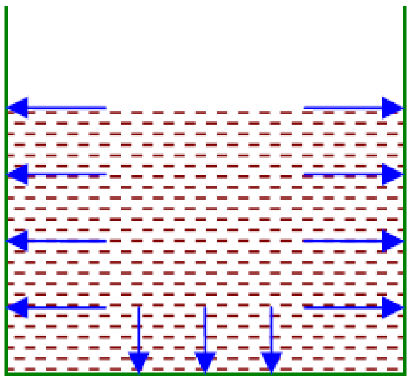
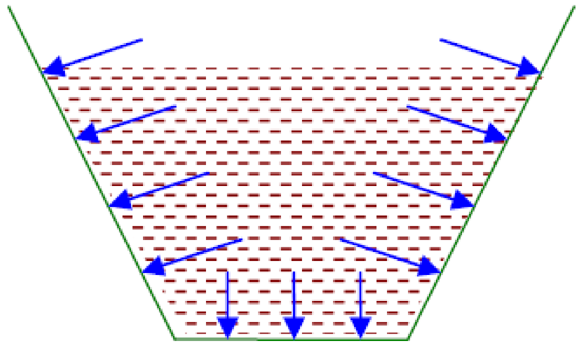
PRESSURE AND ITS MEASUREMENTS:





Fluid is a state of matter which exhibits the property of flow. When a certain mass of fluids is held in static equilibrium by confining it within solid boundaries, it exerts force along direction perpendicular to the boundary in contact. This force is called fluid pressure.

• **Pressure distribution:**

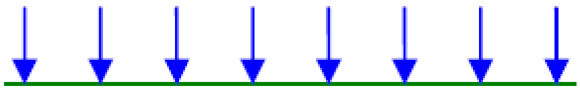
It is the variation of pressure over the boundary in contact with the fluid.

There are two types of pressure distribution.

a) Uniform Pressure distribution.

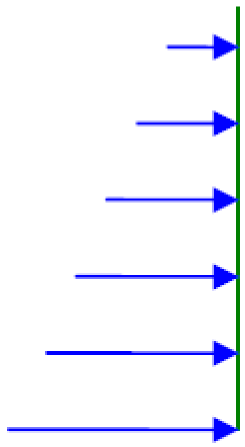
b) Non-Uniform Pressure distribution.

(a) Uniform Pressure distribution:



If the force exerted by the fluid is same at all the points of contact boundary then the pressure distribution is said to be uniform.

(b) Non –Uniform Pressure distribution:



If the force exerted by the fluid is not same at all the points then the pressure distribution is said to be non-uniform.

Intensity of pressure or unit pressure or Pressure:

Intensity of pressure at a point is defined as the force exerted over unit area considered around that point. If the pressure distribution is uniform then intensity of pressure will be same at all the points.

Calculation of Intensity of Pressure:

When the pressure distribution is uniform, intensity of pressure at any points is given by the ratio of total force to the total area of the boundary in contact.

Intensity of Pressure 'p' $=F/A$

When the pressure distribution is non- uniform, then intensity of pressure at a point is given by dF/dA.

Unit of Intensity of Pressure: N/m^2 or pascal (Pa).

Note: 1 MPa $=1N/mm^2$

• **Atmospheric pressure**

Air above the surface of liquids exerts pressure on the exposed surface of the liquid and normal to the surface.

This pressure exerted by the atmosphere is called atmospheric pressure.

Atmospheric pressure at a place depends on the elevation of the place and the temperature.

Atmospheric pressure is measured using an instrument called 'Barometer' and hence atmospheric pressure is also called Barometric pressure.

Unit: kPa .

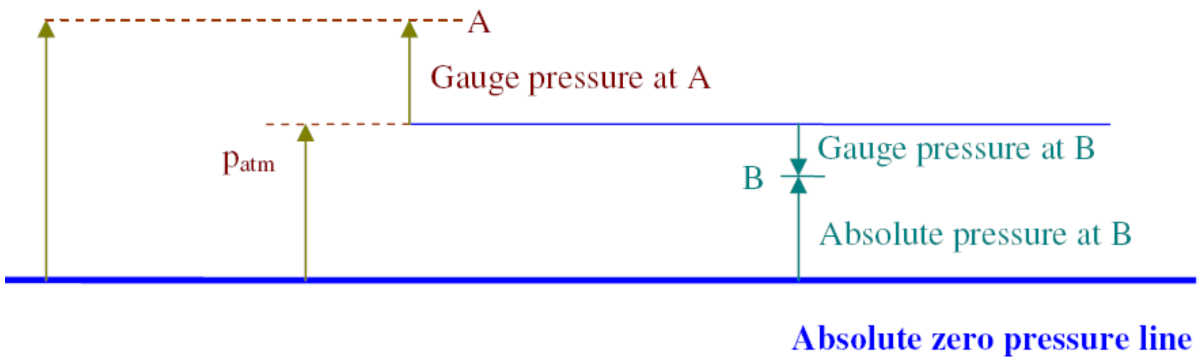
'bar' is also a unit of atmospheric pressure 1bar = 100 kPa.

Absolute pressure and Gauge Pressure:

Absolute pressure at a point is the intensity of pressure at that point measured with reference to absolute vacuum or absolute zero pressure.

Absolute pressure at a point can never be negative since there can be no pressure less than absolute zero pressure.

Absolute pressure at 'A'



Absolute pressure at a point is the intensity of pressure at that point measured with reference to absolute vacuum or absolute zero pressure.

Absolute pressure at a point can never be negative since there can be no pressure less than absolute zero pressure.

