2

Fluid Pressure and its Measurement

2·1 Introduction

We see that whenever a liquid (such as water, oil etc.) is contained in a vessel, it exerts force at all points on the sides and bottom of the container. This force per unit area is called pressure. If P is the force acting on area a, then* intensity of pressure,

$$p = \frac{P}{a}$$

The direction of this pressure is always at right angles to the surface, with which the fluid at rest, comes in contact.

2·2 Pressure Head

Consider a vessel containing some liquid as shown in Fig. 2·1. We know that the liquid will exert pressure on all sides as well as bottom of the vessel. Now let a bottomless cylinder be made to stand in the liquid as shown in the figure.

Let w = Specific weight of the liquid,
h = Height of liquid in the cylinder, and
A = Area of the cylinder base.

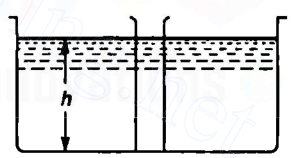


Fig. 2·1. Pressure head.

A little consideration will show, that there will be some pressure on the cylinder base due to weight of the liquid in it. Therefore pressure,

$$p = \frac{\text{Weight of liquid in the cylinder}}{\text{Area of the cylinder base}}$$

$$= \frac{whA}{A} = wh$$

This equation shows that the intensity of pressure at any point, in a liquid, is proportional to its depth, from the surface (as w is constant for the given liquid). It is thus obvious, that the pressure can be expressed in either of the following two ways :

1. As a force per unit area *i.e.*, N/m^2, kN/m^2 etc.
2. As a height of the equivalent liquid column.

*The intensity of pressure, in brief, is generally termed as *pressure.*

Note : The pressure is always expressed in pascal (briefly written as Pa) such that 1 Pa = 1 N/m^2, 1 kPa = 1 kN/m^2 and 1 MPa = 1 MN/m^2 = 1 N/mm^2.

Example 2·1. *Find the pressure at a point 4 m below the free surface of water.*

Solution. Given : $h = 4$ m.

We know that pressure at the point,

$$p = wh = 9{\cdot}81 \times 4 = 39{\cdot}24 \text{ kN/m}^2 = 39{\cdot}24 \text{ kPa} \quad \textbf{Ans.}$$

Example 2·2. *A steel plate is immersed in an oil of specific weight 7·5 kN/m^3 upto a depth of 2·5 m. What is the intensity of pressure on the plate due to the oil ?*

Solution. Given : $w = 7{\cdot}5$ kN/m^3 and $h = 2{\cdot}5$ m.

We know that intensity of pressure on the plate,

$$p = wh = 7{\cdot}5 \times 2{\cdot}5 = 18{\cdot}75 \text{ kN/m}^2 = 18{\cdot}75 \text{ kPa} \quad \textbf{Ans.}$$

Example 2·3. *Calculate the height of a water column equivalent to a pressure of 0·15 MPa.*

Solution. Given : $p = 0{\cdot}15$ MPa $= 0{\cdot}15 \times 10^3$ kN/m^2

Let h = Height of water column in metres.

We know that pressure of water column (p),

$$0{\cdot}15 \times 10^3 = wh = 9{\cdot}81 \times h$$

$$\therefore \quad h = (0{\cdot}15 \times 10^3)/9{\cdot}81 = 15{\cdot}3 \text{ m} \quad \textbf{Ans.}$$

Example 2·4. *What is the height of an oil column of specific gravity 0·9 equivalent to a gauge pressure of 20·3 kPa?*

Solution. Given : Sp. gr. of oil = 0·9 and gauge pressure (p) = 20·3 kPa = 20·3 kN/m^2.

Let h = Height of oil column in metres.

We know that specific weight of oil,

$$w = 0{\cdot}9 \times 9{\cdot}81 = 8{\cdot}829 \text{ kN/m}^3$$

and gauge pressure (p) $\quad 20{\cdot}3 = wh = 8{\cdot}829 \times h$

$$\therefore \quad h = 20{\cdot}3/8{\cdot}829 = 2{\cdot}3 \text{ m} \quad \textbf{Ans.}$$

