# 10 CV 35 FLUID MECHANICS NOTES

## UNIT-2 PRESSURE AND ITS MEASUREMENT

**by**

**Dr. Nagaraj Sitaram, Professor, Civil Department, SBMJCE, Bangalore**

## UNIT-2 PRESSURE AND ITS MEASUREMENT

**2.0 INTRODUCTION:** 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 (Fig.1), it exerts force along direction perpendicular to the boundary in contact. This force is called fluid pressure (compression).

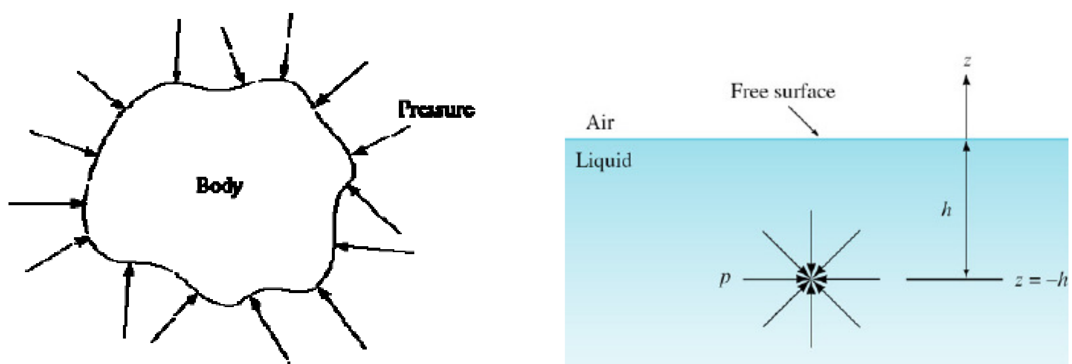



**Fig.1 Definition of Pressure**

*In fluids, gases and liquids, we speak of pressure*; in solids this is normal stress. For a fluid at rest, the pressure at a given point is the same in all directions. Differences or gradients in pressure drive a fluid flow, especially in ducts and pipes.

**2.1 Definition of Pressure:** Pressure is one of the basic properties of all fluids. Pressure (p) is the force (F) exerted on or by the fluid on a unit of surface area (A). Mathematically expressed:

$$p = \frac{F}{A} \qquad \frac{N}{m^2}$$

The basic unit of pressure is Pascal (Pa). When a fluid exerts a force of 1 N over an area of $1m^2$, the pressure equals one Pascal, i.e., 1 Pa = 1 $N/m^2$.Pascal is a very small unit, so that for typical power plant application, we use larger units:

**Units:** 1 kilopascal (kPa) = $10^3$ Pa, and

1 megapascal (MPa) = $10^6$ Pa = $10^3$ kPa.

## 2.2 Pressure at a Point and Pascal's Law:

**Pascal's Principle: Pressure extends uniformly in all directions in a fluid.**

By considering the equilibrium of a small triangular wedge of fluid extracted from a static fluid body, one can show (Fig.2) that for *any* wedge angle θ, the pressures on the three faces of the wedge are equal in magnitude:

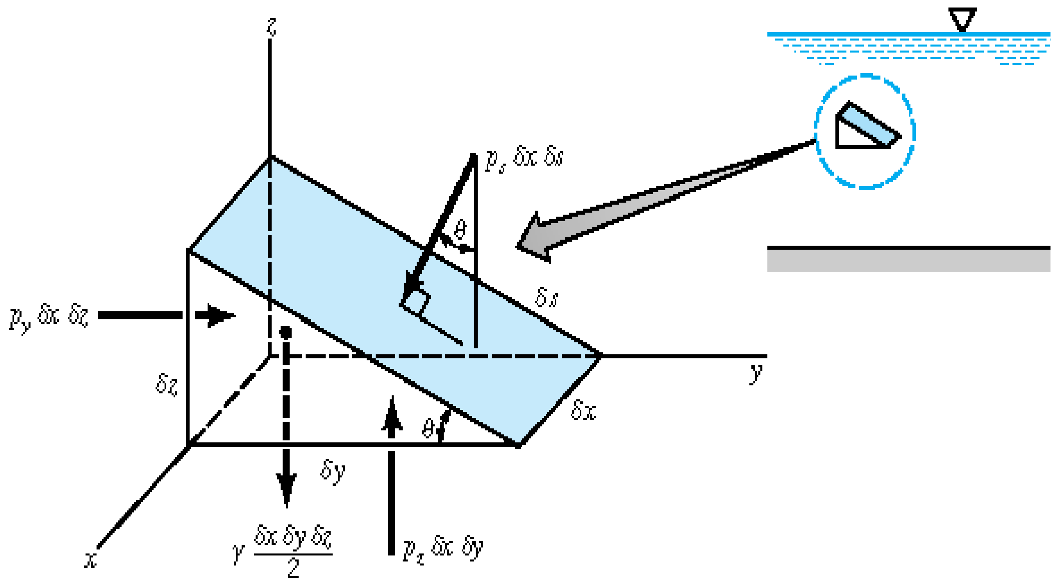



**Fig.2 Pascal's Law**

Independent of $p_x = p_y = p_z$ independent of 'θ'

Pressure at a point has the same magnitude in all directions, and is called **isotropic.**

This result is known as **Pascal's law**.

**2.3 Pascal's Law:** In any closed, static fluid system, a pressure change at any one point is transmitted undiminished throughout the system.

**2.3.1 Application of Pascal's Law:**

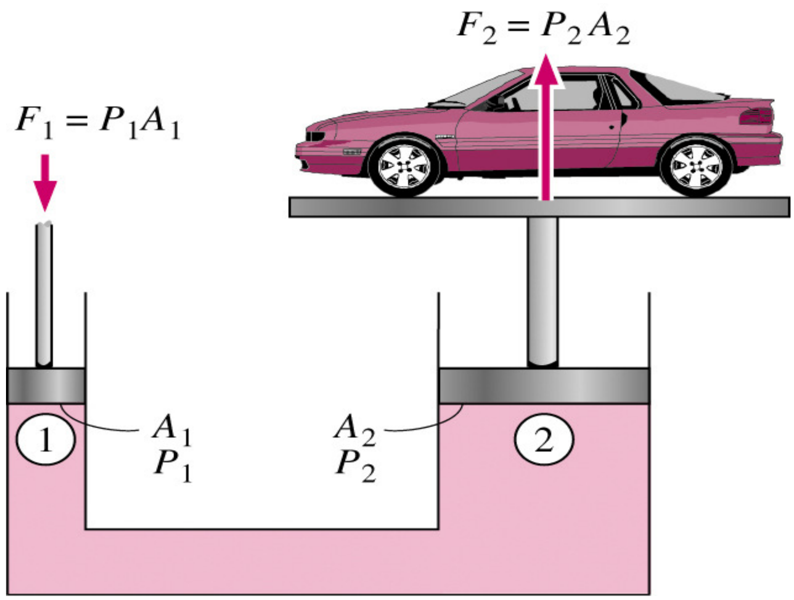



**Fig.3 Application of Pascal's Law**

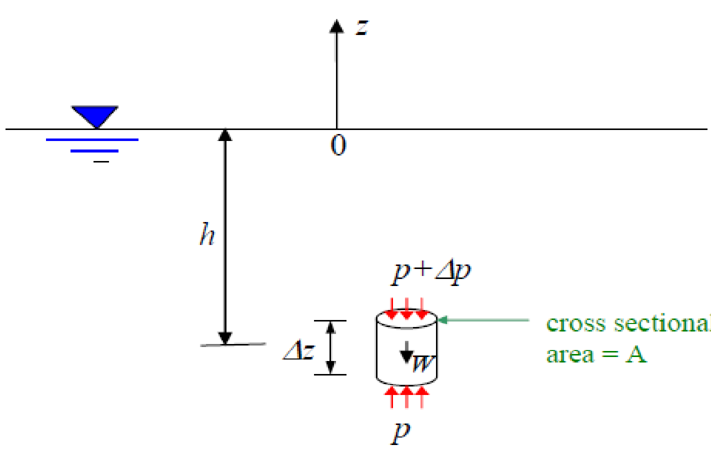
- Pressure applied to a confined fluid increases the pressure throughout by the same amount.
- In picture, pistons are at same height:

$$P_1 = P_2 \rightarrow \frac{F_1}{A_1} = \frac{F_2}{A_2} \rightarrow \frac{F_2}{F_1} = \frac{A_2}{A_1}$$

- Ratio $A_2/A_1$ is called ideal mechanical advantage

**2.4 Pressure Variation with Depth:**

Consider a small vertical cylinder of fluid in equilibrium, where *positive z is pointing vertically upward*. Suppose the origin z = 0 is set at the free surface of the fluid. Then the pressure variation at a depth $z = -h$ below the free surface is governed by



$$(p + \Delta p)A + W = pA$$

$$\Rightarrow \quad \Delta pA + \rho gA\Delta z = 0$$

$$\Rightarrow \quad \Delta p = -\rho g\Delta z$$

$$\Rightarrow \quad \frac{dp}{dz} = -\rho g \quad \text{or} \quad \frac{dp}{dz} = -\gamma \quad \text{Eq.(1)} \quad (\text{as } \Delta z \rightarrow 0)$$

Therefore, the hydrostatic pressure increases linearly with depth at the rate of the specific weight $\gamma = \rho g$ of the fluid.