If the intensity of pressure at a point is measured with reference to atmospheric pressure, then it is called gauge pressure at that point.

Gauge pressure at a point may be more than the atmospheric pressure or less than the atmospheric pressure. Accordingly gauge pressure at the point may be positive or negative.

Negative gauge pressure is also called vacuum pressure.

From the figure, It is evident that, Absolute pressure at a point = Atmospheric pressure ± Gauge pressure.

NOTE: If we measure absolute pressure at a Point below the free surface of the liquid, then,

p = g. Y + patm

If gauge pressure at a point is required, then atmospheric pressure is taken as zero, then,

p = g. Y

Pressure Head

It is the depth below the free surface of liquid at which the required pressure intensity is available.

P = gh

h = *P/* g

For a given pressure intensity ‘h’ will be different for different liquids since, ‘g’ will be different for different liquids. Whenever pressure head is given, liquid or the property of liquid like specify gravity, specific weight, mass density should be given.

Eg:

(i) 3m of water

(ii) 10m of oil of S = 0.8.

(iii) 3m of liquid of g = 15 kN/m3

(iv) 760mm of Mercury.

(v) 10m _ not correct.

NOTE:

1. To convert head of a liquid to head of another liquid.

$$S = \frac{\gamma}{\gamma_{Standard}}$$

$$S_1 = \frac{\gamma_1}{\gamma_{Standard}}$$

$$p = \gamma_1 h_1$$

$$\therefore \gamma_1 = S_1 \gamma_{Standard}$$

$$p = \gamma_2 h_2$$

$$\gamma_{21} = S_2 \gamma_{Standard}$$

$$\boxed{\gamma_1 h_1 = \gamma_2 h_2}$$

$$\therefore S_1 \ \gamma_{Standard} \ h_1 = S_2 \ \gamma_{Standard} \ h_2$$

$$\boxed{S_1 h_1 = S_2 h_2}$$

2. Swater x hwater = Sliquid x hliquid

1x hwater = Sliquid x hliquid

h water = Sliquid x hliquid

Pressure head in meters of water is given by the product of pressure head in meters of liquid and specific gravity of the liquid.

Eg: 10meters of oil of specific gravity 0.8 is equal to 10x0.8 = 8 meters of water.

Eg: Atmospheric pressure is 760mm of Mercury.

NOTE:

P	=	g	h
kPa		kN/m^3	m

Problem:

1. Calculate intensity of pressure due to a column of 0.3m of (a) water (b) Mercury

(c) Oil of specific gravity-0.8.

a) h = 0.3m of water

$\gamma = 9.81\ \frac{kN}{m^3}$

p = ?

$p = \gamma h$

p = 2.943 kPa

c) h = 0.3 of Hg

$\gamma = 13.6 \times 9.81$

$\gamma = 133.416\ kN/m^3$

$p = \gamma\ h$

$= 133.416 \times 0.3$

p = 40.025 kPa

2. Intensity of pressure required at a points is 40kPa. Find corresponding head in (a) water (b) Mercury (c) oil of specific gravity-0.9.

(a) p = 40 kPa

$\gamma = 9.81\ \frac{kN}{m^3}$

h = ?

$h = \frac{p}{\gamma}$

h = 4.077 m of water

(b) p = 40 kPa

$\gamma = (13.6 \times 9.81\ N/m^3$

$\gamma = 133.416\ \frac{KN}{m^3}$

$h = \frac{p}{\gamma}$

h = 0.299 m of Mercury

c) p = 40 kPa

$\gamma = 0.9 \times 9.81$

$\gamma = 8.829\ \frac{KN}{m^3}$

$h = \frac{p}{\gamma}$

h = 4.53 m of oil S = 0.9

4. Standard atmospheric pressure is 101.3 kPa Find the pressure head in (i) Meters of water (ii) mm of mercury (iii) m of oil of specific gravity 0.8.

(i) $p = \gamma h$

$101.3 = 9.81 \times h$

$h = 10.3$ m of water

(ii) $p = \gamma h$

$101.3 = (13.6 \times 9.81) \times h$

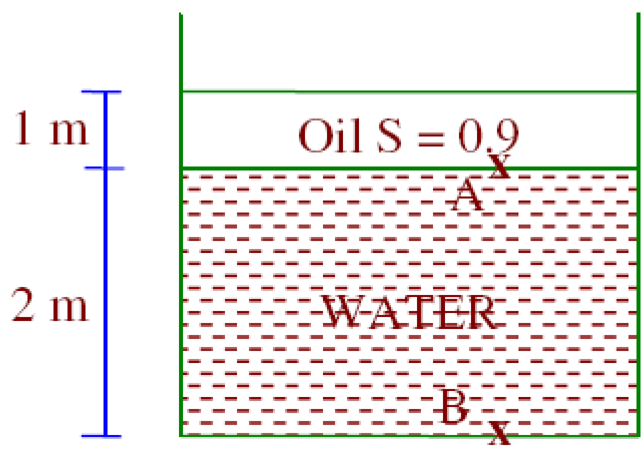
$h = 0.76$ m of mercury

(iii) $p = \gamma h$

$101.3 = (0.8 \times 9.81 \times h$

$h = 12.9$ m of oil of $S = 0.8$

5. An open container has water to a depth of 2m and above this an oil of S = 0.9 for a depth of 1m. Find the intensity of pressure at the interface of two liquids and at the bottom of the tank.