EXERCISE 2·1

1. Find the pressure at a point 1·6 m below the free surface of water in a swiming pool. **[Ans.** 15·7 kPa]
2. A point is located at a depth of 1·6 m from the free surface of an oil of specific weight 8·0 kN/m^3. Calculate the intensity of pressure at the point. **[Ans.** 12·8 kPa]
3. Find the height of water column corresponding to a pressure of 5·6 kPa, **[Ans.** 0·57 m]
4. Determine the height of an oil column of specific gravity 0·8, which will cause a pressure of 25 kPa. **[Ans.** 3·19 m]
5. Calculate the height of mercury column equivalent to a gauge pressure of 150 kPa. **[Ans.** 1·12 m]

2·3 Pascal's Law

It states, "*The intensity of pressure at any point in a fluid at rest, is the same in all directions.*"

Proof. Consider a very small right-angled triangular element ABC of a liquid as shown in Fig. 2·2.

Let p_X = Intensity of horizontal pressure on the element of the liquid,

p_Y = Intensity of vertical pressure on the element of the liquid,

p_Z = Intensity of pressure on the diagonal of the tri-angular element of the liquid, and

θ = Angle of the triangular element of the liquid.

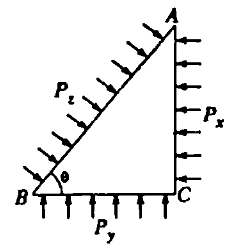


Fig. 2·2. Element of liquid.

Now pressure on the vertical side AC of the liquid,

$$P_X = p_X \times AC \qquad ...(i)$$

Similarly, pressure on the horizontal side BC of the liquid,

$$P_Y = p_Y \times BC \qquad ...(ii)$$

and pressure on the diagonal AB of the liquid,

$$P_Z = p_Z \times AB \qquad .(iii)$$

Since the element of the liquid is at rest, therefore sum of the horizontal and vertical components of the liquid pressures must be equal to zero.

Resolving the forces horizontally,

$$P_Z \sin\theta = P_X$$

or $$p_Z \,.\, AB \,.\, \sin\theta = p_X \,.\, AC \qquad ...(\because P_Z = p_Z \,.\, AB)$$

From the geometry of the figure, we find that

$$AB \sin\theta = AC$$

$\therefore$ $$p_Z \,.\, AC = p_X \,.\, AC$$

or $$p_Z = p_X \qquad ...(iv)$$

Now resolving the forces vertically,

i.e., $$P_Z \cos\theta = P_Y - W \qquad ...(\text{where } W = \text{Weight of the liquid element})$$

Since we are considering a very small triangular element of the liquid, therefore neglecting weight of the liquid (W), we find that

$$P_Z \cos\theta = P_Y$$

$\therefore$ $$p_Z AB \,.\cos\theta = p_Y \,.\, BC$$

From the geometry of the figure, we find that

$$AB \cos\theta = BC$$

$\therefore$ $$P_Z \,.\, BC = P_Y \,.\, BC$$

or $$p_Z = p_Y \qquad ...(v)$$

Now from equations (*iv*) and (*v*), we find that

$$p_X = p_Y = p_Z$$

Thus the intensity of pressure at any point in a fluid, at rest, is the same in all directions.

2·4 Atmospheric Pressure

It has been established, since long, that the air possesses some weight. Subsequently, it was also thought that the air, due to its weight, must exert some pressure on the surface of the earth. Since the air is compressible, therefore its density is different at different heights. The density of air has also been found to vary from time to time due to the changes in its temperature and humidity. It is thus obvious, that due to these difficulties, the atmospheric pressure (which is due to weight of the atmosphere or air above the surface of the earth) cannot be calculated, as is done in the case of liquids. However, it is measured by the height of the column of liquid that it can support.

It has been observed that at sea level, the pressure exerted by the column of air of 1 square metre cross-sectional area and of height equal to that of the atmosphere is 103 kN. Thus we may say that the atmospheric pressure at the sea level is 103 kN/m^2 (or 103 kPa). It can also be expressed as 10·3 metres of water, in terms of equivalent water column or 760 mm of mercury in terms of equivalent mercury column.

2·5 Gauge Pressure

It is the pressure, measured with the help of a pressure measuring instrument, in which the atmospheric pressure is taken as datum. Or in other words, the atmospheric pressure on the gauge scale is marked as zero. Generally, this pressure is above the atmospheric pressure.