**Homogeneous fluid: ρ is constant**

By simply integrating the above equation-1:

$$\int dp = -\int \rho g \, dz \quad \Rightarrow \quad p = -\rho gz + C$$

Where *C* is constant of integration

When $z = 0$ (on the free surface), $p = C = p_0 =$ (the atmospheric pressure).

Hence, $$p = -\rho gz + p_0$$

Pressure given by this equation is called ABSOLUTE PRESSURE, i.e., measured above perfect vacuum.

However, for engineering purposes, it is more convenient to measure the pressure above a datum pressure at atmospheric pressure. By setting $p_0 = 0$,

$$p = -\rho gz + 0 = -\rho gz = \rho gh$$

$$p = \gamma h$$

The equation derived above shows that when the density is constant, **the pressure in a liquid at rest increases linearly with depth from the free surface.**

For a given pressure intensity 'h' will be different for different liquids since, 'γ' will be different for different liquids.

$$\therefore h = \frac{P}{\gamma}$$

Hint-1: To convert head of 1 liquid to head of another liquid.

$$\mathbf{S} = \frac{\gamma}{\gamma_{\mathbf{Staandard}}}$$

$$\mathbf{S}_1 = \frac{\gamma_1}{\gamma_{\mathbf{Staandard}}}$$

$p = \gamma_1 h_1$

$$\therefore \gamma_1 = \mathbf{S}_1 \gamma_{\mathbf{Staandard}}$$

$p = \gamma_2 h_2$

$$\gamma_{21} = \mathbf{S}_2 \gamma_{\mathbf{Staandard}}$$

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

$$\therefore \mathbf{S}_1\ \gamma_{\mathbf{S\,tan\,dard}}\,\mathbf{h}_1 = \mathbf{S}_2\ \gamma_{\mathbf{S\,tan\,dard}}\,\mathbf{h}_2$$

$$\boxed{\mathbf{S}_1\mathbf{h}_1 = \mathbf{S}_2\mathbf{h}_2}$$

Hint: 2 $S_{water} \text{ x } h_{water} = S_{liquid} \text{ x } h_{liquid}$

$1\text{x } h_{water} = S_{liquid} \text{ x } h_{liquid}$

$$\boxed{h_{water} = S_{liquid} \text{ x } h_{liquid}}$$

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: Atm pressure is 760mm of Mercury.

NOTE: $P = \gamma\ h$

$$\begin{array}{ccc} P & \gamma & h \\ \downarrow & \downarrow & \downarrow \\ kPa & \frac{kN}{m^3} & m \end{array}$$

**Solved Examples:**

Ex. 1. Calculate intensity of pressure due to a column of 0.3m of (a) water (b) Mercury (c) Oil of specific gravity-0.8.

Soln: (a) Given : h = 0.3m of water

$$\gamma_{water} = 9.81 \frac{kN}{m^3}$$

$$p = ?$$

$$p_{water} = \gamma_{water} h_{water}$$

$$p_{water} = 2.943 \text{ kPa}$$

(b) Given: h = 0.3m of Hg

$\gamma_{mercury}$ = Sp.Gr. of Mercury X $\gamma_{water}$ = 13.6 x 9.81

$\gamma_{mercury}$ = 133.416 kN/$m^3$

$p_{mercury} = \gamma_{mercury}\ h_{mercury}$

= 133.416 x 0.3

**p = 40.025 kPa or 40.025 kN/$m^2$**

(c) Given: h = 0.3 of Oil Sp.Gr. = 0.8

$\gamma_{oil}$ = Sp.Gr. of Oil X $\gamma_{water}$ = 0.8 x 9.8

$\gamma_{oil}$ = 7.848 kN/$m^3$

$p_{oil} = \gamma_{oil}\ h_{oil}$

= 7.848 x 0.3

**$p_{oil}$ = 2.3544 kPa or 2.3544 kN/$m^2$**

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

Solution: Given Intensity of pressure at a point 40 kPa i.e. p = 40 kN/$m^2$

(a) Head of water $h_{water}$ =?

$$h_{water} = \frac{p}{\gamma_{water}} = \frac{40}{9.81}$$

$$h_{water} = 4.077 \text{m of water}$$

(b) Head of mercury 'h$_{mercury}$ = ?

$\gamma_{mercury}$ = Sp.Gr. of Mercury X $\gamma_{water}$ = 13.6 x 9.81

$\gamma_{mercury}$ = 133.416 kN/m$^3$

$$h_{mercury} = \frac{p}{\gamma_{mercury}} = \frac{40}{133.416}$$

$h_{water}$ = 0.3m of **mercury**

(c) Head of oil 'h$_{oil}$ = ?

$\gamma_{oil}$ = Sp.Gr. of Oil X $\gamma_{water}$ = 0.9 x 9.81

$\gamma_{oil}$ = 8.829 kN/m$^3$

$$h_{oil} = \frac{p}{\gamma_{oil}} = \frac{40}{8.829}$$

$h_{oil}$ = 4.53m of **oil**

Ex.3 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 0.6.

(i) Meters of water $h_{water}$

$p = \gamma_{water} h_{water}$

101.3 = 9.81 x $h_{water}$

$h_{water}$ = 10.3 m of water

(ii) Meters of water $h_{water}$

$p = \gamma_{mercury}$ x $h_{mercury}$

101.3 = (13.6x9.81) x $h_{mercury}$

h = 0.76 m of mercury

(iii) $p = \gamma_{oil} h_{oil}$

101.3 = (0.6 x 9.81) x h

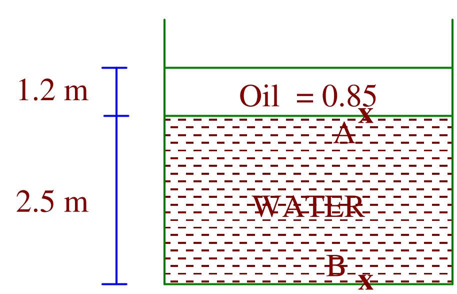
h = 17.21m of oil of S = 0.6

Ex.4 An open container has water to a depth of 2.5m and above this an oil of S = 0.85 for a depth of 1.2m. Find the intensity of pressure at the interface of two liquids and at the bottom of the tank.

**(i) At the Oil - water int erface**

$p_A = \gamma_{0il} h_{oil} = (0.85 \times 9.81) \times 1.2$

$p_A = 10$ **kPa**




**(ii) At the bottom of container**

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

$p_B = p_A + \gamma_{water} h_{water}$

$p_B$ = 10 kPa + 9.81 x 2.5

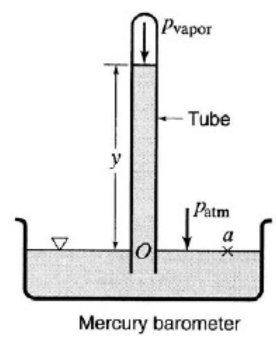
$p_B$ = 34.525 kPa

**2.5 Types of Pressure:** Air above the surface of liquids exerts pressure on the exposed surface of the liquid and normal to the surface.

- **Atmospheric pressure**

The 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. *However, for engineering purposes, it is more convenient to measure the pressure above a datum pressure at atmospheric pressure.* By setting $p_{atmophere} = 0$,




$$p = -\rho gz = \rho gh$$

**Unit:** kPa . 'bar' is also a unit of atmospheric pressure 1-bar = 100 kPa.= 1 kg/cm$^2$

- **Absolute 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 is the intensity of pressure at that point measured with reference to absolute vacuum or absolute zero pressure (Fig.4) .