$p_A = \gamma_{a1}\ h_{oil}$

$= (0.9\ x\ 9.81)\ x\ 1$

$p_A = 8.829\ kPa$

$p_B = \gamma_{oil}\ xh_{oil} + \gamma_{water} + h_{water}$

$p_A = 8.829\,kPa + 9.81\ x\ 2$

$p_B = 28.45\,kPa$

6. Convert the following absolute pressure to gauge pressure (a) 120kPa (b) 3kPa (c) 15m of H2o (d) 800mm of Hg.

(a) $p_{abs} = p_{atm} + p_{gauge}$

$\therefore\ p_{gauge} = p_{abs} - p_{atm} = 120 - 101.3 = 18.7$ kPa

(b) $p_{gauge} = 3-101.3 = -98.3$ kPa

$p_{gauge} = 98.3$ kPa (vacuum)

(c) $h_{abs} = h_{atm} + h_{gauge}$

$15 = 10.3 + h_{gauge}$

$h_{gauge} = 4.7$m of water

(d) $h_{abs} = h_{atm} + h_{gauge}$

$800 = 760 + h_{gauge}$

$h_{gauge} = 40$ mm of mercury

Measurement of Pressure

Various devices used to measure fluid pressure can be classified into,

1. Manometers
2. Mechanical gauges.

Manometers are the pressure measuring devices which are based on the principal of balancing the column of the liquids whose pressure is to be measured by the same liquid or another liquid. Mechanical gauges consist of an elastic element which deflects under the action of applied pressure and this movement will operate a pointer on a graduated scale.

Classification of Manometers:

Manometers are broadly classified into

a) Simple Manometers

b) Differential Manometers.

a) Simple Manometers

Simple monometers are used to measure intensity of pressure at a point.

They are connected to the point at which the intensity of pressure is required. Such a point is called gauge point.

b) Differential Manometers

Differential manometers are used to measure the pressure difference between two points. They are connected to the two points between which the intensity of pressure is required.

Types of Simple Manometers

Common types of simple manometers are

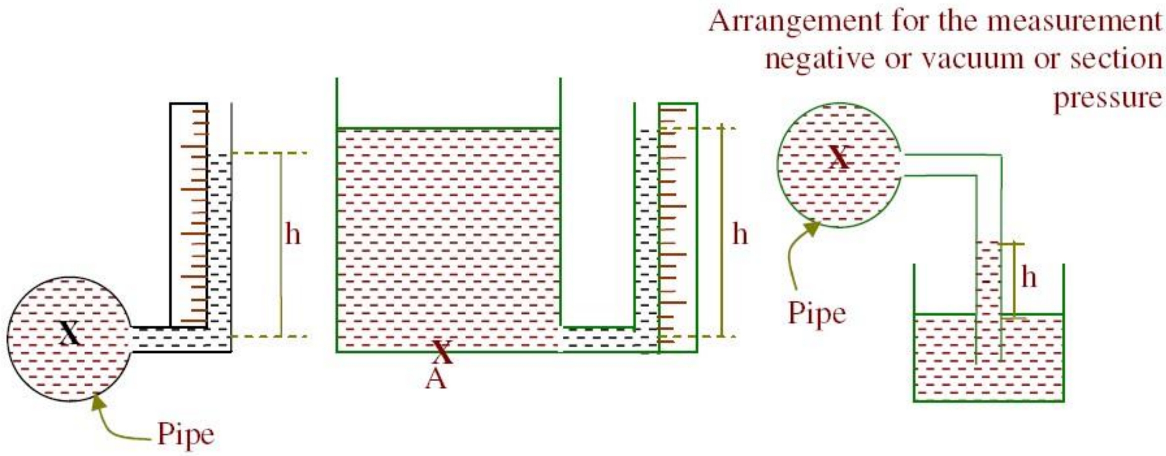
a) Piezometers

b) U-tube manometers

c) Single tube manometers

d) Inclined tube manometers

a) Piezometers:



Piezometer consists of a glass tube inserted in the wall of the vessel or pipe at the level of point at which the intensity of pressure is to be measured. The other end of the piezometer is exposed to air. The height of the liquid in the piezometer gives the pressure head from which the intensity of pressure can be calculated.

To minimize capillary rise effects the diameters of the tube is kept more than 12mm.