2·6 Absolute Pressure

It is the pressure equal to the algebraic sum of atmospheric and gauge pressures. It may be noted that if the gauge pressure is minus (as in the case of vacuums or suctions), the absolute pressure will be atmospheric pressure *minus* gauge pressure. *e.g.*, if the absolute pressure at any point is 150 kN/m^2 and the atmospheric pressure is 103 kN/m^2, then the gauge pressure at that point will be $150 - 103 = 47$ kN/m^2. A little consideration will show, that if the pressure intensity at a point is more than the local atmospheric pressure, the difference of these two pressures is called the positive gauge pressure. However, if the pressure intensity is less than the local atmospheric pressure, the difference of these two pressures is called the negative gauge pressure or vacuum pressure. Mathematically,

$$p_{absolute} = p_{atmospheric} + p_{gauge}$$

2·7 Measurement of Fluid Pressure

The principles, on which all the pressure measuring devices are based, are almost the same. However, for convenient sake, we may split up the same into the following two types :

1. By balancing the liquid column (whose pressure is to be found out by the same or another column. These are also called tube gauges to measure the pressure.
2. By balancing the liquid column (whose pressure is to be found out) by the spring or dead weight. These are also called mechanical gauges to measure the pressure.

2·8 Tube Gauges to Measure Fluid Pressure

The devices used for measuring the fluid pressure by tube gauges are :

1. Piezometer tube. 2. Manometer.

2·9 Piezometer Tube

A piezometer tube is the simplest form of instrument, used for measuring, moderate pressures. It consists of a tube, one end of which is connected to the pipeline in which the pressure is required to be found out. The other end is open to the atmosphere, in which the liquid can rise freely without overflow. The height, to which the liquid rises up in the tube, gives the pressure head directly.

If the pressure of a liquid flowing in a pipe is to be found out, the piezometer tube is connected to the pipe as shown in Fig. 2·3. While connecting the piezometer to a pipe, care should always be taken that the tube should not project inside the pipe beyond its surface. All burrs and roughness near the hole must be removed, and the edge of the hole should be rounded off.

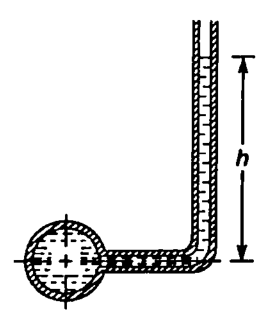


Fig. 2·3. Piezometer tube.

It may be noted that piezometer tube is meant for measuring gauge pressure only as the surface of the liquid, in the tube, is exposed to the atmosphere. A piezometer tube is also not suitable for measuring negative pressure; as in such a case the air will enter in the pipe through the tube.

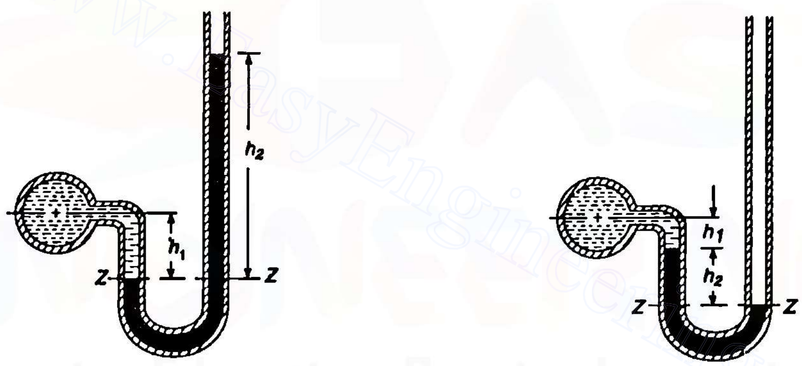
2·10 Manometer

Strictly speaking, a manometer is an improved form of a piezometer tube. With the help of a manometer, we can measure comparatively high pressures and negative pressures also. Following are the few types of manometers :

1. Simple manometer,
2. Micromanometer,
3. Differential manometer, and
4. Inverted differential manometer.

2·11 Simple Manometer

A simple manometer is a slightly improved form of a piezometer tube for measuring high as well as negative pressures. A simple manometer, in its simplest form, consists of a tube bent in U-shape, one end of which is attached to the gauge point and the other is open to the atmosphere as shown in Fig. 2·4 (*a*) and (*b*).



(*a*) Positive pressure (*b*) Negative pressure

Fig. 2·4. Simple manometer.

The liquid used in the bent tube or simple manometer is, generally, mercury which is 13·6 times heavier than water. Hence it is suitable for measuring high pressures also.