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

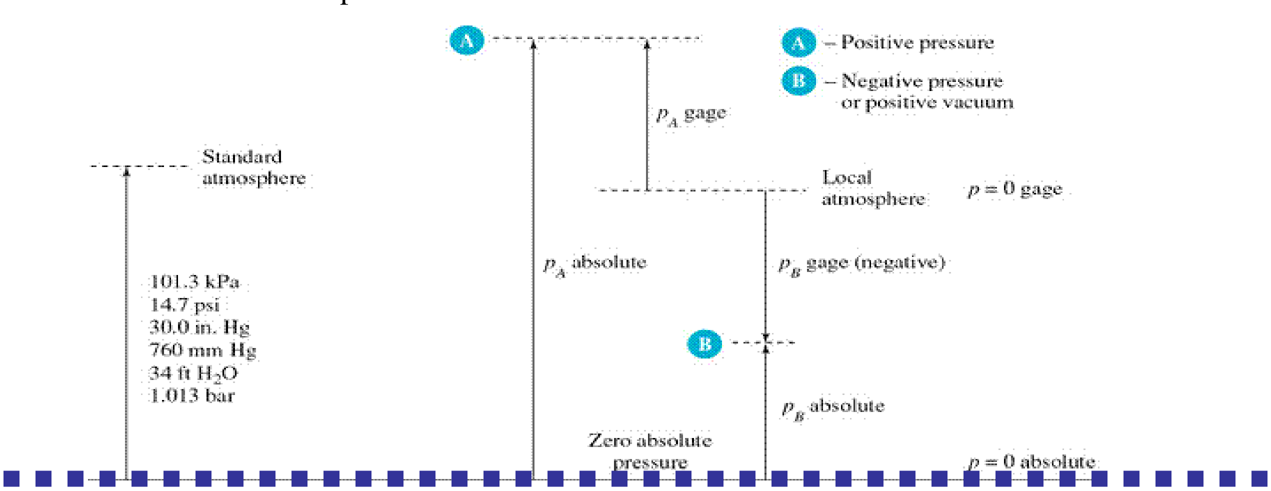



**Fig.4 Definition of Absolute Pressure, Gauge Pressure and Vacuum Pressure**

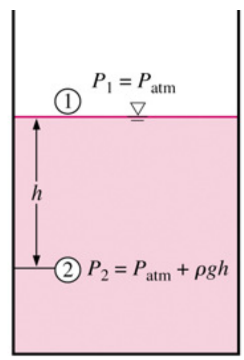
**Gauge Pressure:** If the intensity of pressure at a point is measurement with reference to atmosphere pressure, then it is called gauge pressure at that point.

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 (Fig.4)

**Negative gauge pressure:** It is also called vacuum pressure. From the figure, It is the pressure measured below the gauge pressure (Fig.4).

**Absolute pressure at a point = Atmospheric pressure ± Gauge pressure**

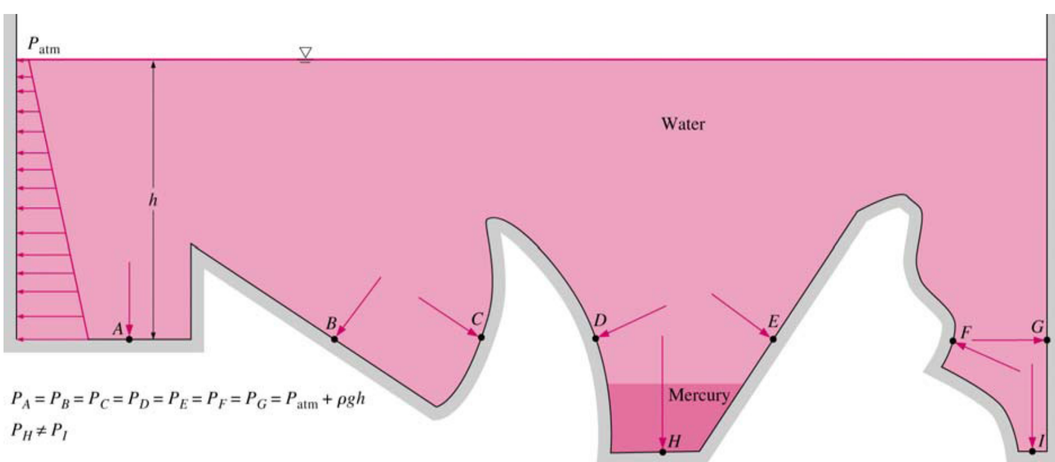
NOTE: If we measure absolute pressure at a Point below the free surface of the liquid, then, $\mathbf{p_2\ (absolute) = \gamma.\ h + p_{atm}}$ $\mathbf{p_1 = p_{atm}}$




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

$$\mathbf{p_2\ (gauge) = \gamma.\ h = \rho gh}$$

Also, the pressure is the same at all points with the same depth from the free surface regardless of geometry, provided that the points are interconnected by the same fluid. However, the thrust due to pressure is perpendicular to the surface on which the pressure acts, and hence its direction depends on the geometry.



**Solved Example:** Convert the following absolute pressure to gauge pressure:

(a) 120kPa (b) 3kPa (c) 15m of $H_2O$ (d) 800mm of Hg.

**Solution:**

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

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

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

## 2.6 Vpour Pressure:

Vapor pressure is defined as the pressure at which a liquid will boil (vaporize) and is in equilibrium with its own vapor. Vapor pressure rises as temperature rises. For example, suppose you are camping on a high mountain (say 3,000 m in altitude); the atmospheric pressure at this elevation is about 70 kPa and the boiling temperature is around 90°C. This has consequences for cooking. For example, eggs have to be cooked longer at elevation to become hard-boiled since they cook at a lower temperature.

A pressure cooker has the opposite effect. Namely, the tight lid on a pressure cooker causes the pressure to increase above the normal atmospheric value. This causes water to boil at a temperature even greater than 100°C; eggs can be cooked a lot faster in a pressure cooker!

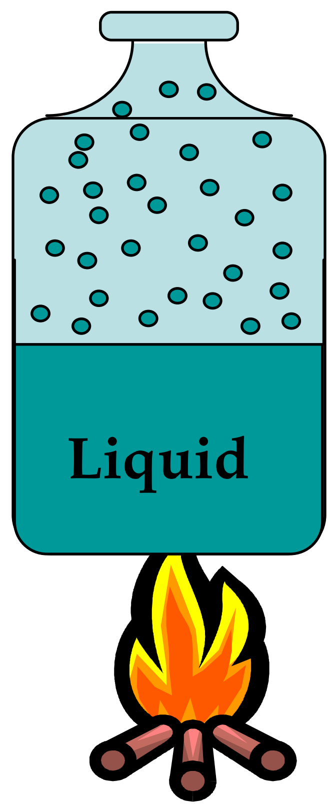



**Fig.5**

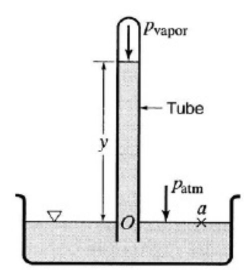
Vapor pressure is important to fluid flows because, in general, pressure in a flow decreases as velocity increases. This can lead to ***cavitation***, which is generally destructive and undesirable. In particular, at high speeds the local pressure of a liquid sometimes drops below the vapor pressure of the liquid. In such a case, ***cavitation*** occurs. In other words, a "cavity" or bubble of vapor appears because the liquid vaporizes or boils at the location where the pressure dips below the local vapor pressure.

Cavitation is not desirable for several reasons. First, it causes noise (as the cavitation bubbles collapse when they migrate into regions of higher pressure). Second, it can lead to inefficiencies and reduction of heat transfer in pumps and turbines (turbo machines). Finally, the collapse of these cavitation bubbles causes pitting and corrosion of blades and other surfaces nearby. The left figure below shows a cavitating propeller in a water tunnel, and the right figure shows cavitation damage on a blade.

## 2.7 Measurement of Pressure:

**Measurement of pressure**
- Barometer
- Simple manometer
- Piezometer column
- Bourdon gage
- Pressure transducer

**2.7.1 Barometer:** A *barometer* is a device for measuring atmospheric pressure. A simple barometer consists of a tube more than 760 mm long inserted in an open container of mercury with a closed and evacuated end at the top and open tube end at the bottom and with mercury extending from the container up into the tube.



Mercury barometer

Strictly, the space above the liquid cannot be a true vacuum. It contains mercury vapor at its saturated vapor pressure, but this is extremely small at room temperatures (e.g. 0.173 Pa at 20$^o$C).

