4022 FLUID MECHANICS & HYDRAULIC MACHINERY

Module 1

Course Outline

- **CO1 Explain fluid properties and pressure measurement techniques.**
- M1.01 List and Define various properties of fluids.
- M1.02 Solve Simple problems related to density, specific weight, specific volume, and specific gravity.
- M1.03 Explain the terms pressure and pressure head State and explain Pascal’s law. Explain Absolute, Gauge, Atmospheric and Vacuum pressures.
- M1.04 Solve problems related to pressure and pressure head.
- M1.05 Illustrate the principle of working of piezometer, simple U-tube manometer, differential manometer, inverted differential manometer, bourdon’s tube.
- M1.06 Solve problems on pressure measuring instruments.

FLUID

- It is a substance which is capable of flowing.

- A fluid is defined as a substance which deforms continuously when subjected to a shear force, however the small the shear force may be.

CLASSIFICATION OF FLUIDS

1. Liquids
2. Gases including vapours.

- Liquids occupy a definite volume and are not compressible.
- Eg:- Water, Oil etc.
- Gases are fluids which can be compressed and expanded.
- Eg:- Air, Nitrogen etc.

Fluid Mechanics

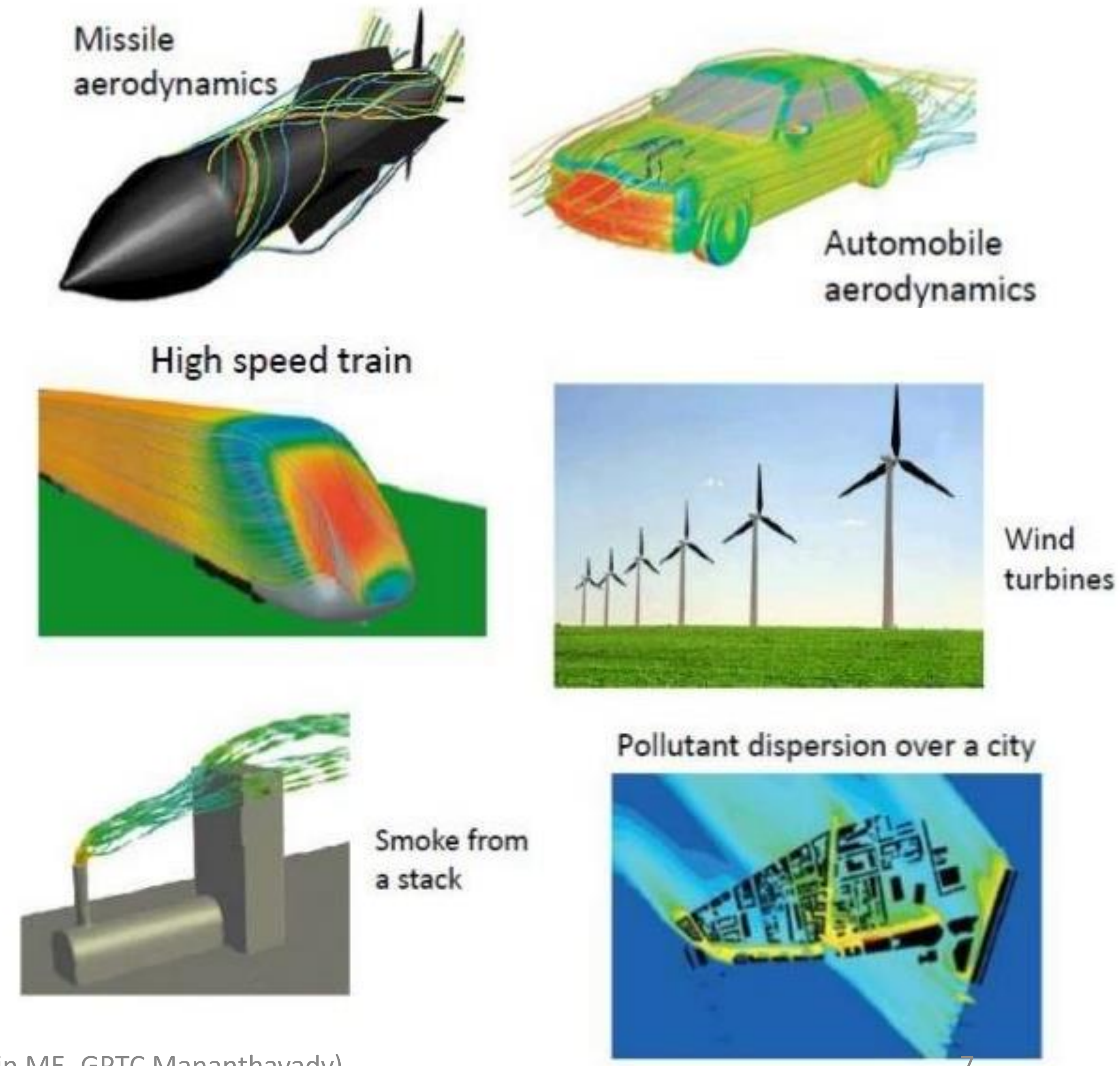
- It is a branch of science which deals with the action of fluid at rest or in motion, and with application of devices in engineering using fluids.

HYDRAULICS

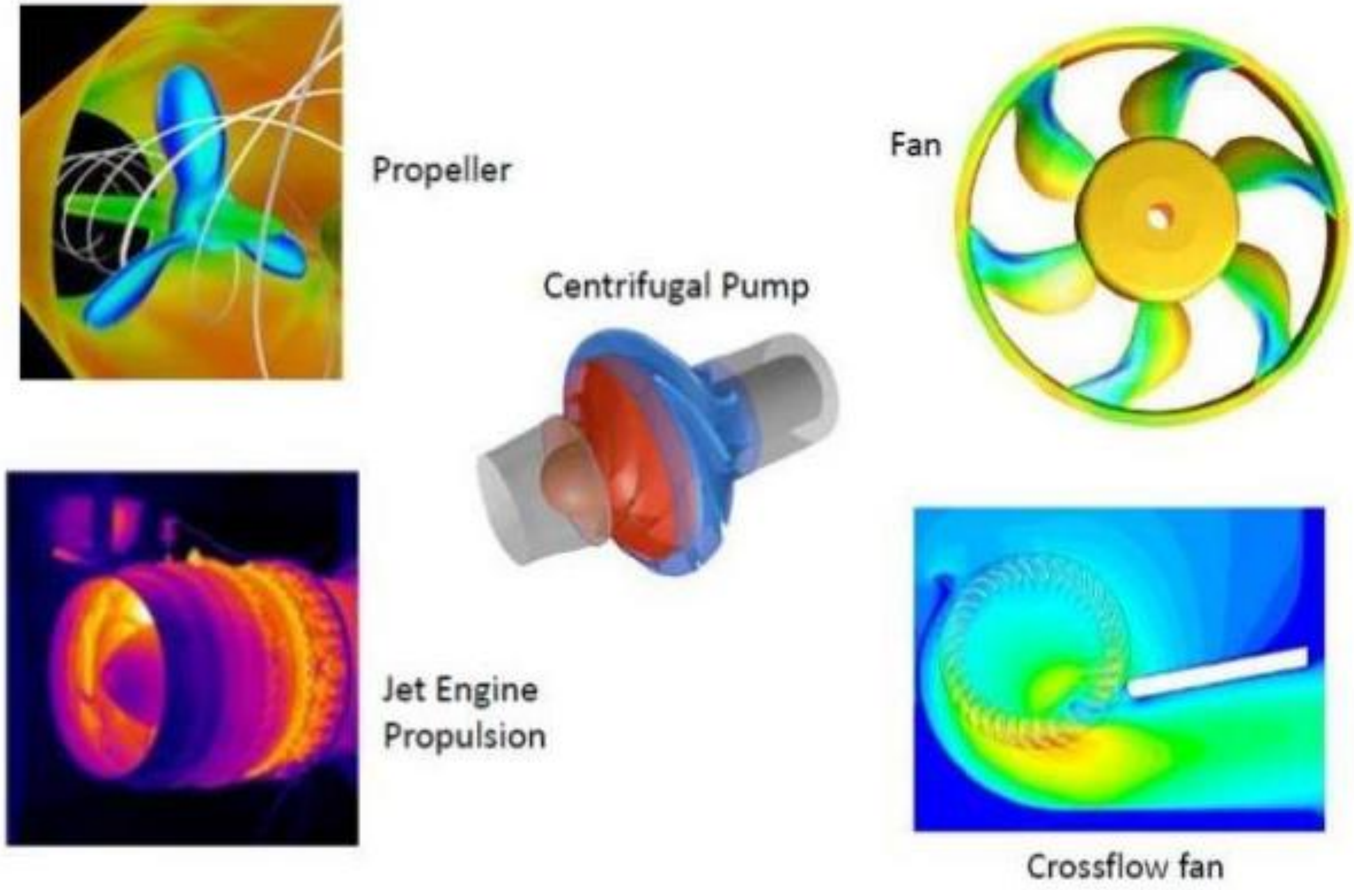
- It is a science and engineering subject dealing with mechanical properties of fluids.

APPLICATIONS OF HYDRAULICS (IMPORTANCE)

- Machine tool industry
- Plastic processing machine
- Hydraulic presses
- Construction machinery
- Lifting and transporting
- Agricultural machinery
- Cement plants
- Oil refinery



- Steel mills
- Aerospace industry
- Distilleries
- Paper mills
- Cotton mills
- Dairy farms
- Chemical plants



CLASSIFICATION OF HYDRAULICS

- HYDROSTATICS
- It is the branch of hydraulics which deals with the properties and laws governing the behaviour of fluid at rest.
- Eg:- water stored in reservoir or tank.
- HYDRODYNAMICS
- It is the branch of hydraulics which deals with the properties and laws governing the behaviour of fluids in motion with considering the force which causes the motion.
- Eg:- water flowing through a turbine, water discharged by a pump etc.
- HYDROKINEMATICS
- It is the branch of hydraulics which deals with the properties and laws governing the behaviour of fluids in motion without considering the forces which causes the motion.

PROPERTIES OF FLUIDS

DENSITY or MASS DENSITY (ρ)

- It is the ratio of mass of fluid to its volume and is denoted by the symbol ρ(rho)
- $\rho = \dfrac{\text{mass of fluid}}{\text{Volume of fluid}} = \dfrac{m}{V}$
- m = total mass of fluid in kg.
- v = total volume of fluid in m^3.
- SI unit of density is kg/m^3
- Density of liquids may be considered as constant while that of gases changes with the variation of pressure and temperature.
- The value of density of water, $\rho_{water} = 1000\ kg/m^3$

SPECIFIC WEIGHT or WEIGHT DENSITY (ω)

- It is the ratio of weight per unit volume of a liquid.
- It is also known as weight density and is denoted by ω (omega)
- $\omega = \dfrac{\text{Weight of fluid}}{\text{Volume of fluid}} = \dfrac{W}{V}$
- w = Weight of fluid in N
- = mass of fluid x acceleration due to gravity
- W = mg
- $\omega = \dfrac{mg}{V} = \rho g$
- The value of specific weight of water is,
- $\omega_{water} = 1000 \times 9.81 = 9810\ N/m^3$
- SI unit of specific weight is N/m^3

SPECIFIC VOLUME (ϑ)

- It is defined as the volume of a fluid occupied by unit mass.
- $\vartheta = \frac{\text{Volume of fluid}}{\text{Mass of fluid}} = \frac{V}{m}$
- $\vartheta = \frac{1}{(m/V)}$
- $\vartheta = \frac{1}{\rho}$
- It is the reciprocal of mass density.
- SI unit is m^3/kg

SPECIFIC GRAVITY or RELATIVE DENSITY (S)

- It is defined as the ratio of mass density of a substance to the mass density of a standard substance. or
- It is defined as the ratio of the weight density of a substance to the weight density of a standard substance.
- For liquids, standard substance is water at 4^0C.
- For gases standard substance is taken as air or hydrogen at 0^0C.
- $S_{\text{liquid}} = \frac{\rho_{liquid}}{\rho_{\text{water}}}$ or $\frac{\omega_{liquid}}{\omega_{\text{water}}}$
- $S_{\text{gas}} = \frac{\rho_{gas}}{\rho_{air}}$ or $\frac{\omega_{gas}}{\omega_{air}}$
- It is a unitless quantity.
- $S_{\text{water}} = \frac{\rho_{water}}{\rho_{\text{water}}}$ or $\frac{\omega_{water}}{\omega_{\text{water}}}$
- Specific gravity of water, $S_{\text{water}} = 1$
- $S_{\text{mercury}} = 13.6$

PROBLEMS

Q.1. Calculate specific weight, mass density and weight of 1 litre of petrol having specific gravity 0.7.

Given data:

- Volume, V = 1 litre
- $S_{petrol} = 0.7$
- $\omega=?$, $\rho=?$, $w=?$
- 1 litre = 1000 cm^3
- 1 m = 100 cm
- 1 cm = 1/100 m = 10^{-2} m
- 1 cm^3 = $(10^{-2})^3$ m^3
- = 10^{-6} m^3
- Volume = 1000 x 10^{-6} m^3
- = 10^{-3} m^3

- $S_{petrol} = 0.7 = \frac{\omega_{petrol}}{\omega_{water}}$
- $\omega_{petrol} = 0.7 \times \omega_{water}$
- $= 0.7 \times 9810$
- $= 6867\ N/m^3$
- $S_{petrol} = \frac{\rho_{petrol}}{\rho_{water}}$
- $\rho_{petrol} = S_{petrol} \times \rho_{water}$
- $= 0.7 \times 1000 = 700\ kg/m^3$
- $\omega = \frac{W}{V}$
- $w = \omega \times v = 6867 \times 10^{-3} = 6.867\ N$

Q.2. Calculate the specific weight, density and specific gravity of 1litre of liquid which weighs 10 N?

