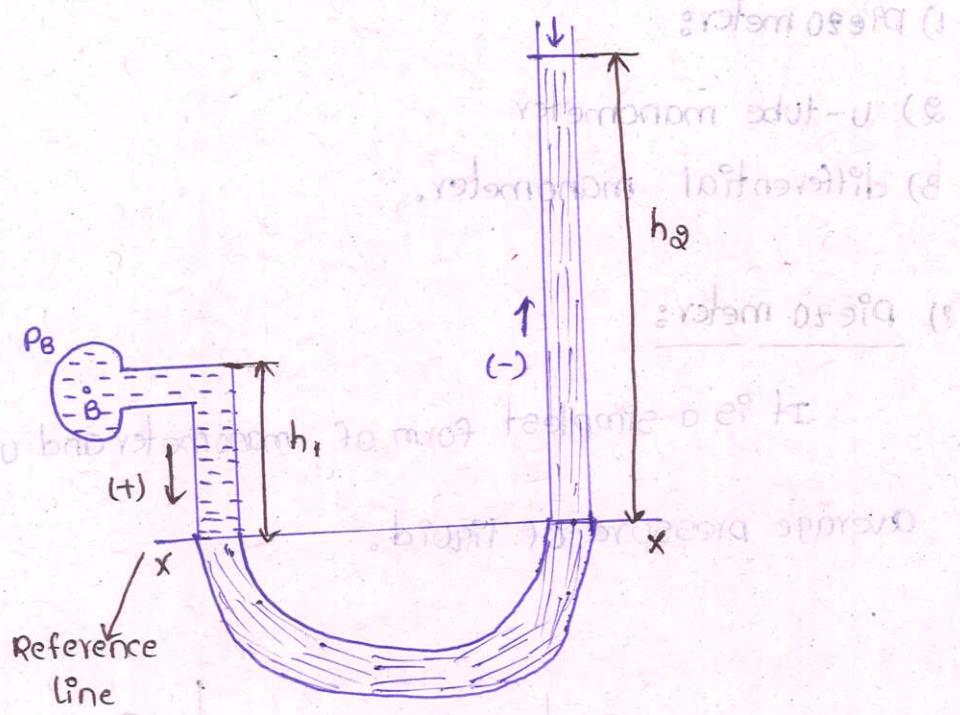
→ It consists of glass tube and a pipe fitted to the tube containing liquid in which pressure is to be calculated. The pressure of the liquid in the tube is represented by the liquid height and read on the scale, which is attached to the tube. Thus if w is the specific weight of the liquid then pressure ' p ' at any point is given by

$$P = wgh$$

$$\boxed{P = \rho gh}$$

(2) Single column U-tube manometer:

As the area of the pressure reservoir of wall is large, the fall of heavy liquid level will be small. This downward movement will cause a small rise in the tube.