Merits

_ Simple in construction

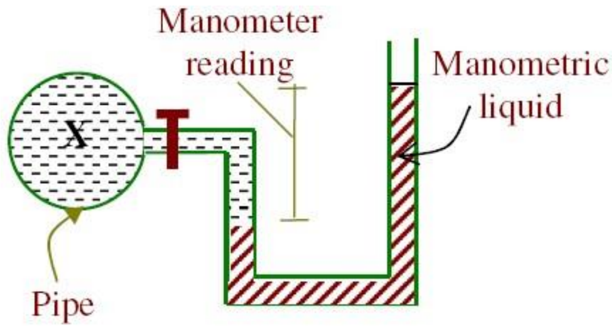
_ Economical

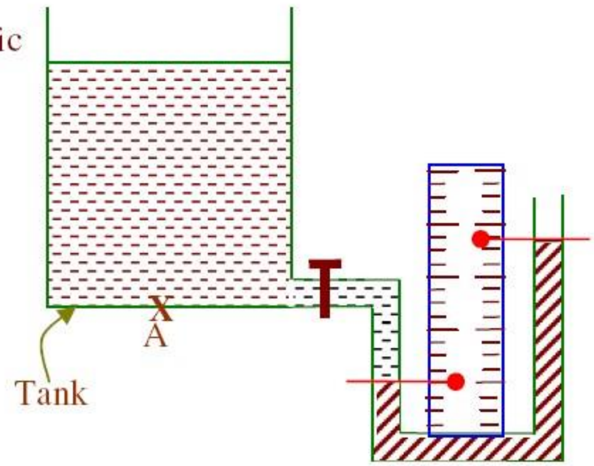
Demerits

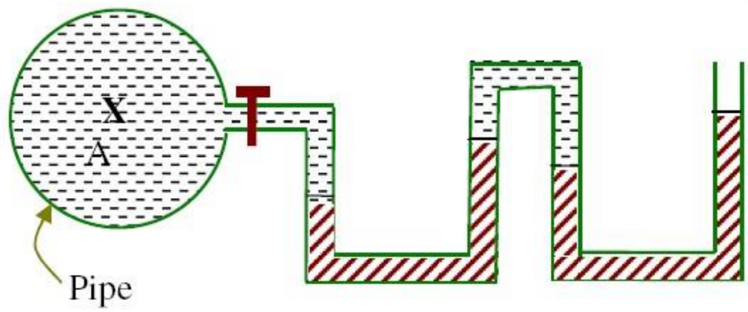
_ Not suitable for high pressure intensity.

_ Pressure of gases cannot be measured.

(b) U-tube Manometers:







A U-tube manometers 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. U-tube consists of a liquid of specific of gravity other than that of fluid whose pressure intensity is to be measured and is called manometric liquid.

• **Manometric liquids**

¨ Manometric liquids should neither mix nor have any chemical reaction with the fluid whose pressure intensity is to be measured.

¨ It should not undergo any thermal variation.

¨ Manometric liquid should have very low vapour pressure.

¨ Manometric liquid should have pressure sensitivity depending upon the magnitude of pressure to be measured and accuracy requirement.

• **To write the gauge equation for manometers**

Gauge equations are written for the system to solve for unknown quantities.

Steps:

1. Convert all given pressure to meters of water and assume unknown pressure in meters of waters.

2. Starting from one end move towards the other observing the following points.

¨ Any horizontal movement inside the same liquid will not cause change in pressure.

¨ Vertically downward movement causes increase in pressure and upward motion causes decrease in pressure.

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

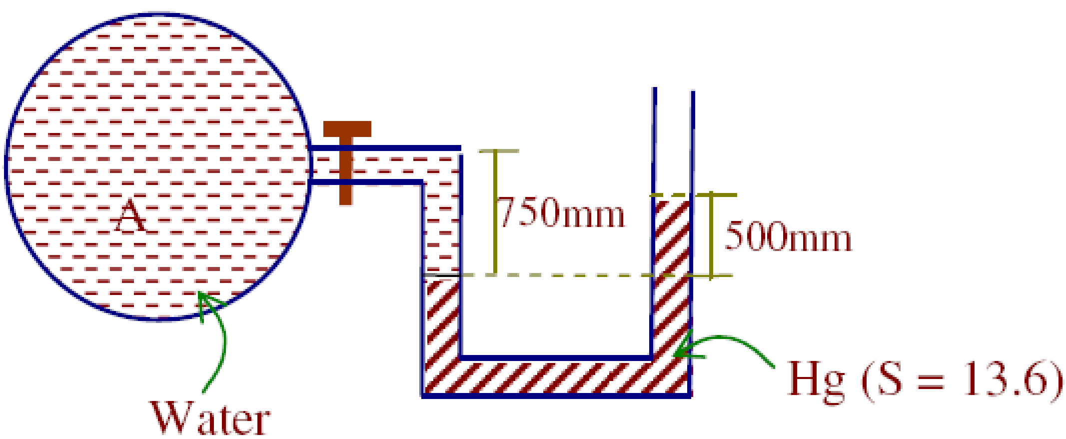
¨ Take atmospheric pressure as zero (gauge pressure computation).

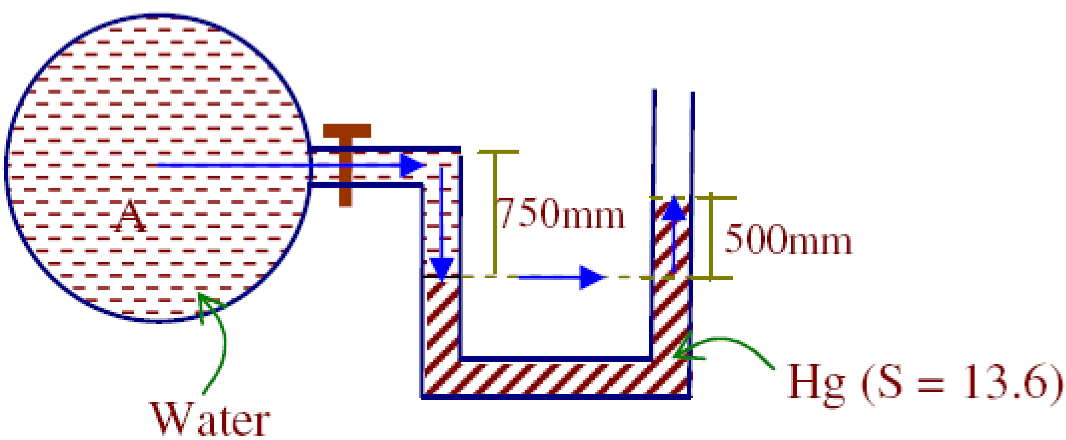
3. Solve for the unknown quantity and convert it into the required unit.