Given data:

$V = 1$ litre $= 10^{-3}$ m^3

$W = 10$ N

$\omega=?$, $\rho=?$, $S=?$

$$\omega = \frac{W}{V}$$

$= 10/\ 10^{-3} = 10^4$ N/m^3

$\omega = \rho g$

$\rho = \omega/g = 10^4/9.81 = 1019.37$ kg/m^3

$$S_{liquid} = \frac{\rho_{liquid}}{\rho_{water}}$$

$= 1019.37/1000$

$= 1.019$

Q.3. Calculate the specific weight, specific mass, specific volume and specific gravity of liquid having a volume of 4 m^3 and weighs 30 kN ?

- Given data:
- $V = 4\ m^3$
- $W = 30\ kN = 30 \times 10^3\ N$
- $\omega=?,\ \rho=?,\ \vartheta=?,\ S=?$
- $\omega = \frac{W}{V}$
- $= 30 \times 10^3 / 4 = 7500\ N/m^3$
- $\omega = \rho g$
- $\rho = \omega/g = 7500/9.81 = 764.52\ kg/m^3$
- $\vartheta = \frac{1}{\rho} = 1/764.52 = 1.308 \times 10^{-3}\ m^3/kg$
- $S_{liquid} = \frac{\rho_{liquid}}{\rho_{water}}$

  $= 764.52/1000$

  $= 0.764$

Q.4. Determine the mass density of an oil if 3 tons of the oil occupies a volume of 4 m^3 and also find the specific weight of the oil.

Given data:

- m = 3 tons = 3 x 1000 = 3000 kg
- V = 4 m^3
- ρ = ?
- $\rho = \frac{m}{V}$
- = 3000/4
- = 750 kg/m^3
- ω = ρg
- = 750 x 9.81
- = 7357.5 N/m^3

VISCOSITY

- The property of a fluid that measures its resistance to change its shape is called viscosity.

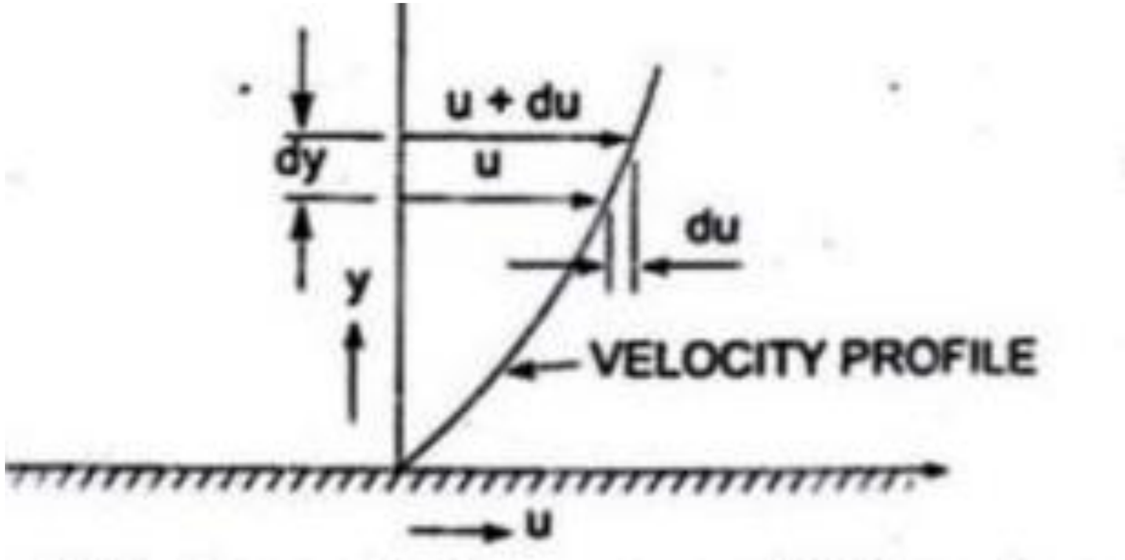
- It is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of the fluid.

- In the case of liquids when temperature increases viscosity decreases.

- In case of gases when temperature increases viscosity also increases.

NEWTONS LAW OF VISCOSITY

- When any fluid flows over a solid surface, the velocity is not uniform at any cross section.
- It is zero at the solid surface and increases to the free stream velocity in the fluid layer far away from the solid surface.



Velocity variation near a solid boundary.

- According to Newtons law of viscosity, the shear force acting between two layers of fluid is directly proportional to the difference in their velocities (du) and area (A) and inversely proportional to the distance (dy) between them.
- $F \propto A \frac{\mathrm{du}}{\mathrm{dy}}$
- $F = \mu A \frac{\mathrm{du}}{\mathrm{dy}}$

Where,

F = Shear force acting on the fluid in newton (N)

A = Area of the fluid layer in m^2.

μ = A constant of proportionality and is known as the coefficient of dynamic viscosity or simply viscosity.

$\frac{\mathrm{du}}{\mathrm{dy}}$ = Shear deformation or velocity gradient or rate of shear strain

- From the above equation we can write, $\frac{\mathrm{F}}{A} = \mu \frac{\mathrm{du}}{\mathrm{dy}}$
- ie, Shear stress, $\tau = \mu \frac{\mathrm{du}}{\mathrm{dy}}$
- $\tau \propto \frac{\mathrm{du}}{\mathrm{dy}}$
- Newtons law of viscosity states that the shear stress on a fluid is proportional to the rate of change of shear strain.
- $\mu = \frac{\tau}{\frac{\mathrm{du}}{\mathrm{dy}}}$
- Viscosity is also defined as the shear stress required to produce unit shear deformation or velocity gradient.

Unit of Viscosity

- $\mu = \frac{\tau}{\frac{\mathrm{du}}{\mathrm{dy}}}$
- $\mu = \frac{\mathrm{F\,dy}}{\mathrm{A\,du}}$
- Substituting units
- $\mu = \frac{\mathrm{N\,m}}{\mathrm{m}^2\, m/s}$
- $= \frac{\mathrm{N\,s}}{\mathrm{m}^2}$ = Pa. s (pascal second)
- SI unit of viscosity = $\frac{\mathrm{N\,s}}{\mathrm{m}^2}$ or Pa. s
- CGS unit of viscosity is Poise
- 1 Poise = $\frac{1}{10}\frac{\mathrm{N\,s}}{\mathrm{m}^2}$
- 1 Centipoise = $\frac{1}{100}$ poise

KINEMATIC VISCOSITY (ϑ)

- It is defined as the ratio between the dynamic viscosity and the density of the fluid.
- $\vartheta = \frac{\mu}{\rho}$
- Unit = $\frac{\text{N}s\ m^3}{\text{m}^2\ \text{kg}}$
- $= \frac{\text{kg}\frac{\text{m}}{\text{s}^2}\ s\ m^3}{\text{m}^2\ \text{kg}}$
- $= \frac{\text{m}^2}{\text{s}}$
- SI unit of kinematic viscosity $= \frac{\text{m}^2}{\text{s}}$
- CGS unit of kinematic viscosity = $\frac{\text{cm}^2}{\text{s}}$ or stokes
- 1 Stokes = $10^{-4}\ \frac{\text{m}^2}{\text{s}}$
- 1 Centistokes = 10^{-2} stokes

COMPRESSIBILITY

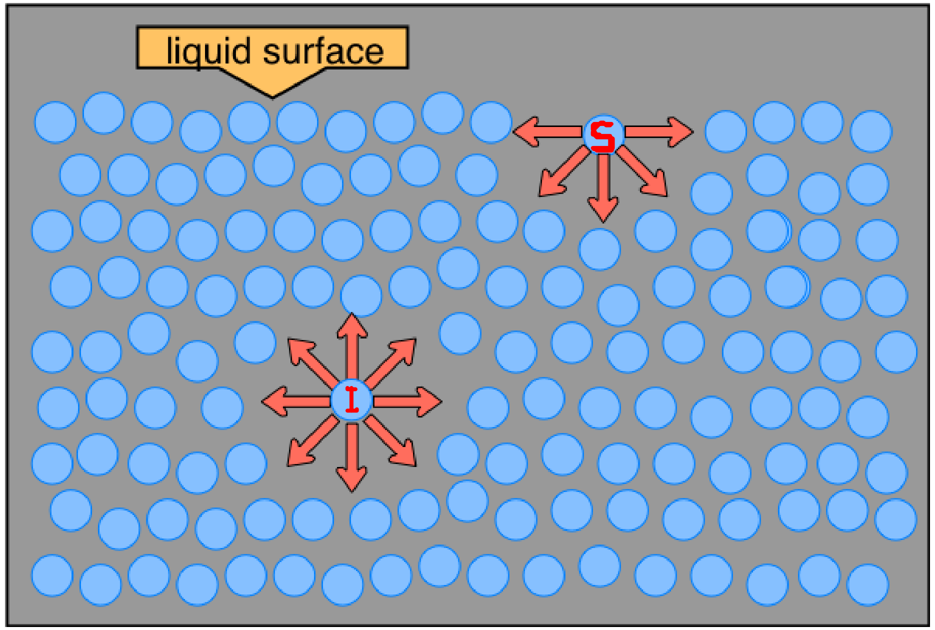
- It is the ability of a fluid to change its volume under pressure.
- Compressibility = $\frac{1}{\text{Bulk modulus}} = \frac{1}{\mathrm{K}}$
- All fluids are elastic in nature.
- Application of pressure on fluids decreases the volume and increases the density and temperature.
- When the pressure is removed, the compressed fluid expands to the original volume.
- This elastic property of fluid is known as bulk modulus of elasticity.
- Bulk modulus is also defined as the ratio of compressive stress to volumetric strain or the inverse of compressibility.
- K = $\frac{\text{Compressive stress}}{\text{Volumetric strain}}$
- Volumetric strain = $\frac{\text{Change in volume}}{\text{Original volume}}$
- SI unit of bulk modulus = N/m^2 or Pascal

COHESION AND ADHESION

- Cohesion refers to the force with which the neighbouring or adjacent molecule attracts each other or it is the force between like molecules.

- Adhesion refers to the force of attraction between the fluid and walls of the container, or it is the forces between unlike molecules.

SURFACE TENSION (σ)



- Consider a particle S on the free surface of the liquid and another particle I within the liquid as shown in figure.
- The particle I is acted on by equal and opposite forces in all direction, hence the resulting forces on particle I is zero.
- So no tension or tensile force acts on this particle.

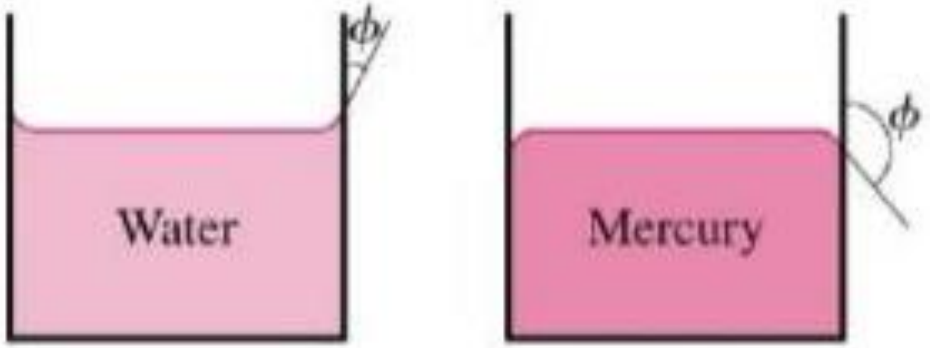
- But in the case of particle S, the forces in the upward direction is zero, but there are forces in the downward direction.
- The resultant of the forces acts vertically in downward direction and pulls the particle in the downward direction.
- Due to this, water surface is in a state of tension.
- This tensile force per unit length is called surface tension.
- $\sigma = \frac{F}{L}$
- SI unit of surface tension = N/m



CAPILLARITY

- It is defined as the phenomenon of the rise or fall of liquid surface relative to the normal level of a liquid when the tube is held vertically in the fluid.
- The rise of liquid surface is known as capillary rise and fall of liquid surface is known as capillary depression.

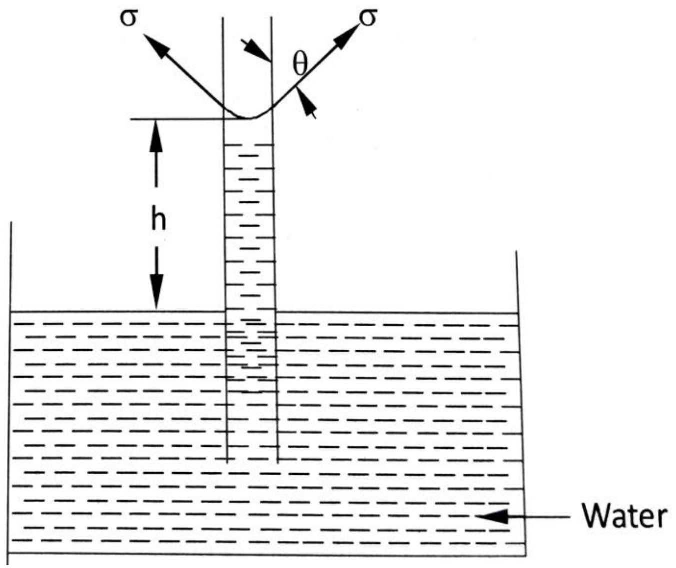
Tissue paper absorbing ink due to capillary action



(a) Wetting fluid (b) Nonwetting fluid

CAPILLARY RISE

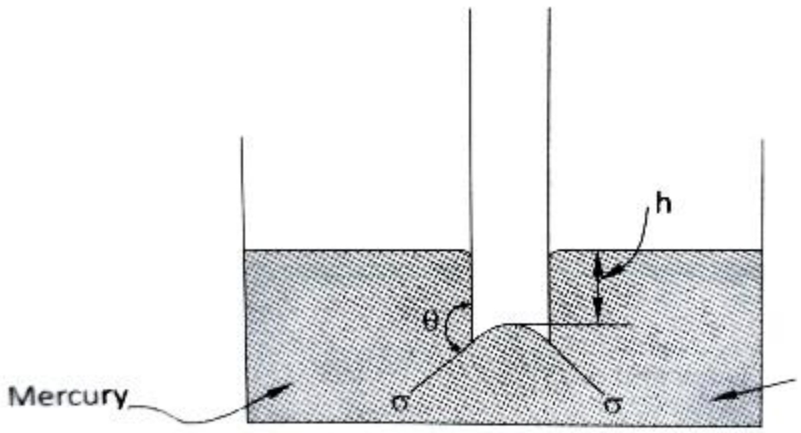
- When a tube of smaller diameter is dipped in water, the water rises in the tube with an upward concave surface.
- This is due to adhesion is more than cohesion.
- Because of this most liquids completely wet the surface.
- The phenomenon of rise in water in the tube of smaller diameter is called capillary rise.
- Height of capillary rise, h = $\frac{4\sigma \cos\theta}{\omega d}$
- σ = surface tension
- d = diameter of glass tube
- ω = specific weight of liquid
- θ = angle of contact between liquid and glass tube



CAPILLARY DEPRESSION

- In the case of mercury, cohesion is more than adhesion. So mercury falls in the glass tube and that is known as capillary depression.