The atmospheric pressure is calculated from the relation $P_{atm} = \rho gh$ where ρ is the density of fluid in the barometer.

$$p_{at'o'} = \gamma_{mercury} \times y + p_{vapor} = p_{atm}$$

With negligible $p_{vapor} = 0$

$$\boxed{p_{atm} = \gamma_{mercury} \times y}$$

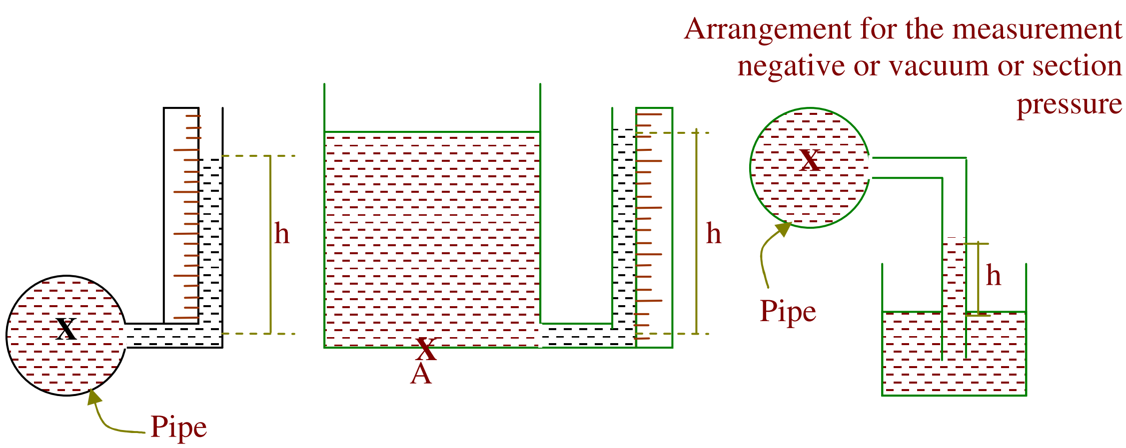
**2.7.2 Simple Manometer:** Simple monometers are used to measure intensity of pressure at a point. They are connected to the point at which the intensity of pressure is required. Such a point is called gauge point

## ♦ 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.

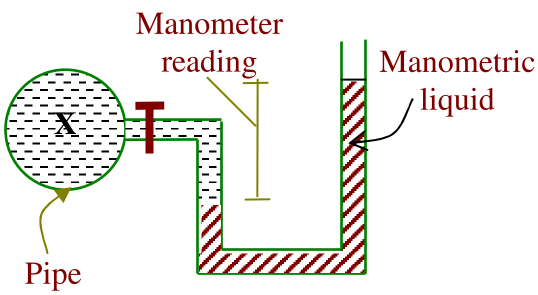
**Merits**

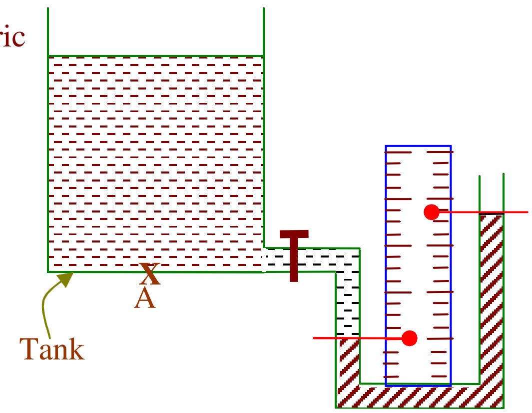
- Simple in construction
- Economical

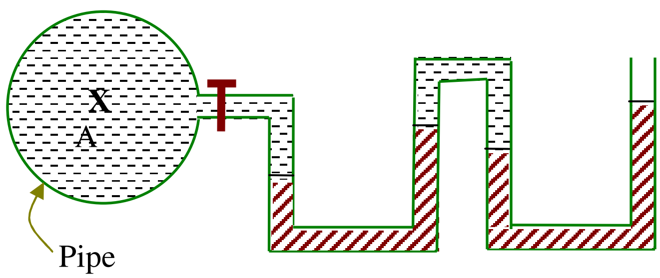
**Demerits**

- 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 monometric 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.

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

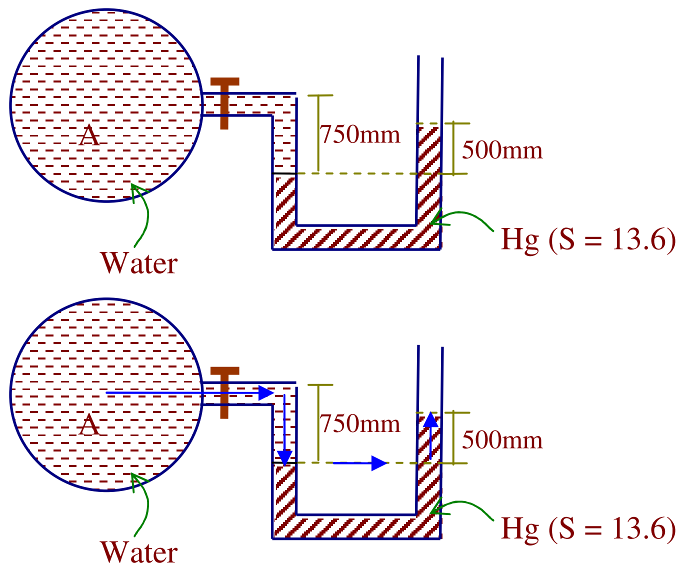
- **To write the gauge equation for manometers**

**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 keeping the following points in mind.
   - 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).
3. Solve for the unknown quantity and convert it into the required unit.

**Solved 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'.

$$h_A + 0.75 - 0.5 x 13.6 = 0$$

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

$$p = \gamma h$$

$$= 9.81 x 6.05$$

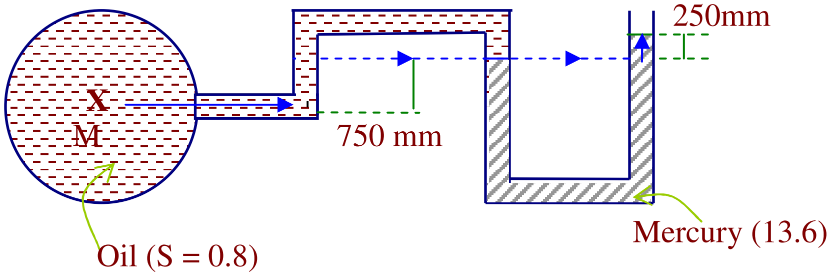
$$p = 59.35\ kPa\,(gauge\ \ pressure)$$

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

$$= 101.3 + 59.35$$

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

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,

$h_M - 0.75 \times 0.8 - 0.25 \times 13.6 = 0$

$h_M = 4$ m of water

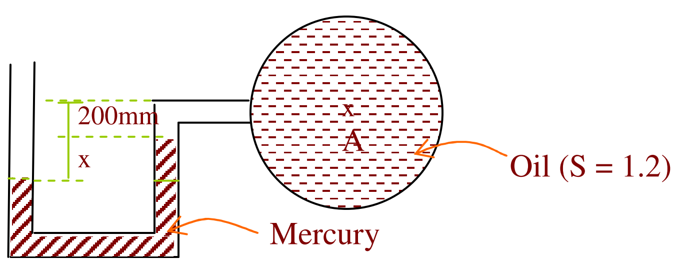
$p = \gamma h$

$p = 39.24\,\text{kPa}$

$p_{abs} = 101.3 + 39.24$

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

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

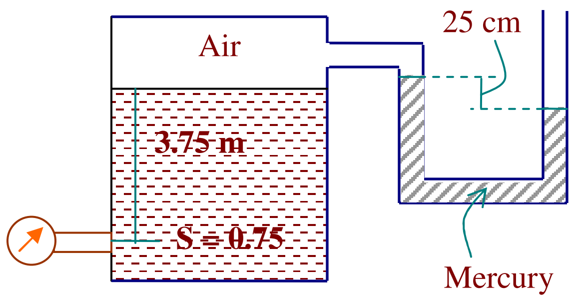
$$\frac{p_A}{\gamma} = \frac{-10}{9.81} = -1.019\ \text{m of water}$$

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

$$-1.019 + 0.2 \times 1.2 + x\,(13.6) = 0$$

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

4. The tank in the accompanying figure consists of oil of S = 0.75. Determine the pressure gauge reading in $\frac{kN}{m^2}$.