Now consider a simple manometer connected to a pipe containing a light liquid under a high pressure. The high pressure in the pipe will force the heavy liquid, in the left limb of the U-tube, to move downward. This downward movement of the heavy liquid in the left limb will cause a corresponding rise of the heavy liquid in the right limb.

The horizontal surface, at which the heavy and light liquid meet in the left limb, is known as a common surface or datum line. Let *Z–Z* be the datum line as shown in Fig. 2·4 (*a*).

Let h_1 = Height of the light liquid in the left limb above the commom surface in metres,

h_2 = Height of the heavy liquid in the right limb above the common surface in metres,

h = Pressure in the pipe, expressed in terms of head of water in metres,

s_1 = Specific gravity of the light liquid, and

s_2 = Specific gravity of the heavy liquid.

It will be interesting to know that the pressures in the left limb and right limb above the datum line are equal. We know that pressure in the left limb above the datum line Z–Z

$$= h + s_1h_1 \text{ m of water} \quad ...(i)$$

Similarly, pressure in the right limb above the datum line Z–Z

$$= s_2h_2 \text{ m of water} \quad ...(ii)$$

Since the pressure in both the limbs above the Z–Z datum is equal, therefore equating the pressures given by equations (*i*) and (*ii*),

$$h + s_1h_1 = s_2h_2$$

or $$h = (s_2h_2 - s_1h_1) \text{ m of water}$$

Note : If a negative pressure is to be measured by a simple manometer, the same can also be measured easily as discussed below :

In this case, negative pressure in the pipe will suck the light liquid which will pull up the heavy liquid in the left limb of the U-tube. This upward movement of the heavy liquid in the left limb will cause a corresponding fall of the liquid in the right limb as shown in Fig. 2·4 (*b*).

In this case, the datum line Z–Z may be considered to correspond with the top level of the heavy liquid in the right column as shown in the figure.

Now the pressure in the left limb above the datum line

$$= h + s_1h_1 + s_2h_2 \text{ m of water}$$

and pressure in the right limb $= 0$

Equating these two pressures,

$$h + s_1h_1 + s_2h_2 = 0$$

or $$h = -s_1h_1 - s_2h_2 = -(s_2h_2 + s_1h_1) \text{ m of water}$$

Example 2·5. *A simple manometer containing mercury is used to measure the pressure of water flowing in a pipeline. The mercury level in the open tube is 60 mm higher than that on the left tube. If the height of water in the left tube is 50 mm, determine the presure in the pipe in terms of head of water.*

Solution. Given : Height of mercury level in the open tube than that in the left tube $h_2 = 60$ mm and height of water in the left tube $h_1 = 50$ mm.

Let h = Pressure in the pipe in terms of head of water

We know that pressure head in the left limb above Z–Z

$$= h + s_1h_1 = h + (1 \times 50)$$
$$= h + 50 \text{ mm of water} \quad ...(i)$$

and pressure head in the right limb above Z–Z

$$= s_2h_2 = 13{\cdot}6 \times 60$$
$$= 816 \text{ mm of water} \quad ...(ii)$$

Since the pressure in both the limbs above the Z–Z datum equal, therefore equating (*i*) and (*ii*),

$$h + 50 = 816$$

or $$h = 816 - 50$$
$$= 766 \text{ mm of water} \quad \textbf{Ans.}$$

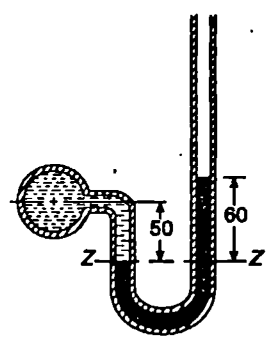


Fig. 2·5.

Example 2·6. *A simple manometer is used to measure the pressure of oil (sp. gravity = 0·8) flowing in a pipeline. Its right limb is open to the atmosphere and the left limb is connected to the pipe. The centre of the pipe is 90 mm below the level of mercury (sp. gravity = 13·6) in the right limb. If difference of mercury levels in the two limbs is 150 mm, find the pressure of oil in the pipe.*

Solution. Given : $s_1 = 0{\cdot}8$; Height of mercury above the centre of the pipeline = 90 mm; $s_2 = 13{\cdot}6$ and $h_2 = 150$ mm.