- Height of capillary depression, h = $\frac{4\sigma\ cos\theta}{\omega d}$
- σ = surface tension
- d = diameter of glass tube
- ω = specific weight of liquid
- θ = angle of contact between liquid and glass tube



TYPES OF FLUIDS

Ideal fluid

- Those fluids which have no viscosity and surface tension and they are incompressible.
- In nature ideal fluids does not exist and these are imaginary fluids.

Real fluid

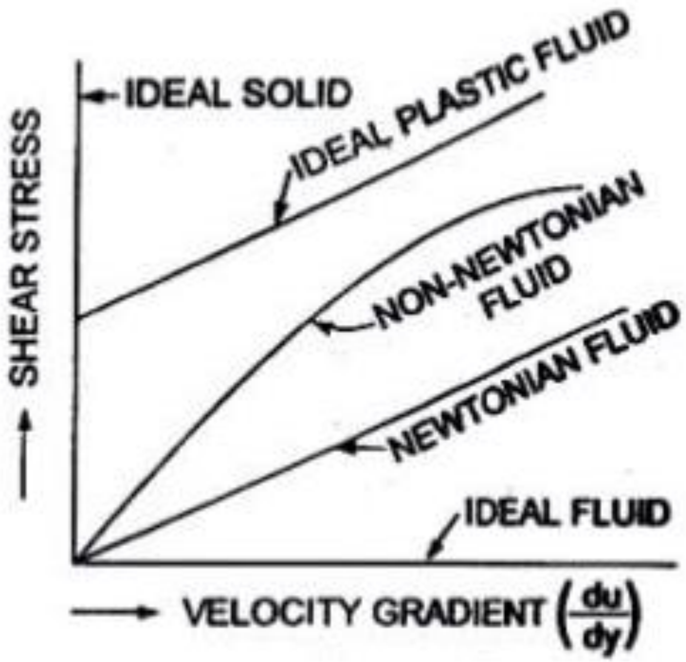
- These fluids have the properties such as viscosity, surface tension and compressibility.

Newtonian fluid

- A real fluid in which shear stress is directly proportional to the rate of shear strain.
- A real fluid which obeys Newtons law of viscosity is known as Newtonian fluid.

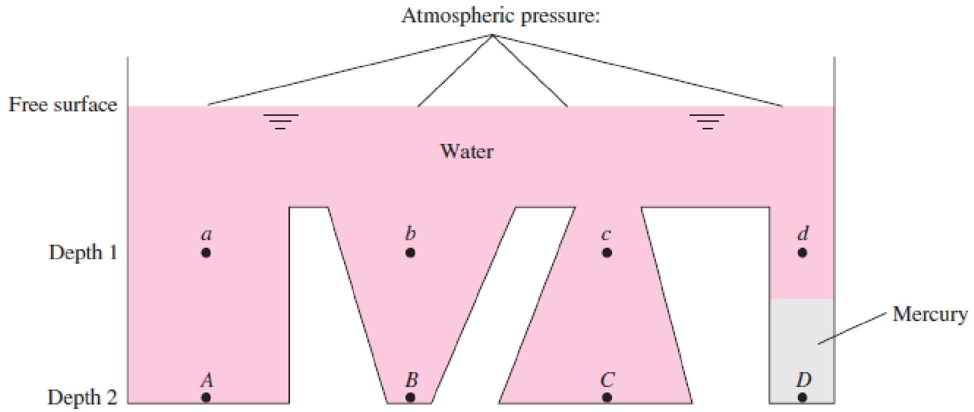
Non-Newtonian fluid

- A real fluid which does not obey the Newtons law of viscosity is known as Non-Newtonian fluid.



FLUID PRESSURE (P)

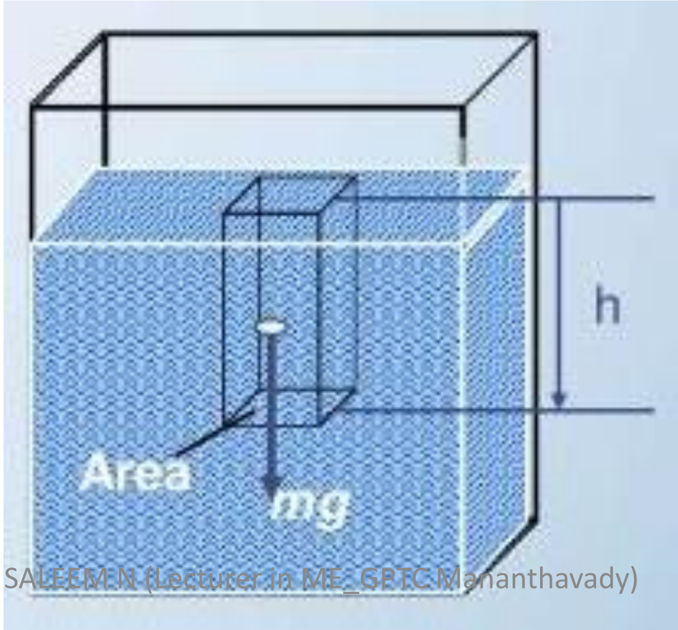
- The pressure or intensity of pressure at a point in a fluid is defined as the normal force exerted by a fluid per unit area at that point.
- $P = \frac{F}{A}$
- Unit of pressure = N/m^2 or Pascal (Pa)
- Higher unit of pressure = bar
- 1 bar = 10^5 N/m^2
- = 10^5 Pa



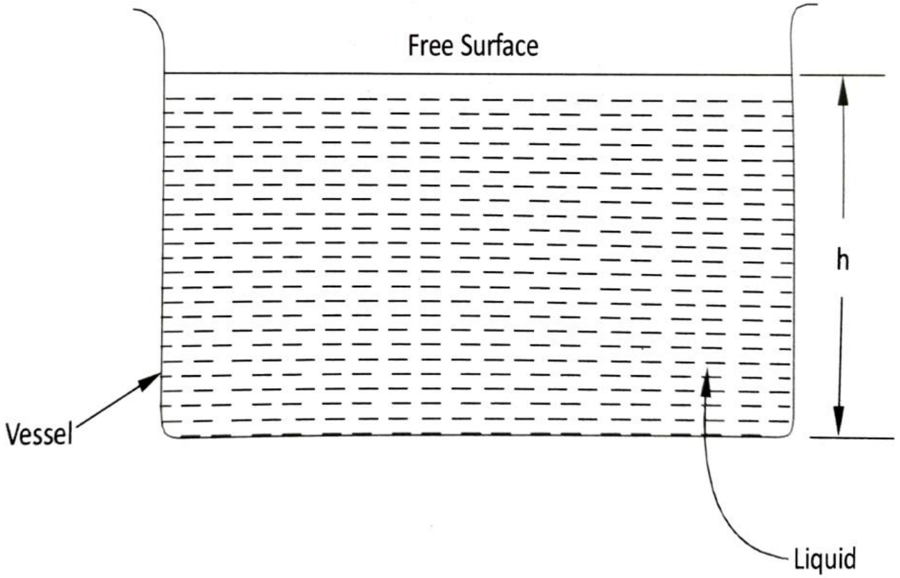
- The fluid pressure increases linearly with depth in a gravity field
- The fluid pressure does not change in the horizontal direction

PRESSURE HEAD (h)

- Pressure head is defined as the height of a liquid column above a reference point in a static liquid.
- It is generally expressed in meters of a liquid column.
- $h = \dfrac{P}{\rho g}$ or $h = \dfrac{P}{\omega}$



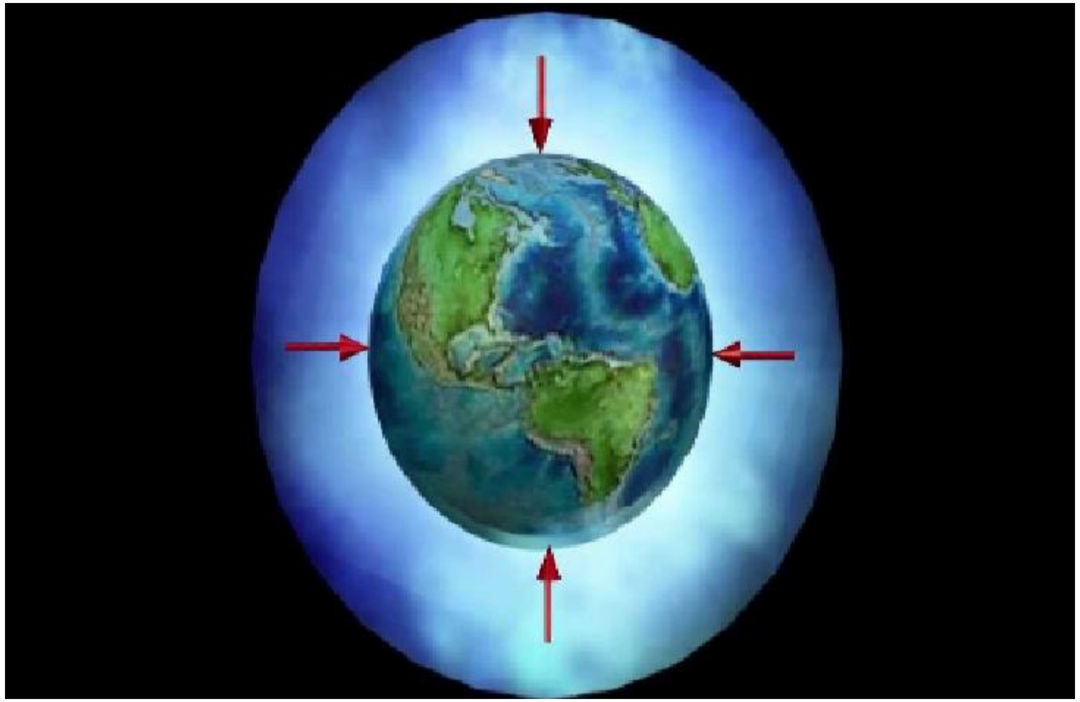
- Consider a vessel with some liquid as shown in figure.
- The liquid will exert a pressure on all the sides as well as bottom side of vessel.
- The pressure at the bottom of the vessel,
- $P = \frac{\text{Weight of liquid}}{\text{Area}} = \frac{mg}{A}$ ....(1)
- We know density, $\rho = \frac{m}{V}$
- So mass, $m = \rho\, v$
- Substitute in equation (1)
- $P = \frac{\rho\, v\, g}{A}$....................(2)



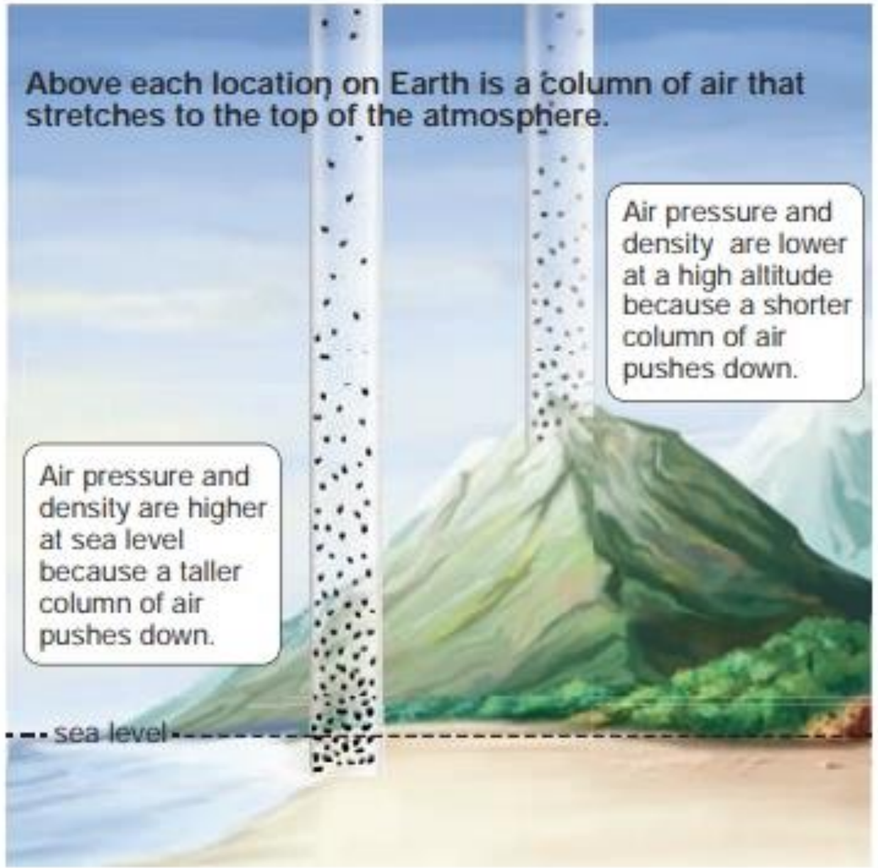
- Volume of liquid,
- v = Area of vessel x Height of liquid
- v = A x h
- Substituting in equation (2)
- $P = \frac{\rho \, A \, h \, g}{A}$
- $P = \rho g h$
- $P = \omega h$,(Since $\omega = \rho g$)
- From this we can write,
- Pressure head, $h = \frac{P}{\rho g}$ or $h = \frac{P}{\omega}$