4. If required calculate absolute pressure.

Problem:

1. Determine the pressure at A for the U- tube manometer shown in fig. Also calculate the absolute pressure at A in kPa.





Let 'h_A' be the pressure head at 'A' in 'meters of water'.

$$h_A + 0.75 - 0.5x13.6 = 0$$

$$h_A = 6.05m\ of\ \ water$$

$$p = \gamma h$$

$$= 9.81x6.05$$

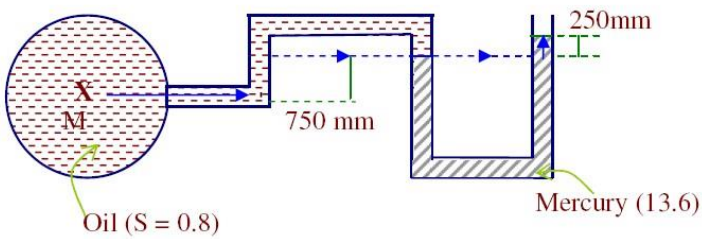
$$p = 59.35\ kPa(gauge\ \ pressure)$$

$$p_{abs} = p_{atm} + p_{gauge}$$

$$= 101.3 + 59.35$$

$$p_{abc} = 160.65\ kPa$$

2. For the arrangement shown in figure, determine gauge and absolute pressure at the point M.



Let 'h_M' be the pressure head at the point 'M' in m of water,

h_M - 0.75 x 0.8 – 0.25 x 13.6 = 0

$h_{M =}$ 4 m of water

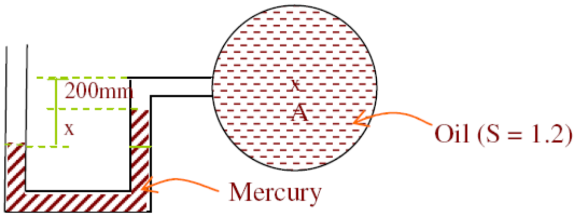
$$p = \gamma h$$

$$p = 39.24\,kPa$$

$$p_{abs} = 101.3 + 39.24$$

$$p_{abs} 140.54\,kPa$$

3. If the pressure at 'At' is 10 kPa (Vacuum) what is the value of 'x'?



p_A = 10 kPa (Vacuum)

p_A = - 10 kPa

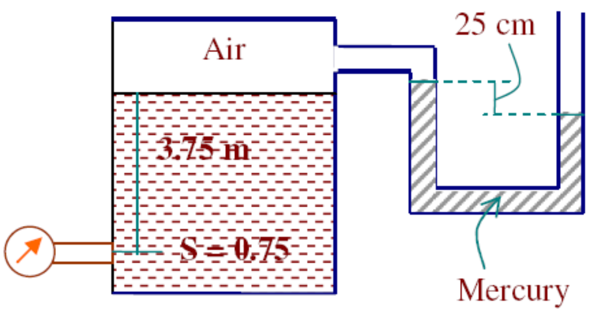
$$\frac{p_A}{\gamma} = \frac{-10}{9.81} = -1.019 \text{ m of water}$$

$$h_A = -1.019 \text{ m of water}$$

$$-1.019 + 0.2 \text{ x } 1.2 + \text{x } (13.6) = 0$$

$$\text{x} = 0.0572 \text{ m}$$

4. The tank in the accompanying figure consists of oil of S = 0.75. Determine the pressure gauge reading in kN/m^2.



Let the pressure gauge reading be 'h' m of water

h – 3.75 x 0.75 + 0.25 x 13.6 = 0

h = - 0.5875 m of water

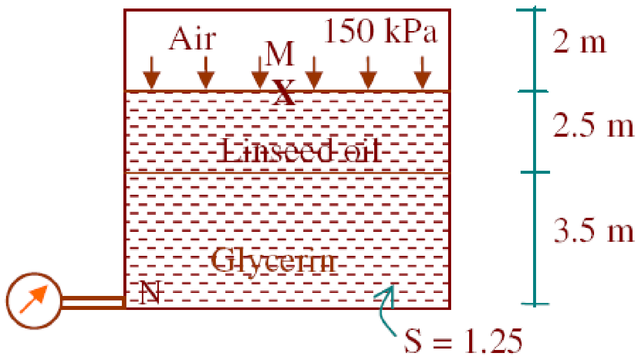
$p = \gamma h$

p = -5.763 kPa

p = 5.763 kPa (Vacuum)

5. A closed tank is 8m high. It is filled with Glycerine up to a depth of 3.5m and linseed oil to another 2.5m. The remaining space is filled with air under a pressure of 150 kPa. If a pressure gauge is fixed at the bottom of the tank what will be its reading.

Also calculate absolute pressure. Take relative density of Glycerine and Linseed oil as 1.25 and 0.93 respectively.



$$P_H = 150\,\text{kPa}$$

$$h_M = \frac{150}{9.81}$$

$$h_M = 15.29\,\text{m of water}$$

Let 'h_N' be the pressure gauge reading in m of water.

$$h_N - 3.5 \times 1.25 - 2.5 \times 0.93 = 15.29$$

$$h_N = 21.99\ \text{m of water}$$

$$p = 9.81 \times 21.99$$

$$p = 215.72\ \text{kPa (gauge)}$$

$$p_{abs} = 317.02\ \text{kPa}$$

DIFFERENTIAL MANOMETERS

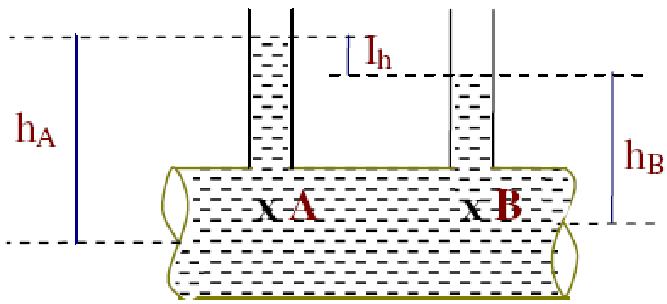
Differential manometers are used to measure pressure difference between any two points. Common varieties of differential manometers are:

(a) Two piezometers.