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

h – 3.75 x 0.75 + 0.25 x 13.6 = 0

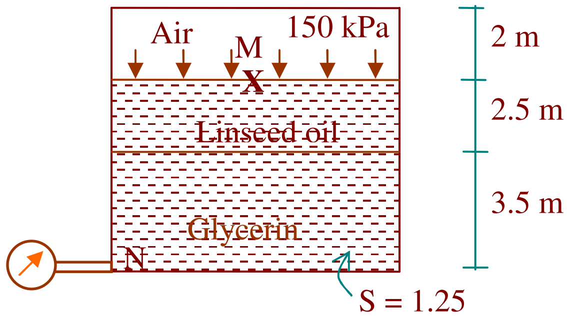
h = - 0.5875 m of water

$p = \gamma h$

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.

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

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

$$p = 9.81 \times 21.99$$

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

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

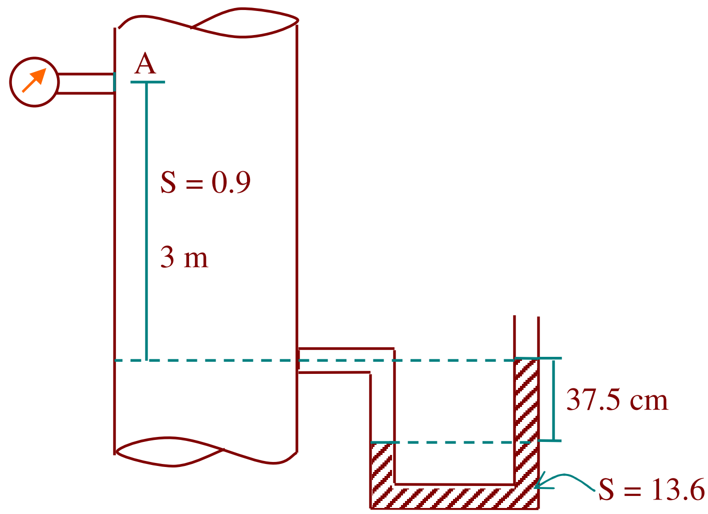
6. A vertical pipe line attached with a gauge and a manometer contains oil and Mercury as shown in figure. The manometer is opened to atmosphere. What is the gauge reading at 'A'? Assume no flow in the pipe.

$$h_A - 3 \times 0.9 + 0.375 \times 0.9 - 0.375 \times 13.6 = 0$$

$$h_A = 2.0625 \text{ m of water}$$

$$p = \gamma \times h$$

$$= 9.81 \times 21.99$$




p = 20.23 kPa (gauge)

$p_{abs}$ = 101.3 +20.23

$p_{abs}$ = 121.53 kPa

- **DIFFERENTIAL MANOMETERS**

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

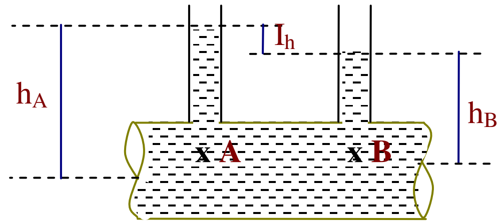
(a) Two piezometers.

(b) Inverted U-tube manometer.

(c) U-tube differential manometers.

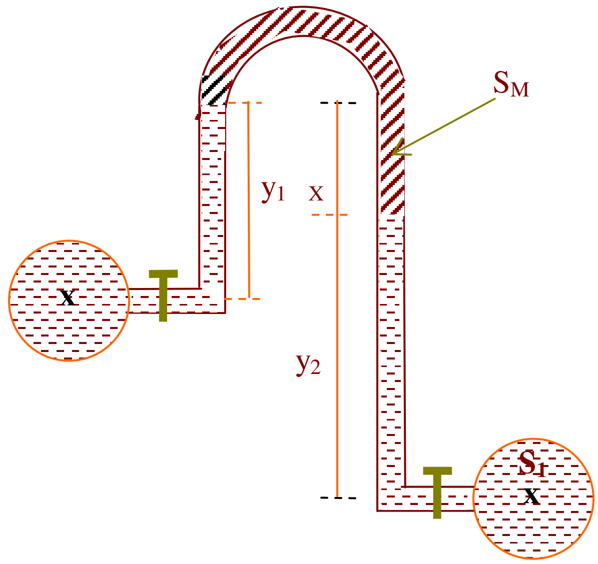
(d) Micromanometers.

**(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 sensitive manometric liquid. Pressure difference between the two points can be calculated by writing the gauge equations for the system.

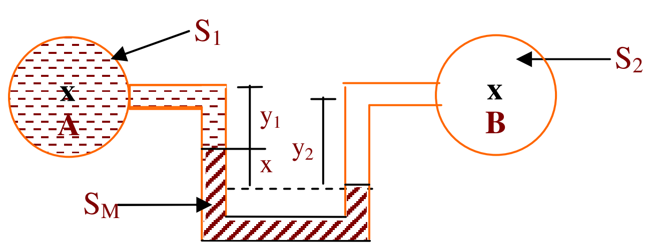
Let '$h_A$' and '$h_B$' be the pr head at 'A' and 'B' in meters of water

$h_A - (Y_1 S_1) + (x S_M) + (y_2 S_2) = h_B.$

$h_A - h_B = S_1 y_1 - S_M x - S_2 y_2,$

$p_A - p_B = \gamma (h_A - h_B)$

**(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 '$h_A$' and '$h_B$' be the pressure head of 'A' and 'B' in meters of water

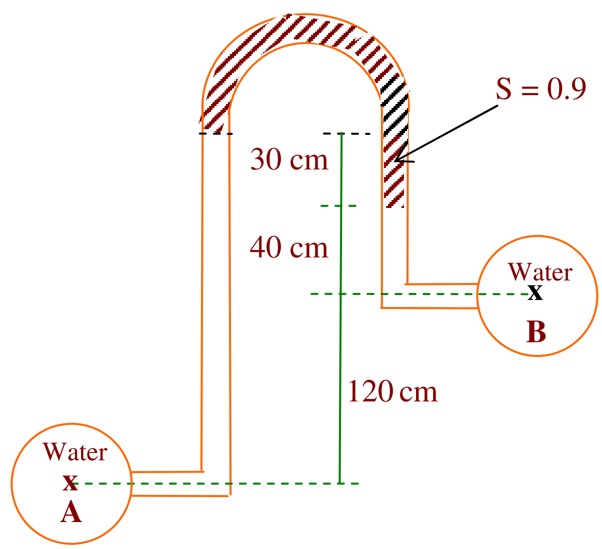
$h_A + S_1 Y_1 + x S_M - Y_2 S_2 = h_B$

$h_A - h_B = Y_2 S_2 - Y_1 S_1 - x S_M$

## Solved Problems:

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

Let $h_A$ and $h_B$ be the pressure heads at A and B in meters of water.