ATMOSPHERIC PRESSURE (P_{atm})

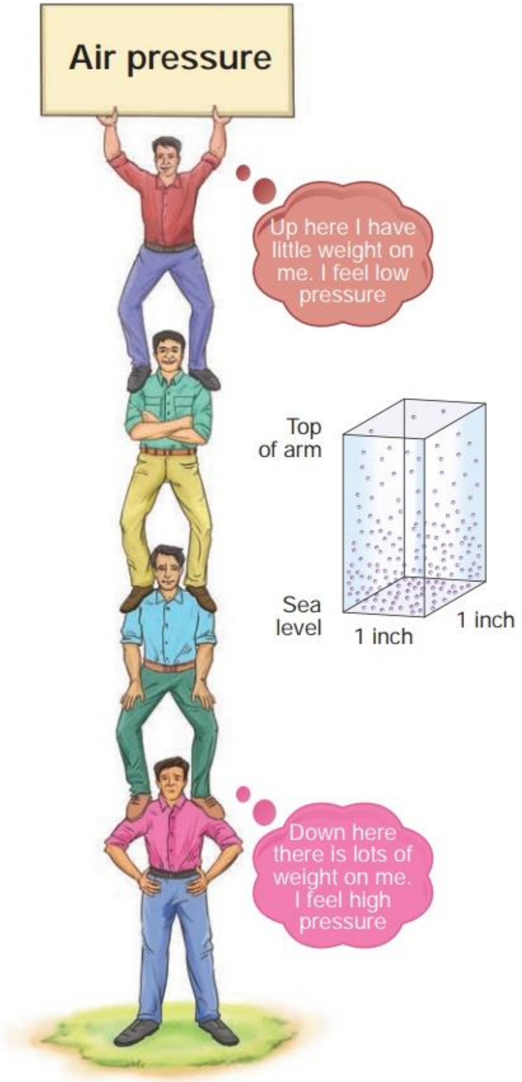
- It is the pressure exerted by the atmosphere.
- It is the pressure at any place due to the weight of air column above that place.
- It is measured by a barometer.
- So it is also called barometric pressure.
- Usually mercury is taken as barometric liquid.



- Atmospheric pressure varies with the altitude of the place, temperature and other weather conditions.



Atmospheric pressure acts like a column



Atmospheric pressure

STANDARD ATMOSPHERIC PRESSURE

- Atmospheric pressure is tabulated with respect sea level
- Used in calculations to maintain uniformity
- The standard atmospheric pressure at mean sea level is
- 1 P_{atm} $= 101.3 KN/m^2$

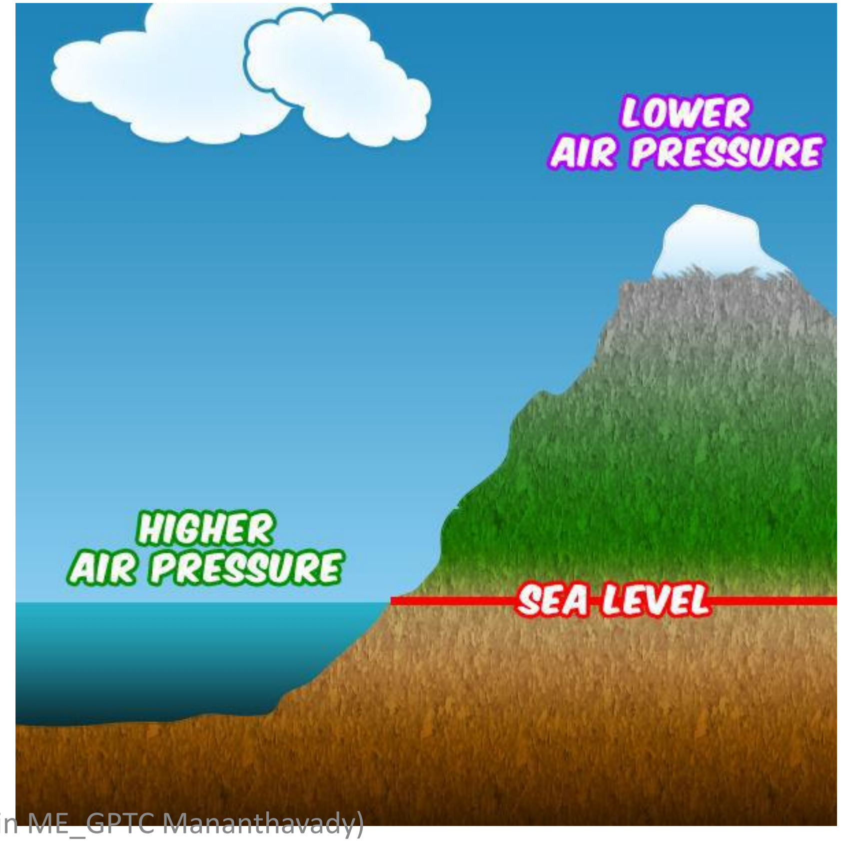
  $= 1.013 bar$

  $= 14.7 psi$

  $= 760 mm$ of Hg

  $= 33.9 ft$ of water

  $= 10.3 m$ of water



GAUGE PRESSURE (P_g)

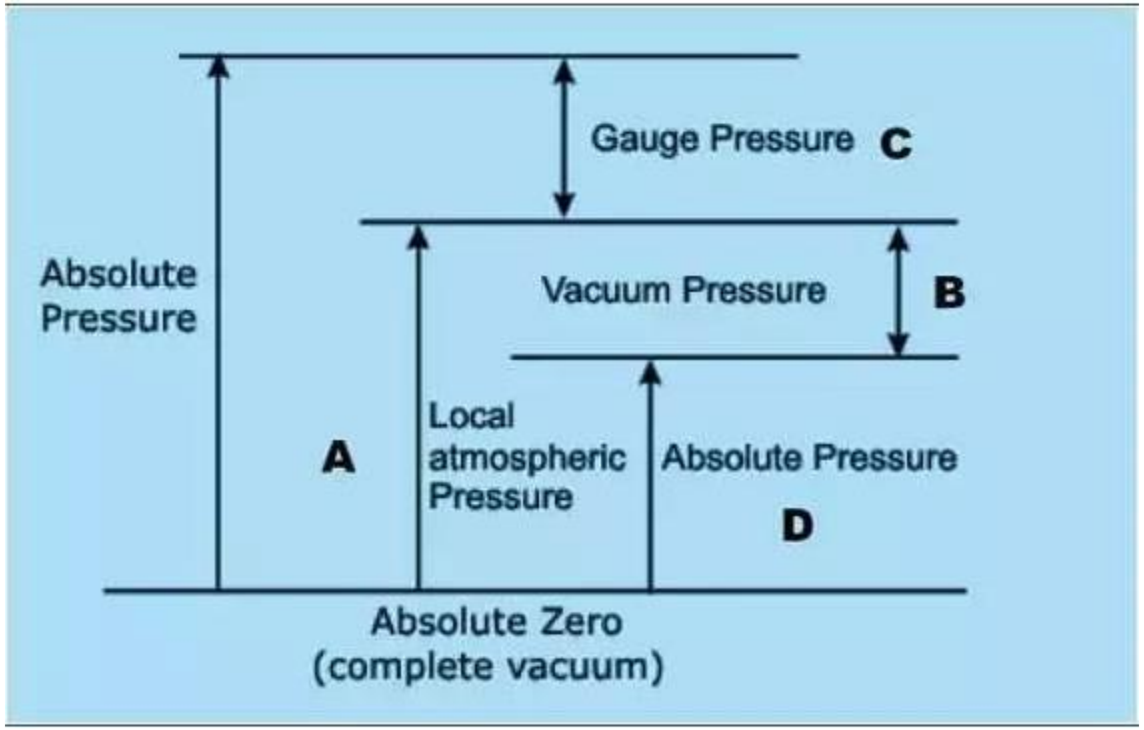
- Pressure of liquids is measured by instruments called pressure gauges.
- The pressure measured by pressure gauges is called gauge pressure.
- Gauge pressure is the pressure measured above atmospheric pressure.

VACUUM PRESSURE (P_v)

- The pressure below atmospheric pressure is called vacuum pressure.
- It is measured by vacuum gauges.
- It is also called negative gauge pressure.

ABSOLUTE PRESSURE (P_{abs})

- The pressure measured above absolute zero pressure line is called absolute pressure.
- In case of positive pressure,
- $P_{abs} = P_{atm} + P_g$
- In case of negative pressure,
- $P_{abs} = P_{atm} - P_v$



PROBLEMS

Q.1. Calculate the intensity of pressure due to a column of 0.6 m of

a) Mercury

b) Water

c) An oil of specific gravity 0.85

Given data:

Pressure head, h = 0.6 m

P = ?

a) Pressure, P = ωh

$$S_{mercury} = \frac{\omega_{mercury}}{\omega_{water}} \qquad (S_{mercury} = 13.6,\ \omega_{water} = 9810\ N/m^3)$$

$$13.6 = \frac{\omega_{mercury}}{9810}$$

$$\omega_{mercury} = 13.6 \times 9810 = 133416\ N/m^3$$

- Pressure, $P = \omega h$

$= 133416 \times 0.6 = 80049.6\ N/m^2$

$= 80.0496\ kPa$

b) Pressure, $P = \omega h$

$\omega_{water} = 9810\ N/m^3$

$P = 9810 \times 0.6 = 5886\ N/m^2$

$= 5.886\ kPa$

c) Pressure, $P = \omega h$, Given, $S_{oil} = 0.85$

$$S_{oil} = \frac{\omega_{oil}}{\omega_{water}}$$

$$0.85 = \frac{\omega_{oil}}{9810}, \quad \omega_{oil} = 0.85 \times 9810 = 8338.5\ N/m^3$$

$P = \omega h = 8338.5 \times 0.6 = 5003.1\ N/m^2 = 5.003kPa$

Q.2. The intensity of pressure of water at a point is 320kPa. Express the pressure in terms of, a) head of water b) head of mercury

Given data:

- P = 320 kPa = 320 x 10^3 Pa
- h = ?

a) Head, h = $\frac{P}{\omega}$

ω_{water} = 9810 N/m^3

$$h = \frac{320 \times 10^3}{9810}$$

= 32.619 m of water

b) Head, h = $\frac{P}{\omega}$

$$S_{mercury} = \frac{\omega_{mercury}}{\omega_{water}}$$

$$13.6 = \frac{\omega_{mercury}}{9810}$$

$\omega_{mercury}$ = 13.6 x 9810

= 133416 N/m^3

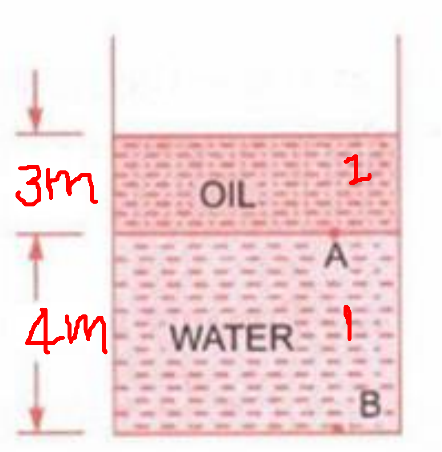
Head, $h = \frac{P}{\omega} = \frac{320 \times 10^3}{133416}$

= 2.398 m of mercury

Q.3. An open tank contains water up to a depth of 4m and above it an oil of specific gravity 0.85 for a depth of 3m. Find the pressure intensity. a) At the interface of two liquids. b) At the bottom of the tank.

Given data:

- $h_1 = 4m$
- $h_2 = 3m$
- $S_1 = 1$
- $S_2 = 0.85$



a) Pressure at the interface of two liquids, $P_2 = \omega_2 h_2$

$$S_2 = \frac{\omega_2}{\omega_1}, \ (\omega_1 = 9810 \ N/m^3)$$

$$\omega_2 = 0.85 \times 9810 = 8338.5 \ N/m^3$$

$$P_2 = \omega_2 h_2 = 8338.5 \times 3 = 25015.5 \ Pa$$

b) Pressure at the bottom of the tank,

$$P = P_1 + P_2$$

$$P_2 = 25015.5 \ Pa$$

$$P_1 = \omega_1 h_1 = 9810 \times 4 = 39240 \ Pa$$

Since $P = P_1 + P_2$

$$= 39240 + 25015.5$$

$$P = 64255.5 \ Pa$$

$$= 64.255 \ kPa$$

Q.4. Find the gauge pressure, absolute pressure and atmospheric pressure at a point 2.5m below the free surface of liquid having density 1.4 x 10^3 kg/m^3. Assume atmospheric pressure as 740mm of mercury. Take specific gravity of mercury equal to 13.6.