(b) Inverted U-tube manometer.

(c) U-tube differential manometers.

(d) Micromanometers.

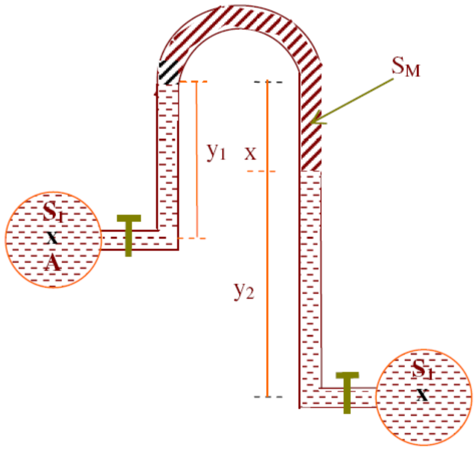


(a) Two Pizometers

The arrangement consists of two pizometers at the two points between which the pressure difference is required. The liquid will rise in both the piezometers. The difference in elevation of liquid levels can be recorded and the pressure difference can be calculated.

It has all the merits and demerits of piezometer.

(b) Inverted U-tube manometers



Inverted U-tube manometer is used to measure small difference in pressure between any two points. It consists of an inverted U-tube connecting the two points between which the pressure difference is required. In between there will be a lighter manometric liquid. Pressure difference between the two points can be calculated by writing the gauge equations for the system.

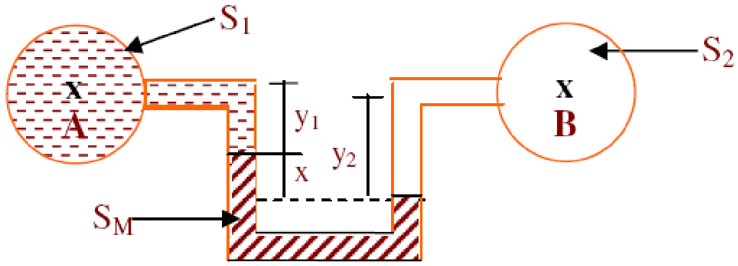
Let 'hA' and 'hB' be the pr head at 'A' and 'B' in meters of water

$hA – (Y1\ S1) + (x\ SM) + (y2\ S2) = hB.$

$hA – hB = S1\ y1 – SM\ x – S2\ y2,$

$pA – pB = g\ (hA – hB)$

(c) U-tube Differential manometers



A differential U-tube manometer is used to measure pressure difference between any two points. It consists of a U-tube containing heavier manometric liquid, the two limbs of which are connected to the gauge points between which the pressure difference is required. U-tube differential manometers can also be used for gases. By writing the gauge equation for the system pressure difference can be determined.

Let 'hA' and 'hB' be the pressure head of 'A' and 'B' in meters of water

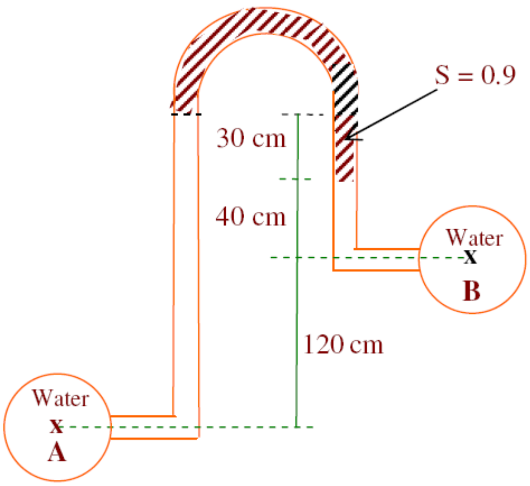
hA + S1 Y1 + x SM – Y2 S2 = hB

hA – hB = Y2 S2 – Y1 S1– x SM

Problems

(1) An inverted U-tube manometer is shown in figure. Determine the pressure difference between A and B in N/m^2

Let hA and hB be the pressure heads at A and B in meters of water.