From the geometry of the manometer, we find that height of oil column from the datum Z–Z,

$$h_1 = 150 - 90 = 60 \text{ mm}$$

Let h = Gauge pressure in the pipe line in terms of water head.

We know that pressure head in the left limb above Z–Z

$$= h + s_1 h_1 = h + (0{\cdot}8 \times 60)$$

$$= h + 48 \text{ mm of water} \quad ...(i)$$

and pressure head in the right limb above Z–Z

$$= s_2 h_2 = 13{\cdot}6 \times 150$$

$$= 2040 \text{ mm of water} \quad ...(ii)$$

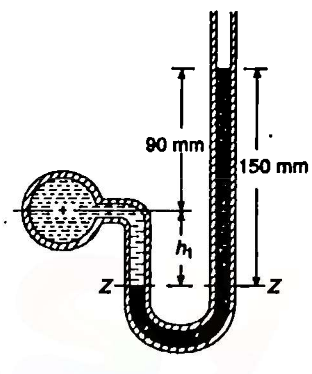


Fig. 2·6.

Since the pressure in both the limbs above the Z–Z datum is equal, therefore equating (*i*) and (*ii*),

$$h + 48 = 2040$$

$$\therefore \quad h = 2040 - 48 = 1992 \text{ mm}$$

$$= 1{\cdot}992 \text{ m of water}$$

and gauge pressure (or pressure of oil in the pipe),

$$p = wh = 9{\cdot}81 \times 1{\cdot}992 = 19{\cdot}54 \text{ kN/m}^2 = 19{\cdot}54 \text{ kPa} \quad \textbf{Ans.}$$

Note : The value h may also be obtained directly by the relation :

$$h = s_2 h_2 - s_1 h_1 = (13{\cdot}6 \times 150) - (0{\cdot}8 \times 60)$$

$$= 1992 \text{ mm} = 1{\cdot}992 \text{ mm of water}$$

Example 2·7. *A simple manometer containing mercury was used to find the negative pressure in the pipe containing water as shown in Fig. 2·7. The right limb of the manometer was open to atmosphere. Find the negative pressure, below the atmosphere in the pipe, if the manometer readings are given in the figure.*

Solution. Given : $h_2 = 50$ mm; $h_1 = 20$ mm; $s_1 = 1$ (because of water) and $s_2 = 13{\cdot}6$ (because of mercury).

Let h = Gauge pressure in the pipe in terms of head of water.

We know that pressure head in the left limb above Z–Z

$$= h + s_1 h_1 + s_2 h_2$$

$$= h + (1 \times 20) + (13{\cdot}6 \times 50)$$

$$= h + 700 \text{ mm} = h + 7 \text{ m of water} \quad ...(i)$$

and pressure head in the right limb above Z–Z

$$= 0$$

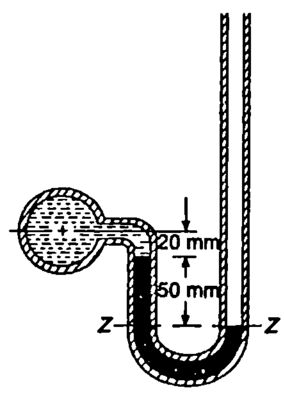


Fig. 2·7.

Since the pressure in both the limbs above the Z–Z datum is equal, therefore equating (*i*) and (*ii*),

$$h + 7 = 0 \quad \text{or} \quad h = -7 \text{ m of water}$$

and gauge pressure in the pipe,

$$p = wh = 9{\cdot}81 \times (-7) = -68{\cdot}67 \text{ kN/m}^2 = -68{\cdot}67 \text{ kPa}$$
$$= 68{\cdot}67 \text{ kPa (Vacuum)} \quad \textbf{Ans.}$$

Example 2·8. *The pressure of water flowing in a pipeline is measured by a manometer containing U-tubes as shown in Fig. 2·8.*

The measuring fluid is mercury in all the tubes and water is enclosed between the mercury columns. The last tube is open to the atmosphere. Find the pressure of oil in the pipeline.