Given data:

- $h = 2.5$ m
- $\rho = 1.4 \times 10^3$ kg/m^3
- h_{atm} = 740mm of mercury
- = 0.74m of mercury
- $S_{mercury} = 13.6$
- $P_{atm} = ?$, $P_g = ?$, $P_{abs} = ?$

1) Atmospheric pressure,

- $P_{atm} = \omega_{mercury} h_{atm}$
- $S_{mercury} = \dfrac{\omega_{mercury}}{\omega_{water}}$
- $\omega_{mercury} = 13.6 \times 9810 = 133416$ N/m^3
- $P_{atm} = 133416 \times 0.74$
- $= 98727.84$ N/m^2 = 98.73 kPa

2) Gauge pressure, $P_g = \omega_l h_l$

- $P_g = \rho_l\, g\, h_l$
- $= 1.4 \times 10^3 \times 9.81 \times 2.5$
- $= 34335$ N/m^2 = 34.33 kPa

3) Absolute pressure,

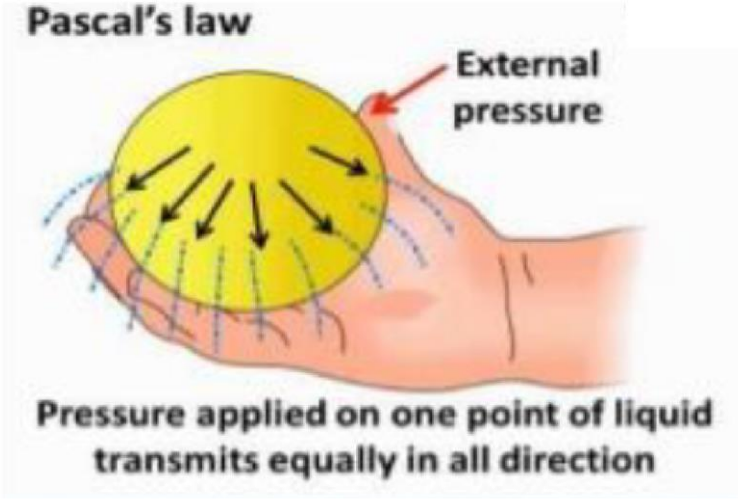
- $P_{abs} = P_{atm} + P_g$
- $= 98.73 + 34.33$
- $= 133.06$ kPa

Assignment 1

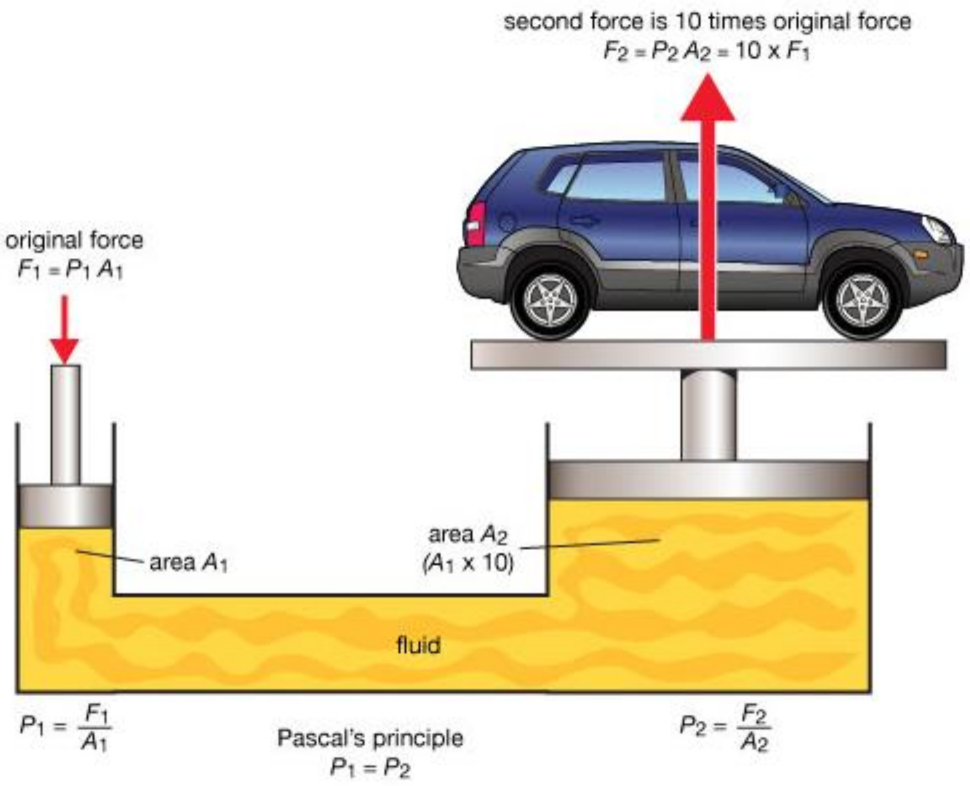
- Q.1. Convert an intensity of pressure 45.45 kPa into corresponding pressure head in terms of, a) Kerosene, ($S_{Kerosene}$ = 0.8) b) Water
- Q.2. What are the gauge pressure and absolute pressure at a point 3m below the free surface of liquid having a density of 1.53 x 10^3 kg/m^3. If the atmospheric pressure is equal to 750mm of mercury. The specific gravity of mercury is 13.6 and density of water is 1000 kg/m^3.
- Q.3. Explain briefly the working principle of bourdon tube pressure gauge with a neat sketch.

Pascals law

- Pascals law states that the pressure or intensity of pressure at any point in a static fluid is same in all direction.
- It states that an external pressure applied to a fluid in a closed vessel is uniformly transmitted throughout the fluid.



- Consider a closed container as shown below.



- According to Pascal's principle, the pressure exerted on a piston produces an equal increase in pressure on another piston in the system.
- If the second piston has an area 10 times that of the first, the force on the second piston is 10 times greater, though the pressure is same as that on the first piston.
- P1=P2
- $\frac{F1}{A1}=\frac{F2}{A2}$

Measurement of Pressure

- Various devices used for measuring pressure are,

1. Mechanical Gauges
2. Manometers

Mechanical gauges

- Used for steady flow & high gauge pressures
- Examples

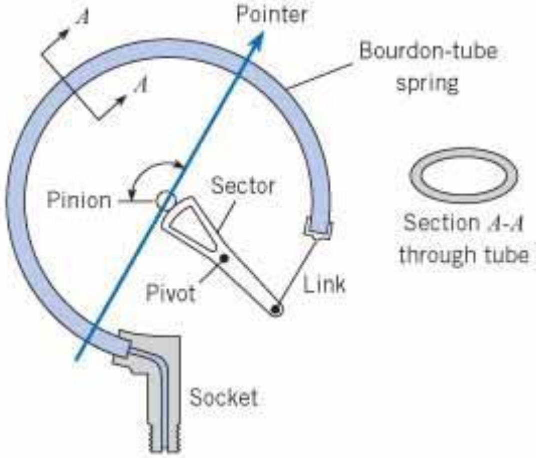
1. Bourdon tube pressure gauge

2. Diaphragm pressure gauge

3. Bellows pressure gauge

4. Dead weight pressure gauge

(a)

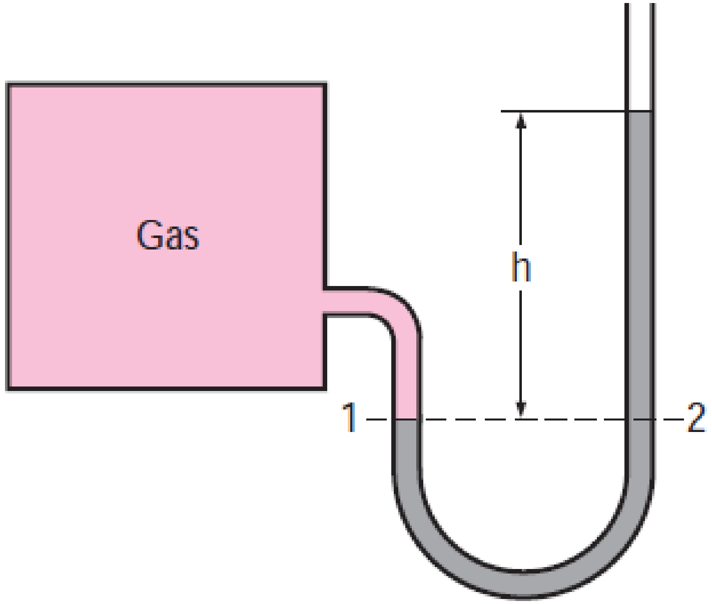


(b)

Manometers

- Commonly used to measure small and moderate pressures of fluids.
- Manometers are pressure measuring devices which are based on the principle of balancing the column of liquid by the same or another liquid column.
- It is classified into two

1. Simple manometers
2. Differential manometers



Simple manometers

- It is used to measure the pressure at a point in a fluid containing in a pipe or vessel.
- It consists of a glass tube having one of its end connected to the gauge point, where the pressure is measured and other end remains open to atmosphere.
- It is classified into two

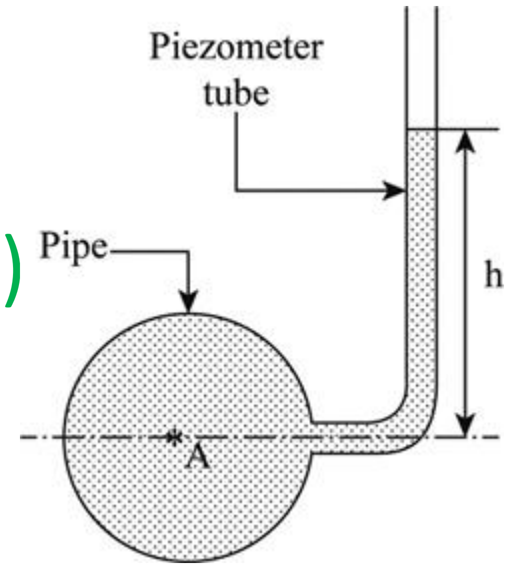
1. Piezometer
2. U-Tube manometer

Piezometer

- It is the simplest type of manometer and it is used for measuring moderate pressures of liquid.
- One end of this manometer is connected to the point where pressure is to be measured and other end is opened to the atmosphere.
- The pressure at any point in the liquid is indicated by height of liquid in the tube.
- The pressure at any point A, $P_A = \omega h$

(ω = specific weight of liquid, h = Pressure head)

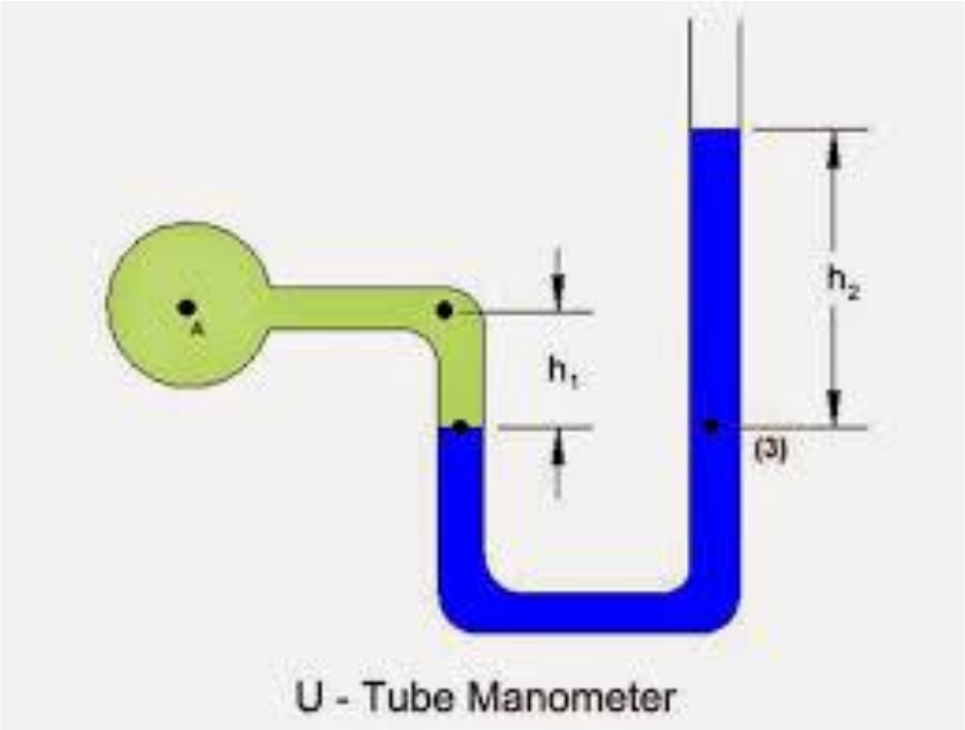
- It is used to measure gauge pressure only.
- It is not used for measuring vacuum pressure.



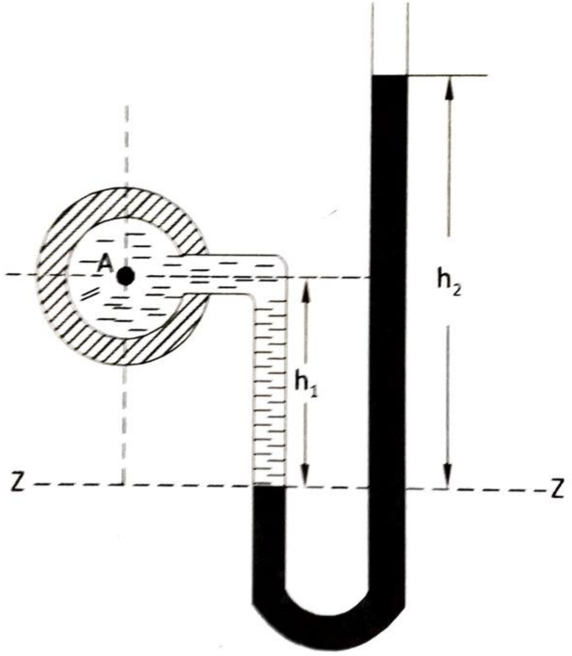
U-Tube manometer

- Piezometers cannot be used when large pressures in the lighter liquids are to be measured.
- Since this would require very long tubes.
- Also gas pressures can not be measured by piezometers.
- These limitations are overcome by the use of U-Tube manometers.
- U-tube manometer consists of a glass tube bent in U shape.
- One end of which is connected to a point at which pressure is to be measured and the other end is open to atmosphere.

- A U-tube manometer can be used to measure the pressure in any fluid (Liquid or gas).
- Pressures above and below atmosphere may be measured by U-tube manometer.