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

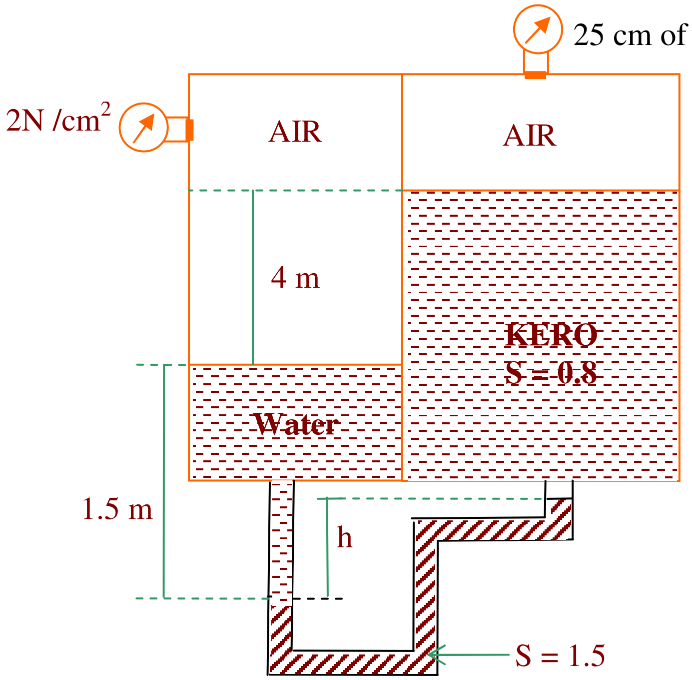
$h_A - h_B = 1.23$ meters of water

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

$p_A - p_B = 12.06$ kPa

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

2. In the arrangements shown in figure. Determine the ho ‘h’.




25 cm of Mercury (Vacuum)
= - 0.25 x 13.6
= - 3.4 m of water

2N/cm$^2$ = 2 x 100$^2$ N/m$^2$ = 20 kPa

h = 20 9.81

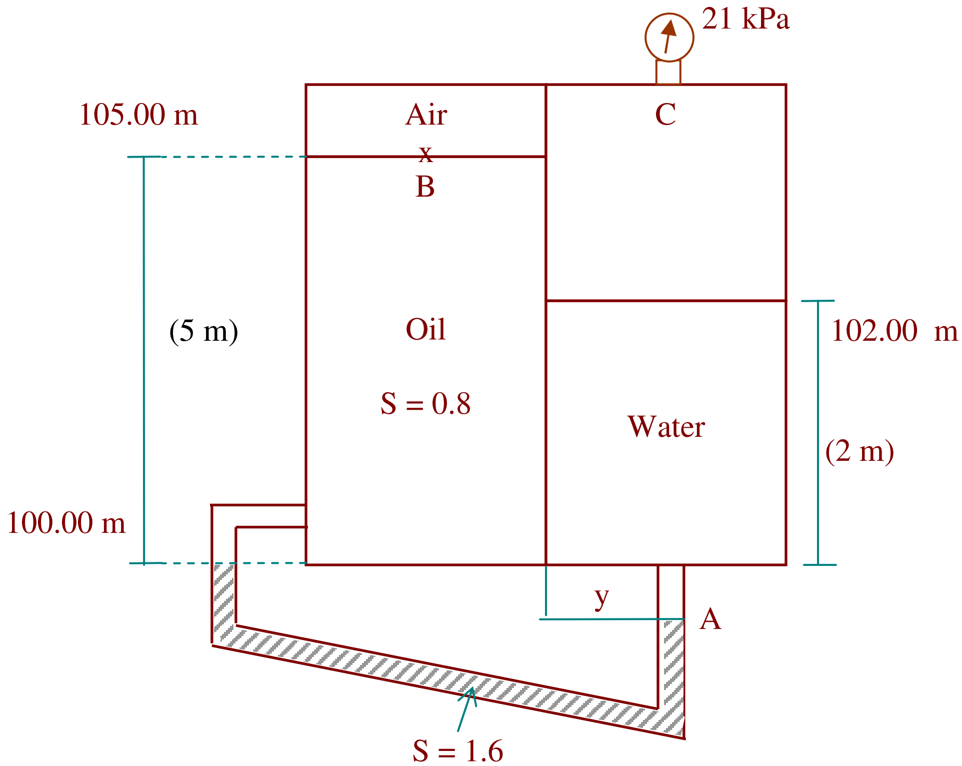
h = 2.038 meters of water

2.038 + 1.5 – (4 + 1.5 – h) 0.8 = – 3.4

h = 3.6 m

3. In the figure given, the air pressure in the left tank is 230 mm of Mercury (Vacuum). Determine the elevation of gauge liquid in the right limb at A. If the liquid in the right

tank is water.




$$h_c = \frac{Pc}{\gamma}$$

$$\frac{21}{9.81}$$

$h_B$ = 230mm of Hg

$$h_c = 2.14 m\, of\ water$$

= 0.23 x 13.6

$h_B$ = - 3.128 m of water

– 3.128 + 5 x 0.8 + y x 1.6 – (y + 2) = 2.14

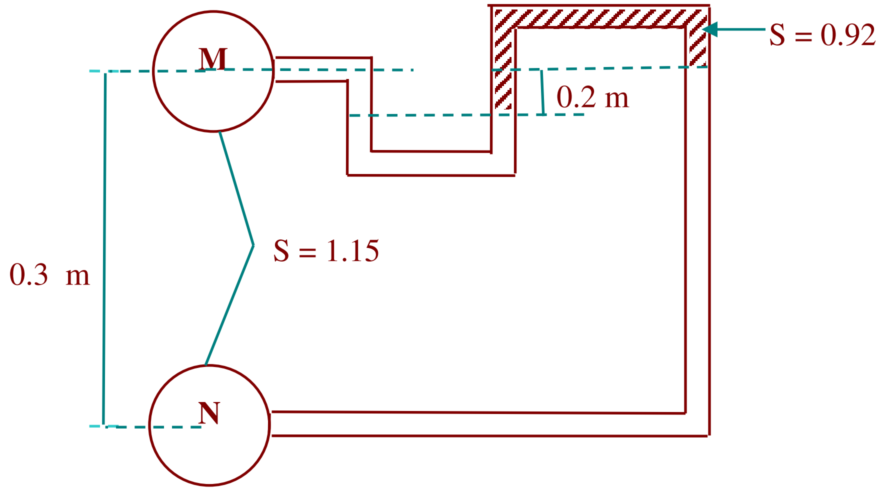
– 3.128 + 5 x 0.8 + y x 1.6 – y – 2 = 2.14

y = 5.446 m

∴ Elevation of A = 100 – 5.446

Elevation of A = 94.553m

4. 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.

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

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

$$hm + 0.391 = hn$$

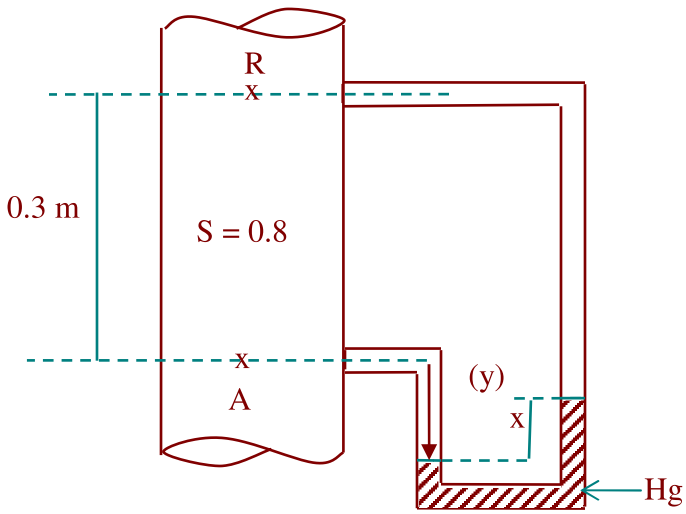
hn – hm = 0.391meters of water

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

$$= 9.81 \times 0.391$$

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

5. 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.




$p_A - p_B = 18 kPa$

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

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

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

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

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

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

$1.835 = 12.8x + 0.24$

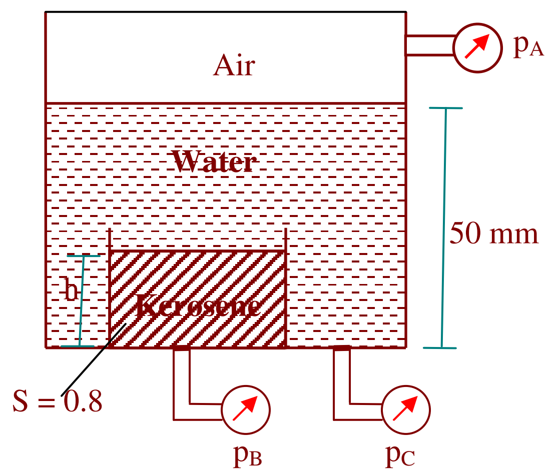
$x = 0.1246$ m

6. A cylindrical tank contains water to a height of 50mm. Inside is a small open cylindrical tank containing kerosene at a height specify gravity 0.8. The following pressures are known from indicated gauges.

$p_B$ = 13.8 kPa (gauge)

$p_C$ = 13.82 kPa (gauge)

Determine the gauge pressure $p_A$ and height h. Assume that kerosene is prevented from moving to the top of the tank.




$p_C = 13.82$ kPa

$h_C = 1.409$ m of water

$p_B = 13.8$ kPa

$h_B = 1.407$ meters of water

$1.409 - 0.05 = h_A \quad \therefore \; h_A = 1.359$ meters of water

$\therefore \; p_A = 1.359 \times 9.81$

$\therefore \; p_A = 13.33$ kPa

$h_B - h \times 0.8 - (0.05 - h) = h_A$

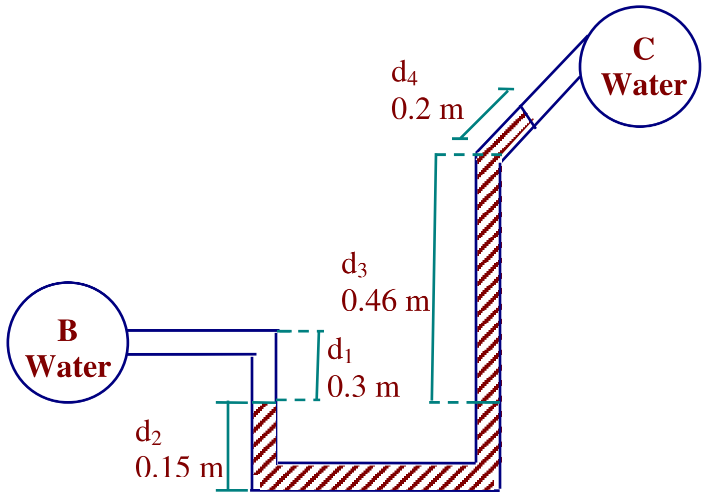
$1.407 - 0.8\,h - 0.05 + h = 1.359$

$0.2\,h = 1.359 - 1.407 + 0.05$

$0.2\,h = 0.002$

$h = 0.02$ m

7. Find the pressure different between A and B if $d_1$ = 300mm, $d_2$ = 150mm, $d_3$ = 460mm, $d_4$ = 200mm and 13.6.




Let $h_A$ and $h_B$ be the pressure head at A and B in m of water.