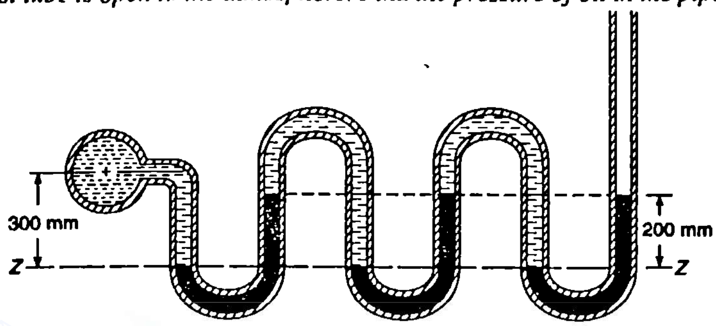


Fig. 2·8.

Solution. Given : No. of tubes = 3; Height of mercury in each column = 200 mm or total height of mercury (h_2) = 3 × 200 = 600 mm; Total height of water (h_1) = 300 + (2 × 200) = 700 mm; s_1 = 1 (because of water) and s_2 = 13·6 (because of mercury).

Let h = Gauge pressure in the pipe in terms of head of water.

We know that pressure head due to water above Z–Z

$$= h + s_1h_1 = h + (1 \times 700) \text{ mm} = h + 0{\cdot}7 \text{ m of water} \quad ...(i)$$

and pressure head due to mercury above Z–Z

$$= s_2h_2 = 13{\cdot}6 \times 600 = 8160 \text{ mm} = 8{\cdot}16 \text{ m of water} \quad ...(ii)$$

Since the pressure heads due to water and mercury are equal, therefore equating (*i*) and (*ii*),

$$h + 0{\cdot}7 = 8{\cdot}16 \quad \text{or} \quad h = 8{\cdot}16 - 0{\cdot}7 = 7{\cdot}46 \text{ m of water}$$

and gauge pressure (or pressure of oil in the pipeline),

$$p = wh = 9{\cdot}81 \times 7{\cdot}46 = 73{\cdot}2 \text{ kN/m}^2 = 73{\cdot}2 \text{ kPa} \quad \textbf{Ans.}$$

Example 2·9. *Fig. 2·9 shows a conical vessel having its outlet at A to which U tube manometer is connected.*

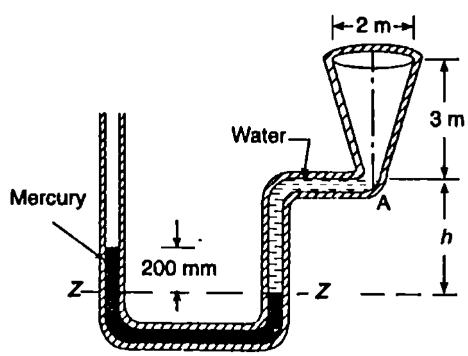


Fig. 2·9.

The reading of the manometer given in the figure shows when the vessel is empty. Find the reading of the manometer when the vessel is completely filled with water.

Solution. Given : Manometer reading when the vessel is empty (h_2) = 200 mm = 0·2 m; s_1 = 1 (because of water) and s_2 = 13·6 (because of mercury).

Let h = Pressure head of oil in terms of head of water.

First of all, let us consider the vessel is to be empty and $Z–Z$ be the datum line. We know that

pressure head in the right limb $= s_1 h_1 = 1 \times h = h$ m of water ...(*i*)

and pressure head in the left limb $= s_2 h_2 = 13{\cdot}6 \times 0{\cdot}2 = 2{\cdot}72$ m of water ...(*ii*)

Since the pressure in both the limbs above the $Z–Z$ datum is equal, therefore equating equations, (*i*) and (*ii*),

$$h = 2{\cdot}72 \text{ m}$$

Now consider the vessel to be completely filled with water. As a result of this, let the mercury level go down by x metres in the right limb, and the mercury level go up by the same amount in the left limb. Therefore total height of water in the right limb

$$= x + h + 3 = x + 2{\cdot}72 + 3 = x + 5{\cdot}72 \text{ m}$$

and pressure head in the right limb $= 1\,(x + 5{\cdot}72) = x + 5{\cdot}72$ m of water ...(*iii*)

We know that manometer reading in this case

$$= 0{\cdot}2 + 2x \text{ m}$$

and pressure head in the left limb

$$= 13{\cdot}6\,(0{\cdot}2 + 2x) = 2{\cdot}72 + 27{\cdot}2\,x \qquad ...(iv)$$

Again equating the pressures of equations (*iii*) and (*iv*),

$$x + 5{\cdot}72 = 2{\cdot}72 + 27{\cdot}2\,x \quad \text{or} \quad 26{\cdot}2\,x = 3{\cdot}0$$

$$\therefore \quad x = 3/26{\cdot}2 = 0{\cdot}115 \text{ m}$$

and manometer reading $= 0{\cdot}2 + (2 \times 0{\cdot}115) = 0{\cdot}43$ m = 430 mm **Ans.**