Measurement of gauge pressure by U-tube manometer

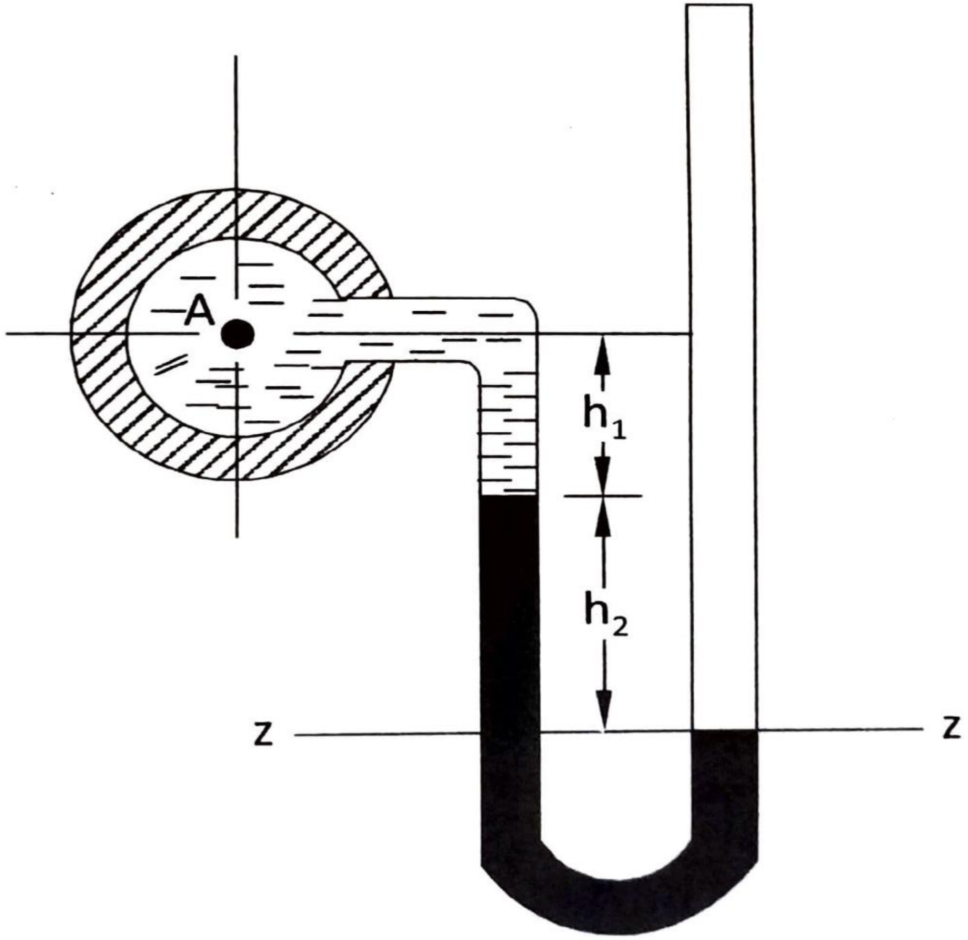


- From the figure, let A be the point at which pressure is to be measured and whose value is P_A.
- The datum line is z-z
- As the pressure head is same for the horizontal surface,
- The pressure at the left limb at z-z = Pressure at the right limb at z-z
- $P_A + \omega_1 h_1 = \omega_2 h_2$
- ω_1 and ω_2 are the specific weight of light liquid and heavy liquid respectively.
- Divide both sides by ω of water.
- $\frac{P_A}{\omega} + \frac{\omega_1 h_1}{\omega} = \frac{\omega_2 h_2}{\omega}$
- S_1 and S_2 are the specific gravity of light liquid and heavy liquid respectively.

- $\frac{P_A}{\omega} + S_1 h_1 = S_2 h_2$
- $\frac{P_A}{\omega} = S_2\, h_2 - S_1\, h_1$
- Unit is m of water.

Measurement of vacuum pressure by U-tube manometer

- For measuring vacuum pressure, the level of heavy liquid in the U-tube manometer is shown in figure.
- The pressure at the left limb at z-z = Pressure at the right limb at z-z
- $P_A + \omega_1 h_1 + \omega_2 h_2 = 0$
- $P_A = -(\omega_1 h_1 + \omega_2 h_2)$
- Divide both sides by ω of water.
- $\frac{P_A}{\omega} = -(\frac{\omega_1 h_1}{\omega} + \frac{\omega_2 h_2}{\omega})$
- $\frac{P_A}{\omega} = -(S_1 h_1 + S_2 h_2)$
- Unit is m of water.



DIFFERENTIAL MANOMETER

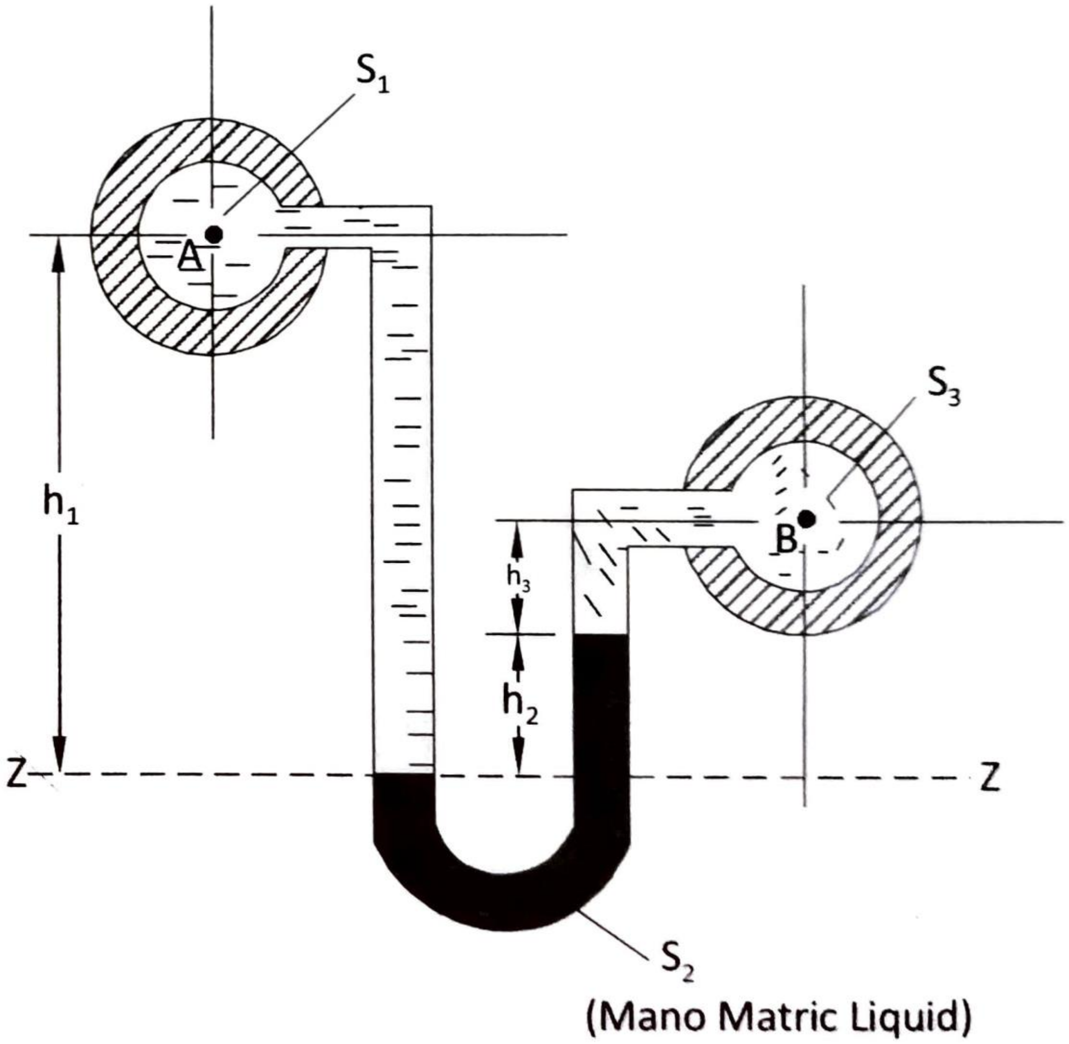
- It is used for measuring the pressure difference between two points in a pipe or in two different pipes.
- It is classified into two.

1. U-Tube differential manometer.
2. Inverted U-Tube differential manometer.

U-TUBE DIFFERENTIAL MANOMETER

- It consists of a glass tube bend in U-shape, the two ends of which are connected to the 2 gauge points between which the pressure difference is to be measured.
- The lower part of the manometer contains a manometric liquid which is heavier than the liquid for which the pressure difference is to be measured.

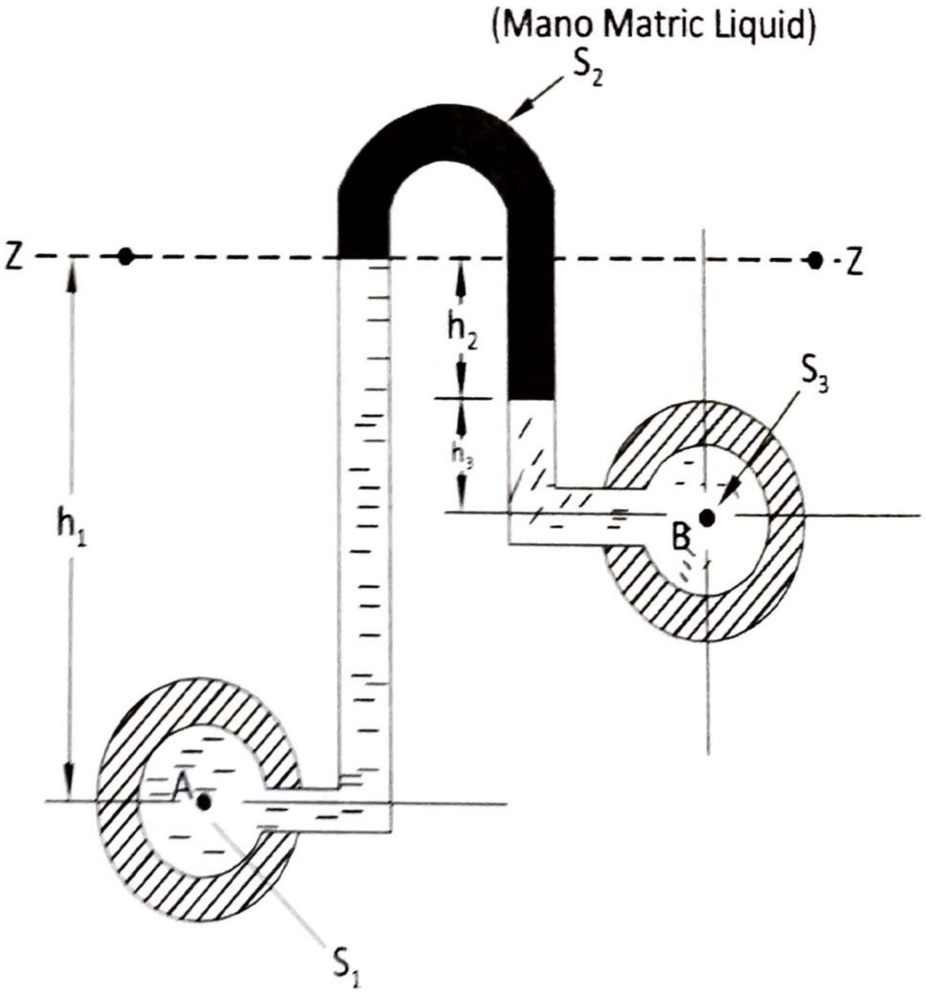
- The pressure head above the datum z-z in the left limb equal to pressure head above the datum z-z in the right limb.
- $P_A + \omega_1 h_1 = \omega_2 h_2 + \omega_3 h_3 + P_B$
- $P_A - P_B = \omega_2 h_2 + \omega_3 h_3 - \omega_1 h_1$
- $\omega_1$and ω_3 are the specific weight of liquid in pipe A and B respectively.
- ω_2 is the specific weight of mercury
- Divide both sides by ω of water.
- $\frac{P_A - P_B}{\omega} = \frac{\omega_2 h_2}{\omega} + \frac{\omega_3 h_3}{\omega} - \frac{\omega_1 h_1}{\omega}$
- $\frac{P_A - P_B}{\omega} = S_2 h_2 + S_3 h_3 - S_1 h_1$
- Unit is m of water.



INVERTED U-TUBE MANOMETER

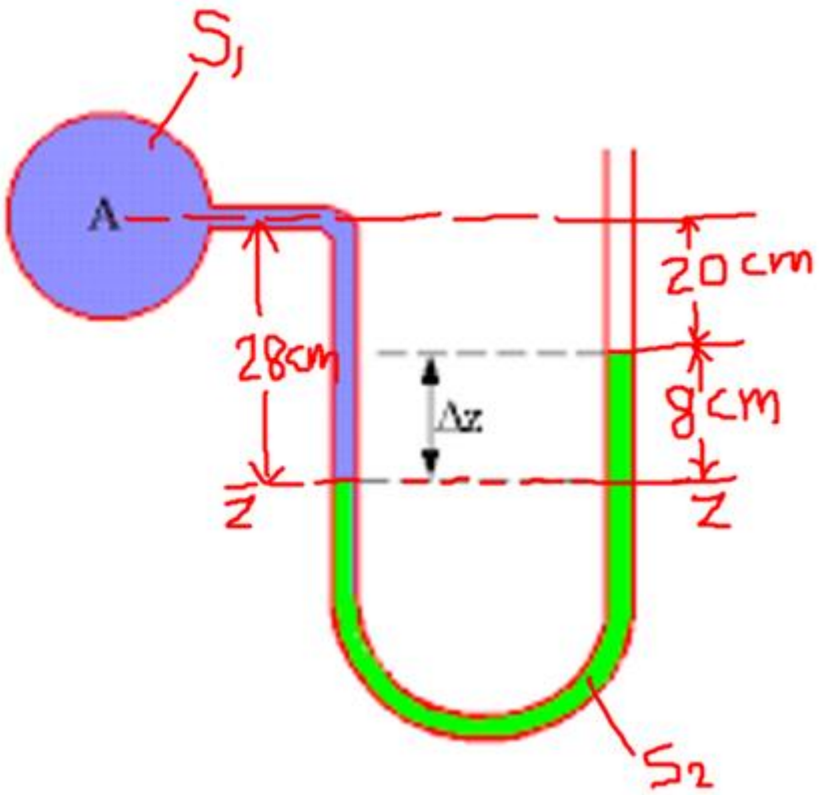
- They are used to estimate the pressure difference between 2 points in the same pipe or in different pipes.
- It is used when the manometric fluid is lighter than the working fluid in pipes or pipe.
- Inverted U-tube manometers are employed for most accurate measurement of small pressure difference between two points.