$h_A - (190 \times 10^{-2}) + (0.3 \times 0.9) + (0.4)\ 0.9 = h_B$

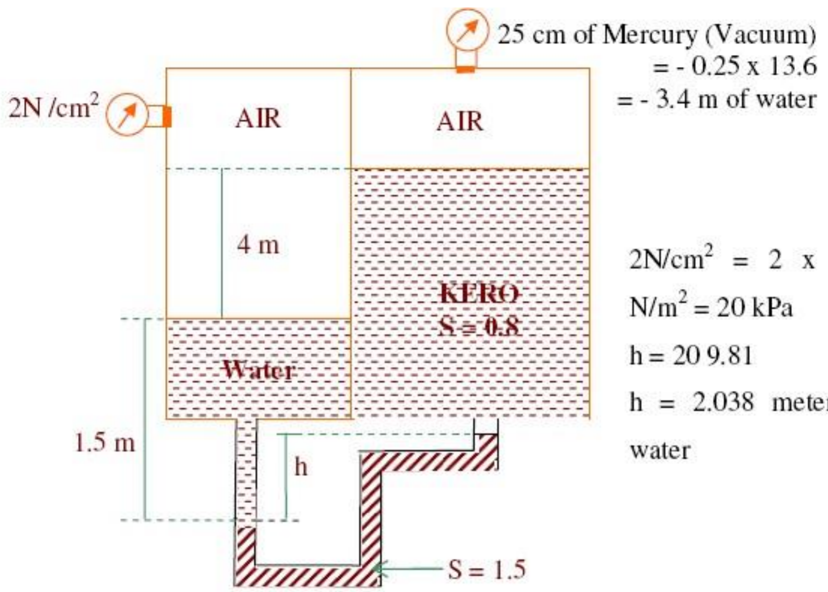
$h_A - h_B = 1.23$ meters of water

$p_A - p_B = \gamma\,(h_A - h_B) = 9.81 \times 1.23$

$p_A - p_B = 12.06$ kPa

$p_A - p_B = 12.06 \times 10^3\ N/m^2$

2. In the arrangements shown in figure. Determine the ho 'h'.



$2N/cm^2 = 2 \times 100^2\ N/m^2 = 20$ kPa

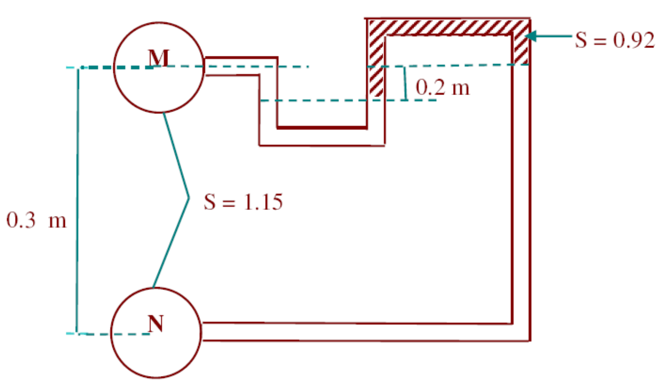
$h = 20\ 9.81$

$h = 2.038$ meters of water

$2.038 + 1.5 - (4 + 1.5 - h)\ 0.8 = -3.4$

$h = 3.6$ m

3. Compute the pressure different between 'M' and 'N' for the system shown in figure.



Let 'h_M' and ' h_N' be the pressure heads at M and N in m of water.

$$hm + y \times 1.15 - 0.2 \times 0.92 + (0.3 - y + 0.2)\ 1.15 = hn$$

$$hm + 1.15\ y\ - 0.184 + 0.3 \times 1.15\ - 1.15\ y + 0.2 \times\ 1.15 = hn$$

$$hm + 0.391 = hn$$

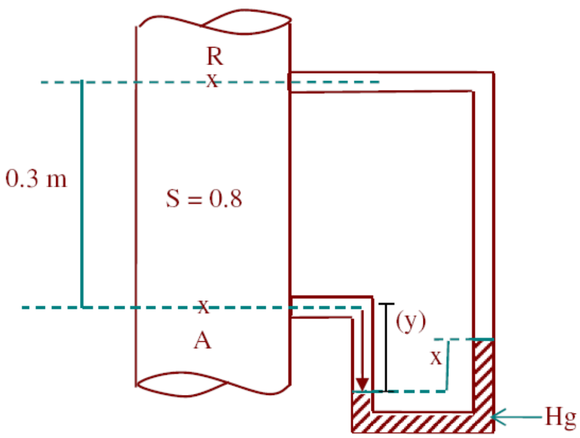
$$hn - hm = 0.391 \text{meters of water}$$

$$p_n - p_m = \gamma\,(h_N - h_m)$$

$$= 9.81 \times 0.391$$

$$p_n - p_m = 3.835 \text{ kPa}$$

4. Petrol of specify gravity 0.8 flows up through a vertical pipe. A and B are the two points in the pipe, B being 0.3 m higher than A. Connection are led from A and B to a U–tube containing Mercury. If the pressure difference between A and B is 18 kPa, find the reading of manometer.



$$p_A - p_B = 18 \text{kPa}$$

$$\frac{P_A - P_B}{\gamma}$$

$$h_A - h_B = \frac{18}{9.81}$$

$$h_A - h_B = 1.835 m\ of\ \ water$$

$$h_A + y \times 0.8 - x\ 13.6 - (0.3 + y - x)\ 0.8 = h_B$$

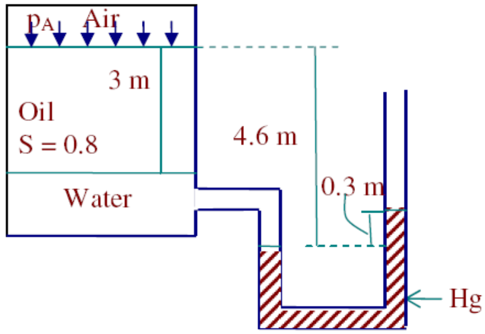
$$h_A - h_B = -0.8y + \ 13.66\ x + 0.24 + 0.8\ y - 0.8\ x$$