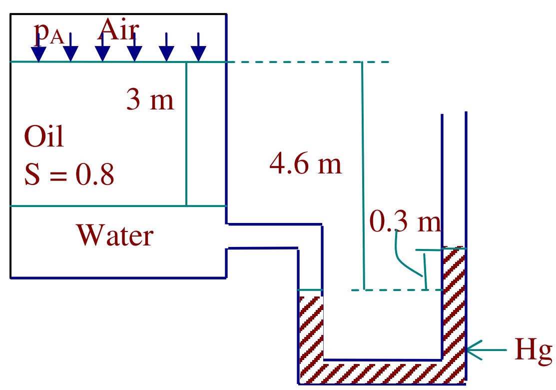
$h_A + 0.3 - (0.46 + 0.2 \sin 45)\, 13.6 = h_B$

$h_A - h_B = 7.88$m of water

$p_A - p_B = (7.88)\,(9.81)$

$p_A - p_B = 77.29$ kPa

8. What is the pressure $p_A$ in the fig given below? Take specific gravity of oil as 0.8.



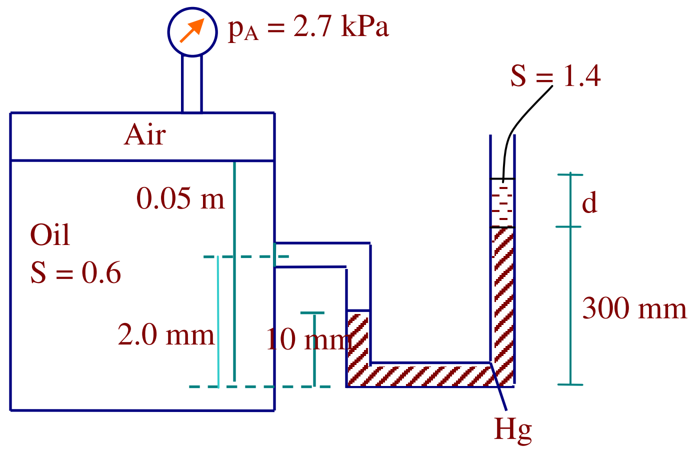

$h_A + (3 \times 0.8) + (4.6 - 0.3)\,(13.6) = 0$

$h_A = 2.24$ m of oil

$p_A = 9.81 \times 2.24$

$p_A = 21.97$ kPa

9. Find 'd' in the system shown in fig. If $p_A = 2.7$ kPa




$$h_A = \frac{p_A}{\gamma} = \frac{2.7}{9.81}$$

$$h_A = 0.2752\, m\ of\ \ water$$

$$h_A + (0.05\, x\, 0.6) + (0.05 + 0.02 - 0.01)0.6$$

$$+ (0.01\, x 13.6) - (0.03\, x 13.6) - d\, x 1.4) = 0$$

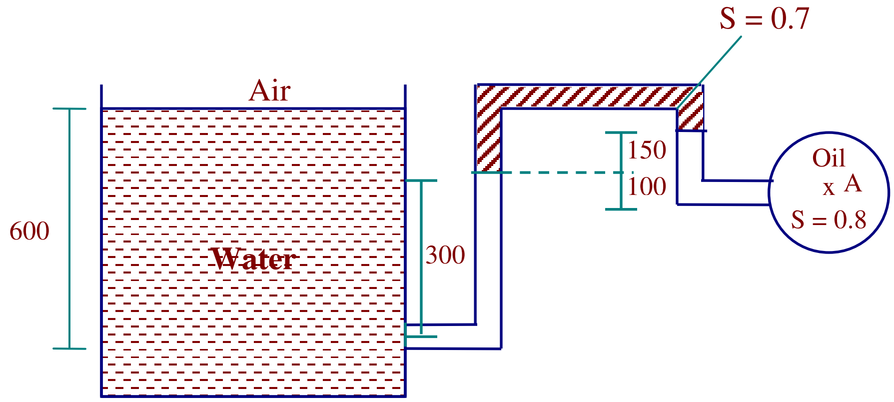
$$0.0692 - 1.4d = 0$$

$$d = 0.0494\, m$$

*or*

$$d = 49.4\, mm$$

10. Determine the absolute pressure at 'A' for the system shown in fig.




$h_A - (0.25 \times 0.8) + (0.15 \times 0.7) + (0.3 \times 0.8) - (0.6) = 0$

$h_A = 0.455$ m of water

$p_A = h_A \times 9.81$

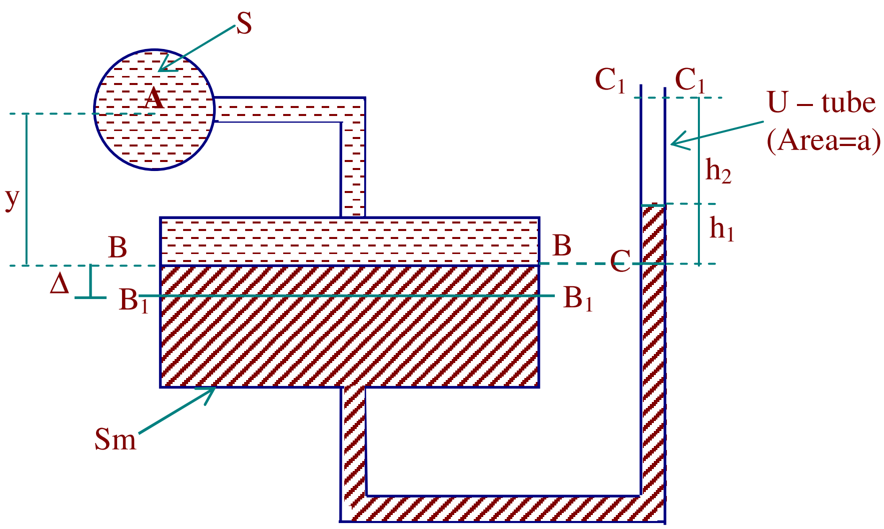
$p_A = 4.464$ kPa

$p_{abs} = 101.3 + 4.464$

$p_{abs} = 105.764$ 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 manometeric liquid in the reservoir is small (Δ) 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,

$+ y \times S - h_1 \times S_m = 0$

$\therefore Sy = S_m h_1$

Let the point A be connected to the manometer. $B_1B_1$ and $C_1$ $C_1$ are the levels of manometeric liquid. Volume of liquid between $BBB_1B_1$ = Volume of liquid between $CCC_1C_1$

$A\Delta = a\, h_2$

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

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

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

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

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

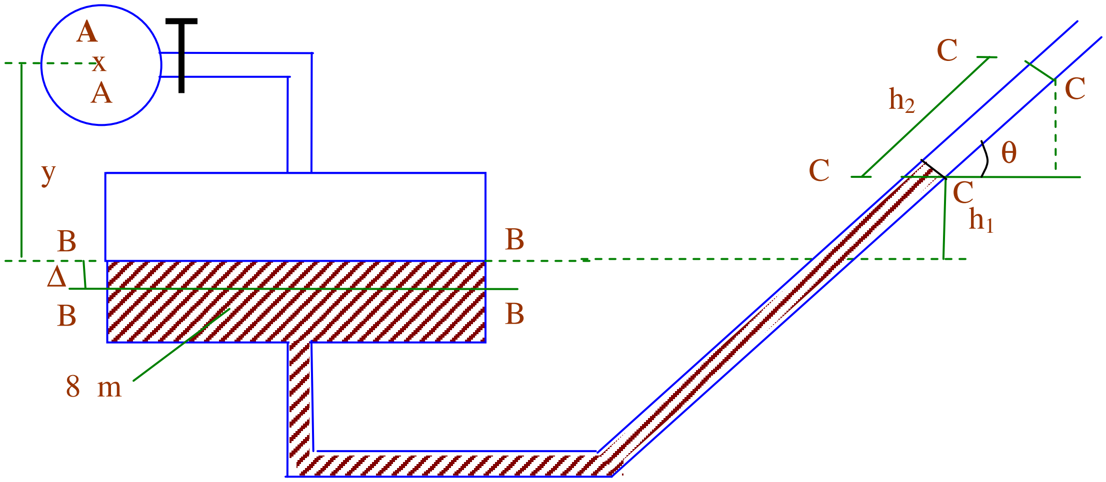
$h_A = \Delta\, (Sm - S) + h_2\, Sm$

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

$\therefore$ 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 $h_A = h_2\, Sm$