- Pressure at z-z in left limb = pressure at z-z in right limb
- $P_A - \omega_1 h_1 = P_B - \omega_2 h_2 - \omega_3 h_3$
- $P_A - P_B = \omega_1 h_1 - \omega_2 h_2 - \omega_3 h_3$
- ω_1 and ω_3 are the specific weight of liquid in pipe A and B respectively.
- ω_2 is the specific weight of liquid in the U-tube.
- Divide both sides by ω of water.
- $\frac{P_A - P_B}{\omega} = \frac{\omega_1 h_1}{\omega} - \frac{\omega_2 h_2}{\omega} - \frac{\omega_3 h_3}{\omega}$
- $\frac{P_A - P_B}{\omega} = S_1 h_1 - S_2 h_2 - S_3 h_3$
- Unit is m of water.



PROBLEMS

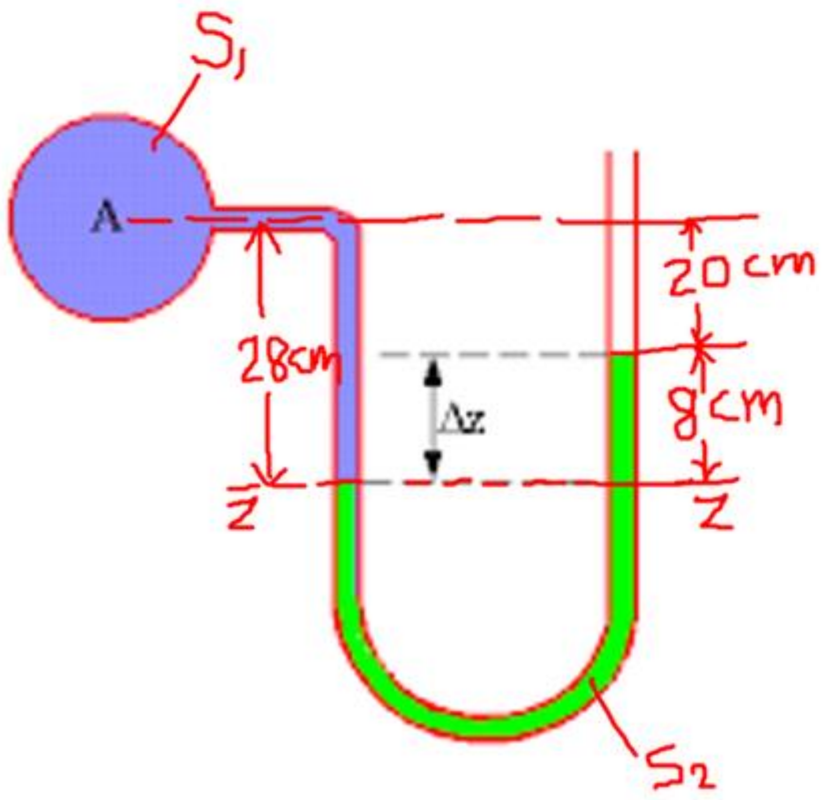
- Q.1. A U-tube manometer fitted to a pipe line containing an oil of specific gravity 0.8. The centre of the pipeline is at a height of 20cm from the free surface of mercury in the right limb. The deflection of mercury is 8cm in the right limb. Determine the pressure of oil in the pipeline?



Given data:

- $S_1 = 0.8$
- $h_1 = 28$ cm
- $= 0.28$ m
- $S_2 = 13.6$
- $h_2 = 8$ cm
- $= 0.08$ m
- $\frac{P_A}{\omega} = S_2\, h_2 - S_1\, h_1$

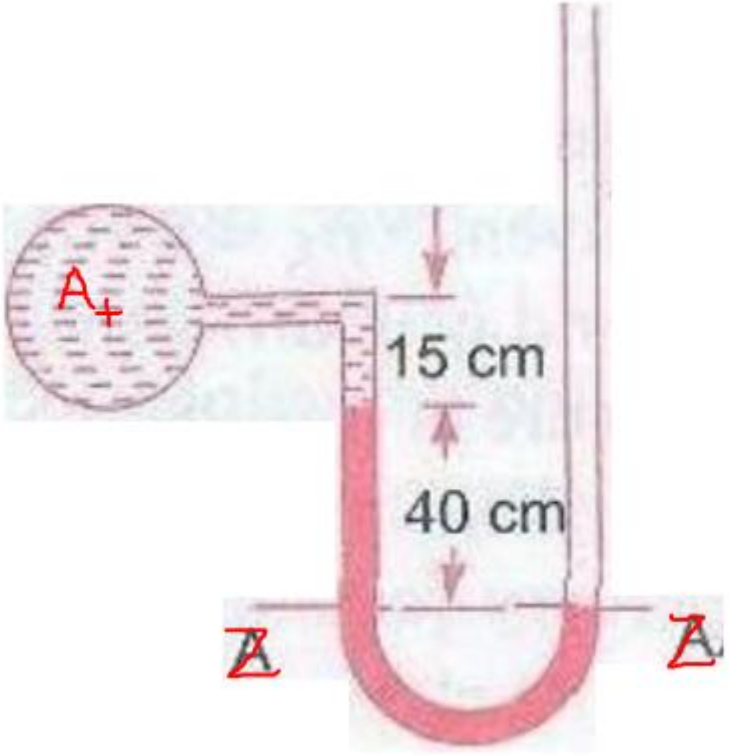
- $\frac{P_A}{\omega} = (13.6 \times 0.08) - (0.8 \times 0.28)$
- $\frac{P_A}{\omega} = 0.864$
- $P_A = 0.864 \times 9810$
- $= 8475.84\ N/m^2$
- $P_A = 8.47$ kPa



Q.2. A simple U-tube Manometer containing mercury is connected to a pipe in which the fluid of sp. gr. 0.8 and having vacuum pressure is, flowing. The other end of the manometer is open to atmosphere. Find the vacuum pressure in pipe, if the difference of mercury level in the two limbs is 40 cm and the height of fluid in the left limb from the centre of pipe is 15 cm below

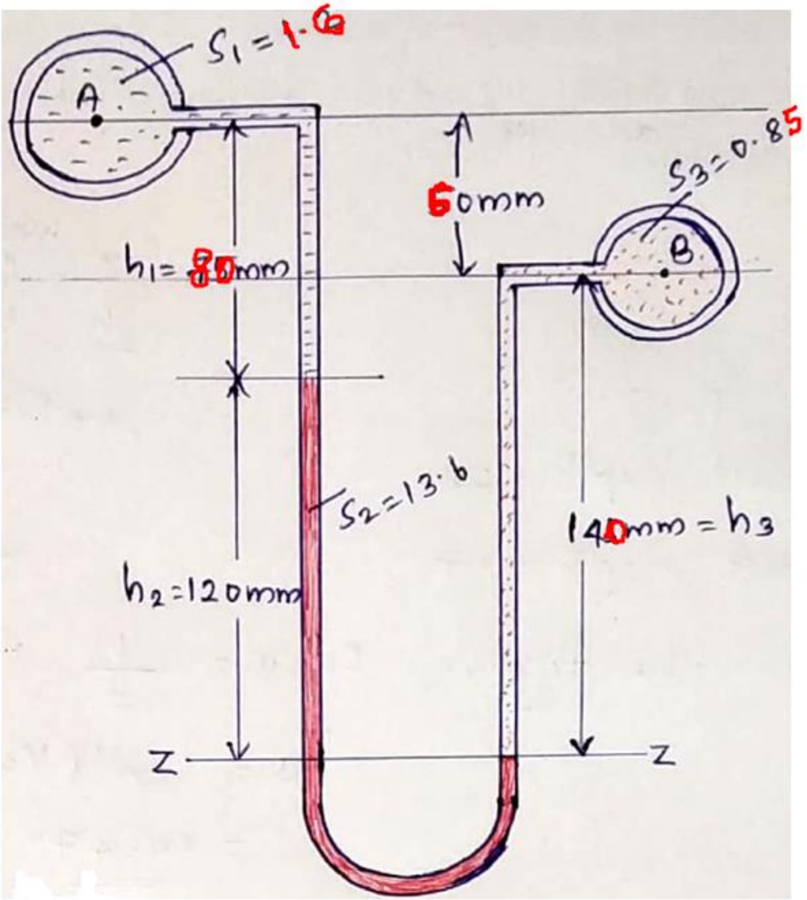
- Given Data:
- $S_1 = 0.8$
- $h_1 = 15$ cm
- $= 0.15$ m
- $S_2 = 13.6$
- $h_2 = 40$ cm
- $= 0.4$ m

- $\frac{P_A}{\omega} = -(S_1h_1 + S_2h_2)$
- $\frac{P_A}{\omega} = -(0.8 \times 0.15 + 13.6 \times 0.4)$
- $\frac{P_A}{\omega} = -5.56$
- $P_A = -5.56 \times 9810$
- $= -54543.6 \ N/m^2$
- $P_A = -54.54$ kPa

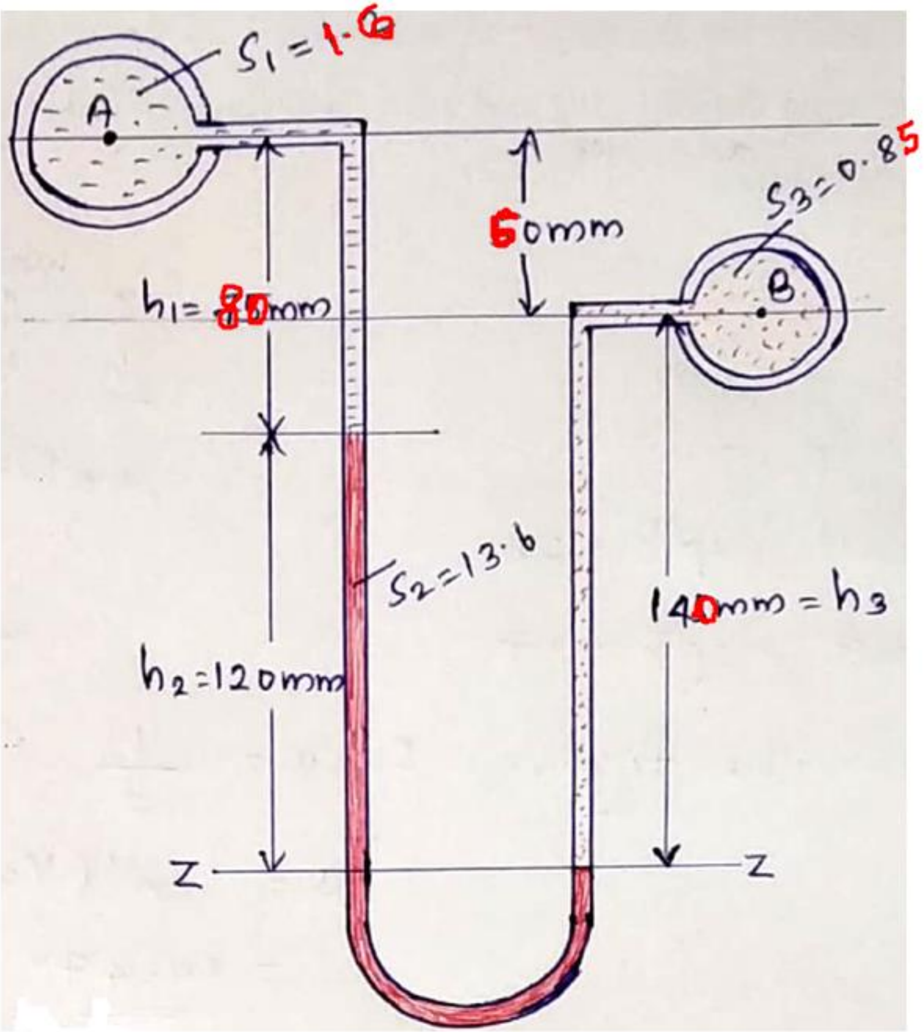


Q.3. A U-tube mercury manometer is connected to two pipes A and B. Pipe B is 60 mm below pipe A. The specific gravity of liquid in pipe A and B is 1.6 and 0.85 respectively. Mercury level in the left limb is 80 mm below the centre of the pipe A. Find the pressure difference between two pipes in kPa if the level difference of mercury in the two limbs of manometer is 120 mm.