$$h_A - h_B = 12.8x + 0.24$$

$$1.835 = 12.8x + 0.24$$

$$x = 0.1246 \text{ m}$$

4. What is the pressure pA in the fig given below? Take specific gravity of oil as 0.8.



$h_A + (3 \times 0.8) + (4.6 - 0.3)(13.6) = 0$

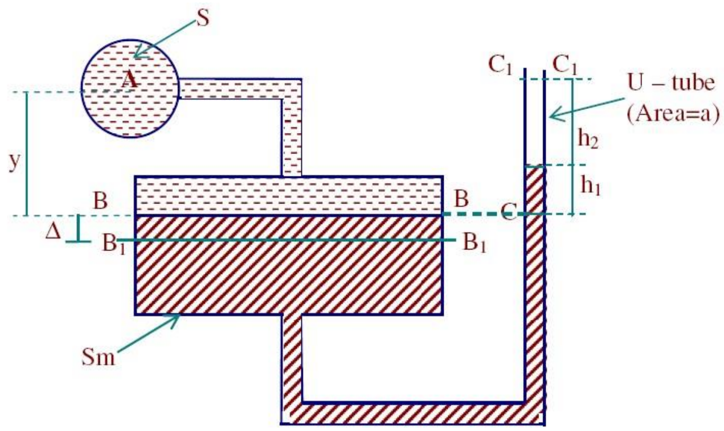
$h_A = 2.24$ m of oil

$p_A = 9.81 \times 2.24$

$p_A = 21.97$ kPa

SINGLE COLUMN MANOMETER:

Single column manometer is used to measure small pressure intensities.



A single column manometer consists of a shallow reservoir having large cross sectional area when compared to cross sectional area of U – tube connected to it. For any change in pressure, change in the level of manometric liquid in the reservoir is small and change in level of manometric liquid in the U- tube is large.

To derive expression for pressure head at A:

BB and CC are the levels of manometric liquid in the reservoir and U-tube before connecting the point A to the manometer, writing gauge equation for the system we have,

+ y x S – h1 x Sm = 0

Sy = Smh1

Let the point A be connected to the manometer. B1B1 and C1 C1 are the levels of manometric liquid. Volume of liquid between BBB1B1 = Volume of liquid between

Let the point A be connected to the manometer. B1B1 and C1 C1 are the levels of manometric liquid. Volume of liquid between BBB1B1 = Volume of liquid between

CCC1C1

$$A\Delta = a\,h_2$$

$$\Delta = \frac{ah_2}{A}$$

Let 'h_A' be the pressure head at A in m of water.

$$h_A + (y + \Delta)\,S - (\Delta + h_1 + h_2)\,Sm = 0$$

$$h_A = (\Delta + h_1 + h_2)\,Sm - (y + \Delta)\,S$$

$$= \Delta\,Sm + \underline{h_1\,Sm} + h_2\,Sm - \underline{yS} - \Delta S$$

$$h_A = \Delta\,(Sm - S) + h_2\,Sm$$

$$h_A = \frac{ah_2}{A}\,(Sm - S) + h_2\,Sm$$

∴ It is enough if we take one reading to get 'h_2' If '$\frac{a}{A}$' is made very small (by increasing 'A') then the I term on the RHS will be negligible.

Then $h_A = h_2\,Sm$

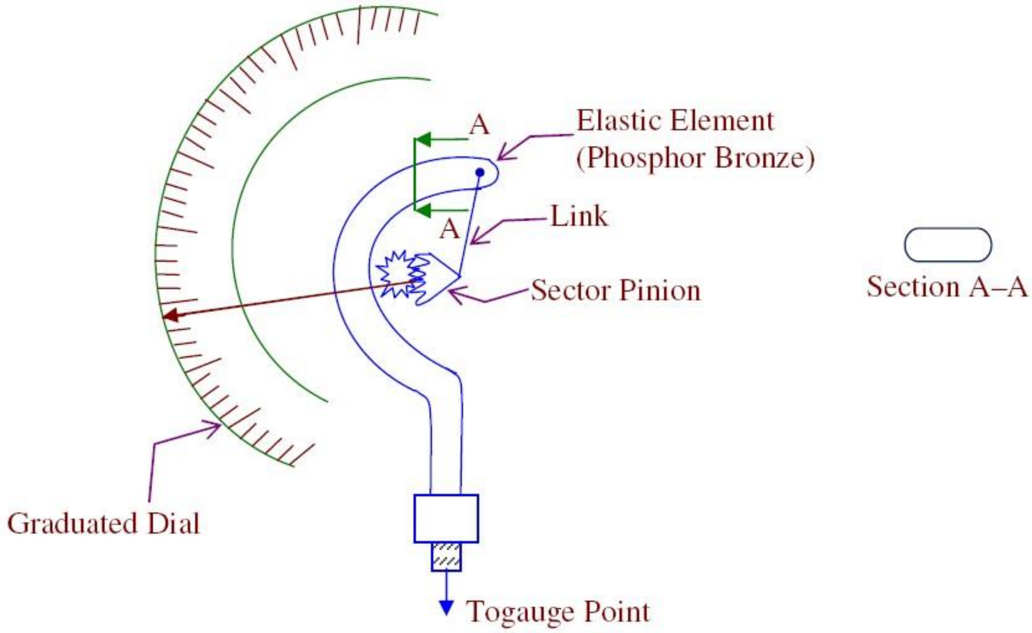
MECHANICAL GAUGES:

Pressure gauges are the devices used to measure pressure at a point.

They are used to measure high intensity pressures where accuracy requirement is less.

Pressure gauges are separate for positive pressure measurement and negative pressure measurement. Negative pressure gauges are called Vacuum gauges.

BASIC PRINCIPLE:



Mechanical gauge consists of an elastic element which deflects under the action of applied pressure and this deflection will move a pointer on a graduated dial leading to the measurement of pressure. Most popular pressure gauge used is Bordon pressure gauge.

The arrangement consists of a pressure responsive element made up of phosphor bronze or special steel having elliptical cross section. The element is curved into a circular arc, one end of the tube is closed and free to move and the other end is connected to gauge point. The changes in pressure cause change in section leading to the movement. The movement is transferred to a needle using sector pinion mechanism. The needle moves over a graduated dial.