**INCLINED TUBE SINGLE COLUMN MANOMETER:**




Inclined tube SCM is used to measure small intensity pressure. It consists of a large reservoir to which an inclined U – tube is connected as shown in fig. For small changes in pressure the reading '$h_2$' in the inclined tube is more than that of SCM. Knowing the inclination of the tube the pressure intensity at the gauge point can be determined.

$$h_A = \frac{a}{A} h_2 \sin\theta (Sm - S) + h_2 \sin\theta . Sm$$

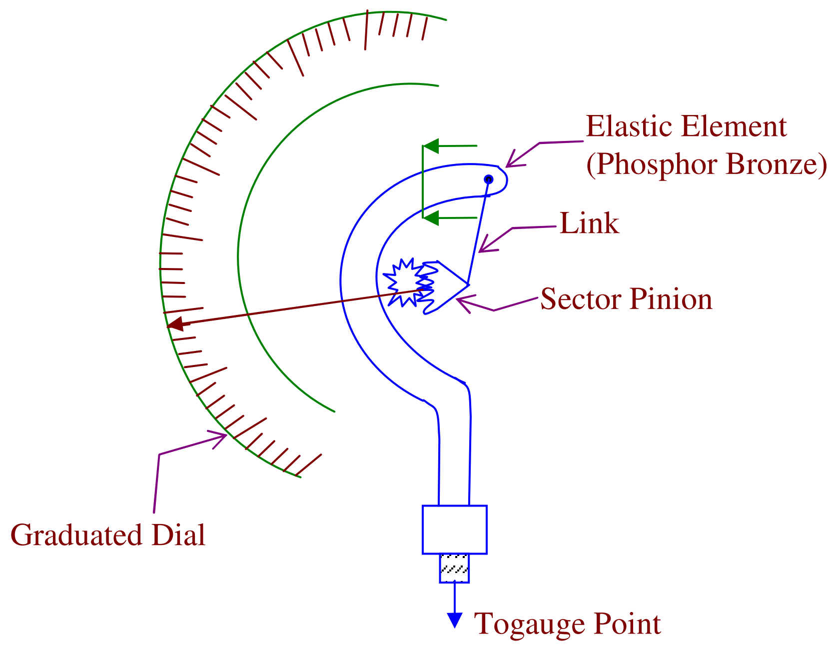
If '$\frac{a}{A}$' is very small then $h_A = (h_2 = \text{Sin}\theta)\, S_m$.

**2.7.3 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.

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.

**BASIC PRINCIPLE:**

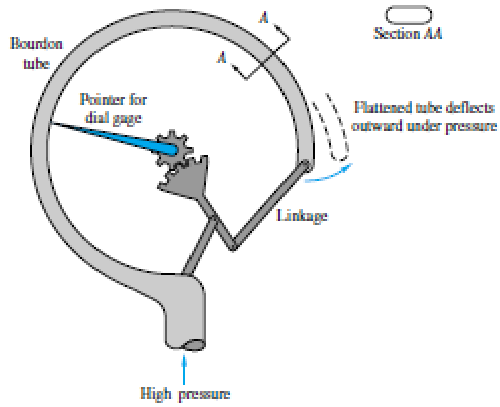


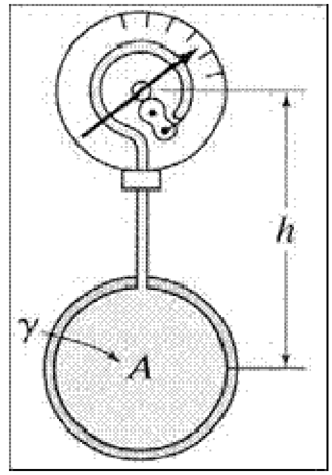

The arrangement consists of a pressure responsive element made up of phosphor bronze or special steel having elliptical cross section. The element is curved into a circular arc, one end of the tube is closed and free to move and the other end is connected to gauge point. The changes in pressure cause 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.

**Bourdon gage:**

Is a device used for measuring gauge pressures the pressure element is a hollow curved metallic tube closed at one end the other end is connected to the pressure to be measured. When the internal pressure is increased the tube tends to straighten pulling on a linkage to which is attached a pointer and causing the pointer to move. When the tube is connected the pointer shows zero. The *bourdon tube*, sketched in figure.

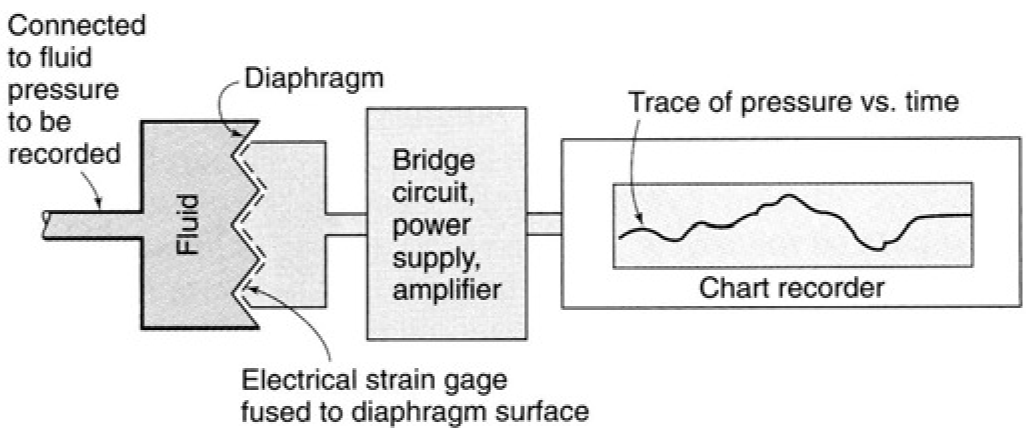
It can be used for the measurement of liquid and gas pressures up to 100s of MPa.




## 2.7.4 Electronic Pressure Measuring Devices:

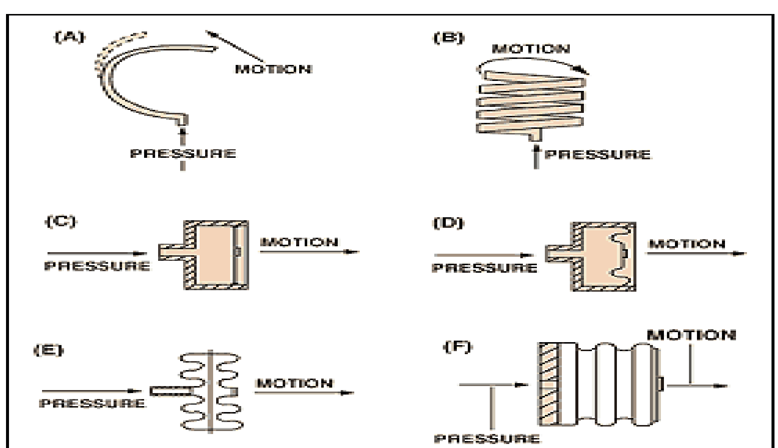
Electronic Pressure transducers convert pressure into an electrical output. These devices consist of a sensing element, transduction element and signal conditioning device to convert pressure readings to digital values on display panel.




**<u>Sensing Elements:</u>**

The main types of sensing elements are

- Bourdon tubes,
- Diaphragms,
- Capsules, and
- Bellows.



**Pressure Transducers:**

A transducer is a device that turns a mechanical signal into an electrical signal or an electrical signal into a mechanical response (e.g., Bourdon gage transfers pressure to displacement).

There are a number of ways to accomplish this kind of conversion

- Strain gage
- Capacitance
- Variable reluctance
- Optical

Normally Electronic Pressure transducers are costly compared to conventional mechanical gauges and need to be calibrated at National laboratories before put in to use.