- Given Data:
- $S_1 = 1.6$, $S_2 = 13.6$, $S_3 = 0.85$
- $h_1 = 80$ mm
- $= 0.08$ m
- $h_2 = 120$ mm
- $= 0.12$ m
- $h_3 = 140$ mm
- $= 0.14$ m

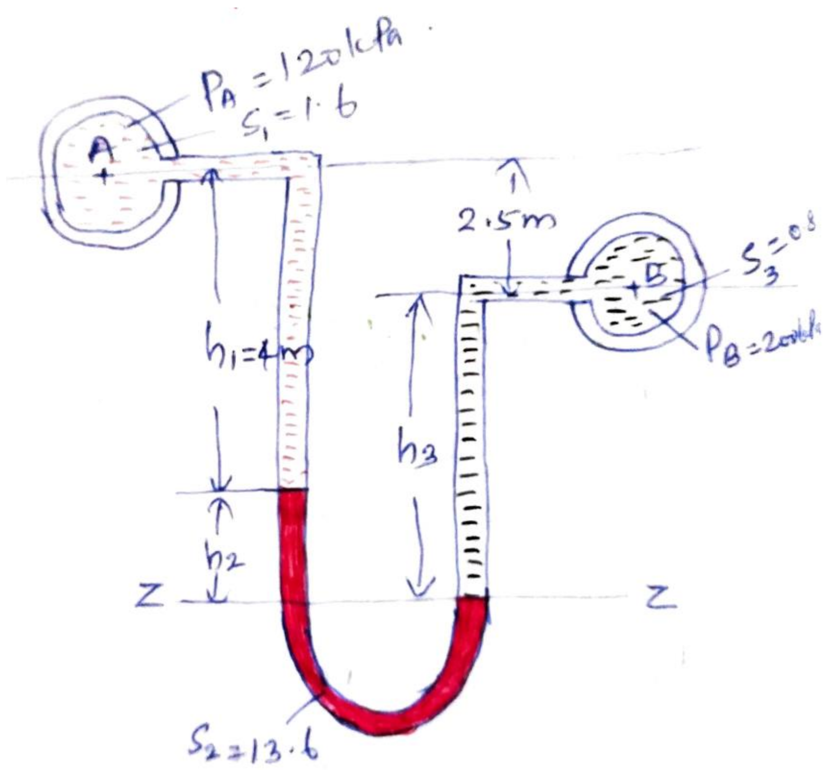


- $\frac{P_A}{\omega} + S_1\, h_1\ + S_2\, h_2 = \frac{P_B}{\omega} + S_3\, h_3$
- $\frac{P_B - P_A}{\omega} = S_1\, h_1\ + S_2\, h_2 - S_3\, h_3$
- $\frac{P_B - P_A}{\omega} = 1.6 \times 0.08 + 13.6 \times 0.12 - 0.85 \times 0.14$
- $\frac{P_B - P_A}{\omega} = 1.641$
- $P_B - P_A = 1.641 \times 9810$
- $= 16098.21\ N/m^2$
- $P_B - P_A = 16.098\ kPa$

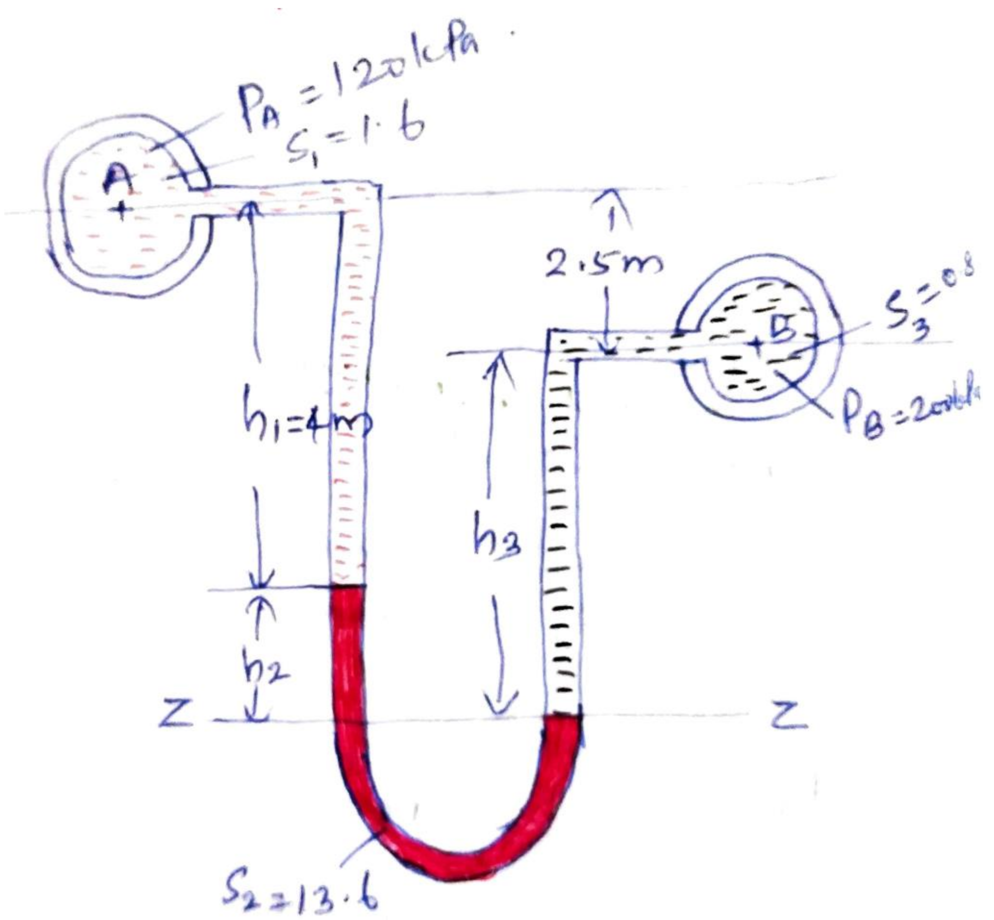


Q.4. A U-tube differential manometer containing mercury is connected on one side to pipe A containing carbon tetrachloride (S=1.6), under a pressure of 120 kPa and on the other side to pipe B containing oil (S=0.8), under a pressure of 200 kPa. The pipe A lies 2.5 m above pipe B and the mercury level in the limb communicating with pipe A lies 4 m below pipe A. Determine the difference in the level of mercury in the two limbs of manometer. Take specific weight of water as 9.81 kN/m^3

- Given data:
- $S_1 = 1.6$, $S_2 = 13.6$, $S_3 = 0.8$
- $h_1 = 4$ m, $h_2 = ?$, $h_3 = h_2 + 1.5$
- $P_A = 120$ kPa $= 120 \times 10^3$ N/m^2
- $P_B = 200$ kPa $= 200 \times 10^3$ N/m^2

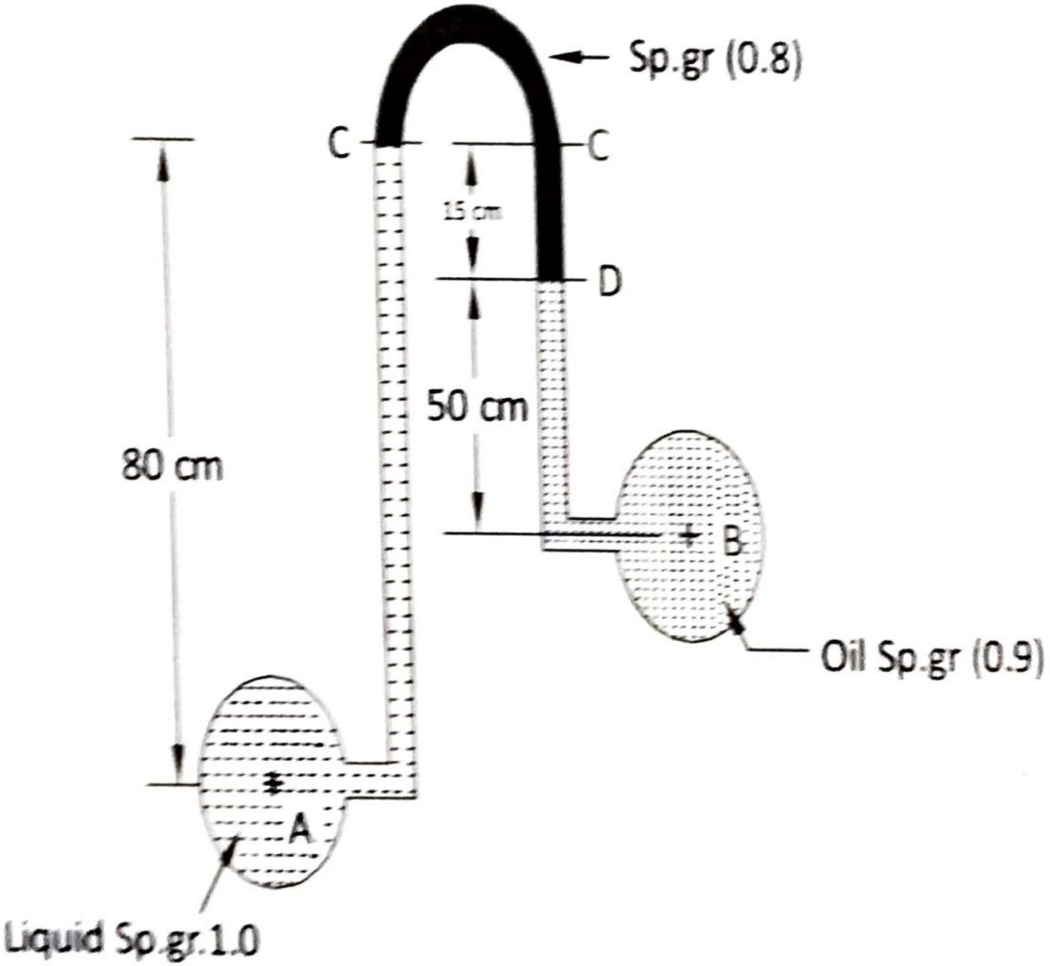


- $\frac{P_A}{\omega} + S_1\, h_1 + S_2\, h_2 = \frac{P_B}{\omega} + S_3\, h_3$
- $\frac{P_B - P_A}{\omega} = S_1\, h_1 + S_2\, h_2 - S_3\, h_3$
- $\frac{P_B - P_A}{\omega} = 1.6 \times 4 + 13.6 \times h_2 - 0.8(h_2 + 1.5)$
- $\frac{P_B - P_A}{\omega} = 6.4 - 1.2 + 12.8\, h_2$
- $\frac{(200 - 120) \times 10^3}{9810} = 5.2 + 12.8\, h_2$
- $8.154 = 5.2 + 12.8\, h_2$
- $2.9549 = 12.8\, h_2$
- $h_2 = 0.23$ m

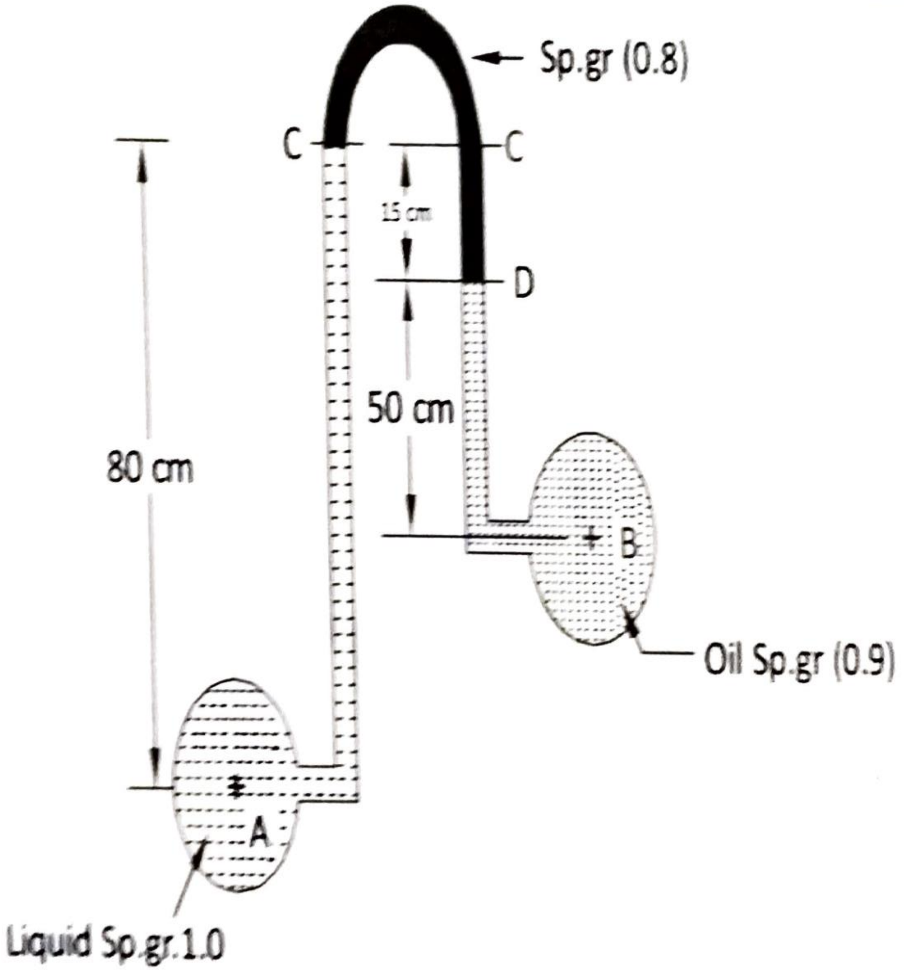


Q.5. An inverted differential manometer, when connected to pipe A and B gives the reading as shown in figure. Determine the pressure of pipe B, if the pressure in pipe A is 100 kN/m^2

- Given data:
- $P_A = 100\ kN/m^2 = 100 \times 10^3\ N/m^2$
- $S_1 = 1$, $S_2 = 0.8$, $S_3 = 0.9$
- $h_1 = 80\ cm = 0.8\ m$
- $h_2 = 15\ cm = 0.15\ m$
- $h_3 = 50\ cm = 0.5\ m$
- $P_B = ?$



- $\frac{P_A}{\omega} - S_1\,h_1 = \frac{P_B}{\omega} - S_2\,h_2 - S_3\,h_3$
- $\frac{100x10^3}{9810} - 1x0.8 = \frac{P_B}{\omega} - 0.8x0.15 - 0.9x0.5$
- $9.394 = \frac{P_B}{\omega} - 0.57$
- $\frac{P_B}{\omega} = 9.394 + 0.57$
- $= 9.964$ m
- $P_B = 9.964 \times 9810$
- $= 97.74 \times 10^3\ N/m^2$



THANK YOU