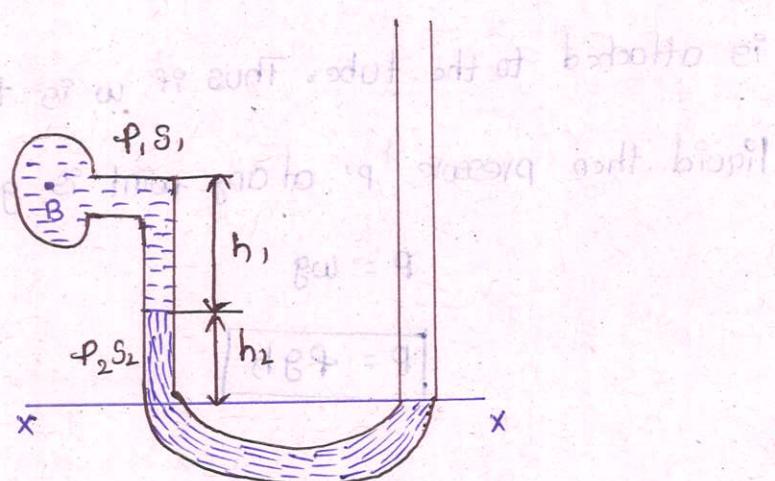


According to the figure

$$P_B + \rho_1 g h_1 - \rho_2 g h_2 = 0$$

$$P_B = \rho_2 g h_2 - \rho_1 g h_1$$

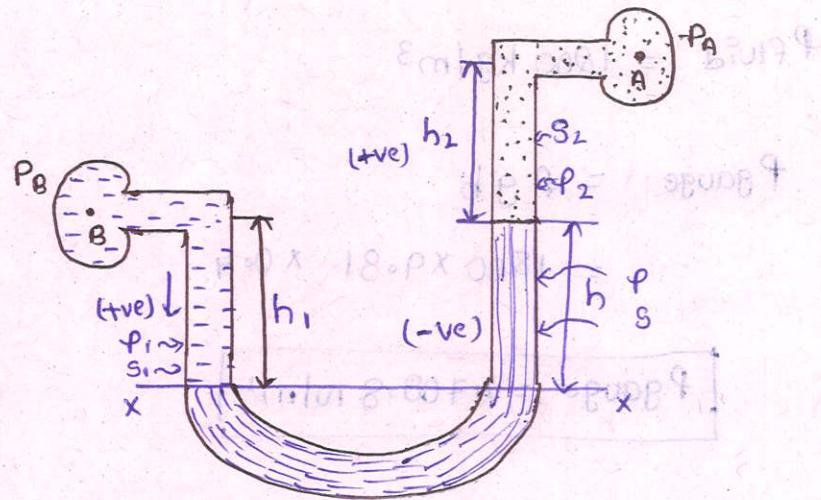
Vacuum pressure: $P_{vac} = P_0 - P_{atm}$



from figure

$$P_B + \rho_1 g h_1 + \rho_2 g h_2 = 0$$

$$P_B = -(\rho_1 g h_1 + \rho_2 g h_2)$$



from figure

$$P_B + \rho_1 g h_1 = P_A + \rho_2 g h_2 + \rho g b$$

$$P_A - P_B = \rho_1 g h_1 - \rho_2 g h_2 - \rho g b$$

problems:

1) what is the gauge pressure / absolute pressure in N/m^2 at 0.4 m

below free surface of liquid specific gravity is 1.2 if Atmo

spheric pressure is 750 mm of Hg.

$$P_{atmp} = \rho g b$$

$$= 13600 \times 9.81 \times \frac{750}{1000}$$

$$= 100062 \text{ N/m}^2$$

$$= 1.00062 \times 10^5 \text{ N/m}^2$$

$$= 1 \text{ bar}$$

$$P_{atmp} = 1 \text{ bar}$$

specific gravity $s = \frac{\rho_{\text{fluid}}}{\rho_{\text{standard fluid}}}$

$$1.2 = \frac{\rho_{\text{fluid}}}{1000}$$

$$1.2 = \frac{\rho_{\text{fluid}}}{1000} = .49$$

$$P_{\text{fluid}} = 1.2 \times 1000$$

$$P_{\text{fluid}} = 1200 \text{ kg/m}^3$$

$$P_{\text{gauge}} = P_{\text{g}} h$$

$$= 1200 \times 9.81 \times 0.4$$

$$P_{\text{gauge}} = 4708.8 \text{ N/m}^2$$

$$P_{\text{absolute}} = P_{\text{atm}} + P_{\text{gauge}}$$

$$= 1.00062 \times 10^5 + 4708.8 \text{ N/m}^2$$

$$P_{\text{absolute}} = 1.047708 \text{ bars}$$

(2) A differential manometer is connected to at A and B as in fig.

At B air pressure 7.848 N/cm^2 find pressure at pipe A.

Ans:

$$P_A + S_A g h \times 9.81 \times 10$$

$$P_A + 0.8 \times 9.81 \times 12 + 13.6 \times 9.81 \times 10$$

$$P_A + 94.176 + 13.6 \times 9.81 \times 10$$

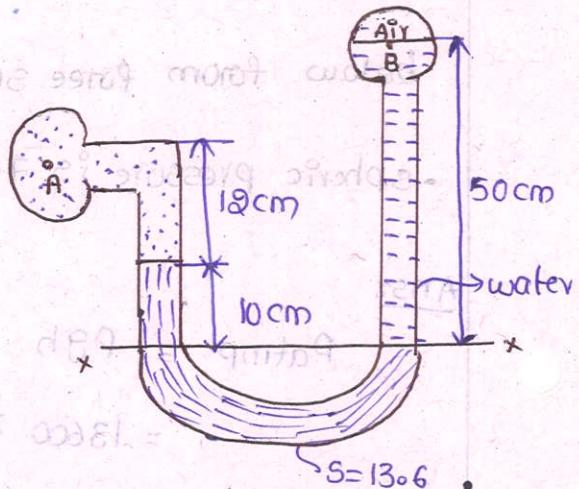
$$P_A + 1428.336 \quad \text{--- (1)}$$

$$P_B + P_{\text{water}} \times 9.81 \times 50$$

$$P_B + 1000 \times 9.81 \times 50$$

$$7.84 + 1000 \times 9.81 \times 50$$

$$490507.84 \quad \text{--- (2)}$$



From eqn (1) and (2)

$$P_A + 1428.336 = 490507.84$$

$$P_A = 490507.84 - 1428.336$$

$$P_A = 489079.5 \text{ N/cm}^2$$