2·12 Micromanometer

It is a modified form of manometer, in which cross-sectional area of one of the limbs (say left limb) is made much larger (about 100 times) than that of the other limb as shown in Fig. 2·10. A micromanometer is used for measuring low pressures, where accuracy is of much importance. Though there are many types of micrometers, yet the following two types are important from the subject point of view :

1. Vertical tube micromanometer, and
2. Inclined tube micromanometer.

1. *Vertical tube micromanometer*

Now consider a vertical tube micromanometer connected to a pipe containing light liquid under a very high pressure. The pressure in the pipe will force the light liquid to push the heavy liquid in the basin downwards. Due to larger area of the basin, the fall of heavy liquid level will be very small. This downward movement of the heavy liquid, in the basin, will cause a considerable rise of the heavy liquid in the right limb. Let us consider our datum line $Z–Z$ corresponding to heavy liquid level before the experiment.

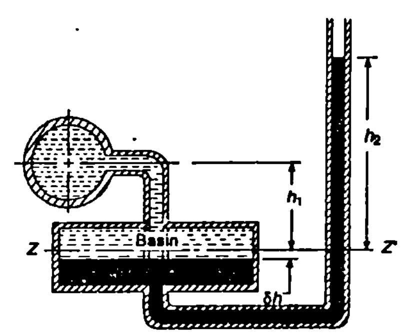


Fig. 2·10.
Vertical micromanometer.

Let δh = Fall of heavy liquid level in the basin in m,

h_1 = Height of light liquid above the datum line in m

h_2 = Height of heavy liquid (after experiment) in the right limb above the datum line in m,

h = Pressure in the pipe, expressed in terms of head of water in m,

A = Cross-sectional area of the basin in m^2,

a = Cross-sectional area of the tube in m^2,

s_1 = Specific gravity of the light liquid, and

s_2 = Specific gravity of the heavy liquid.

We know that the fall of heavy liquid level, in the basin, will cause a corresponding rise of heavy liquid level.

$$\therefore \qquad A.\delta h = ah_2 \qquad \text{or} \qquad \delta h = \frac{a}{A} \times h_2 \qquad ...(i)$$

Now let us take the horizontal surface in the basin, at which the heavy and light liquid meet, as datum line. We also know that the pressures in the left limb and right limb, above the datum line are equal.

$\therefore$ Pressure in the left limb above the datum line Z–Z

$$= h + s_1 h_1 + s_1 \delta h \text{ m of water} \qquad ...(ii)$$

and pressure in the right limb above the datum line

$$= s_2 h_2 + s_2 \delta h \text{ m of water} \qquad ...(iii)$$

Since pressure in both the limbs above Z–Z datum is equal, therefore equating these two pressures,

$$h + s_1 h_1 + s_1 \delta h = s_2 h_2 + s_2 \delta h$$

or

$$h = s_2 h_2 + s_2 \delta h - s_1 h_1 - s_1 \delta h$$

$$= s_2 h_2 - s_1 h_1 + \delta h (s_2 - s_1)$$

Substituting the value of δh from equation (i),

$$h = s_2 h_2 - s_1 h_1 + \frac{a}{A} \times h_2 (s_2 - s_1) \qquad ...(iv)$$

Note : Sometimes, the cross-sectional area of the basin (*i.e.*, A) is made very large and that of the tube (*i.e.*, a) is made very small. Then the ratio a/A is extremely very small, and thus is neglected. Then the above equation becomes :

$$h = s_2 h_2 - s_1 h_1 \qquad ...(i)$$

2. *Inclined tube micromanometer*

Sometimes, the vertical tube of the micromanometer is made inclined as shown in Fig. 2·11. An inclined tube micromanometer is more sensitive than the vertical tube type. Due to inclination, the distance moved by the heavy liquid, in the narrow tube, will be comparatively more, and thus it gives a higher reading for the given pressure.

From the geometry of figure, we find

$$\frac{h_2}{l} = \sin \alpha \qquad \text{or} \qquad h_2 = l \sin \alpha$$

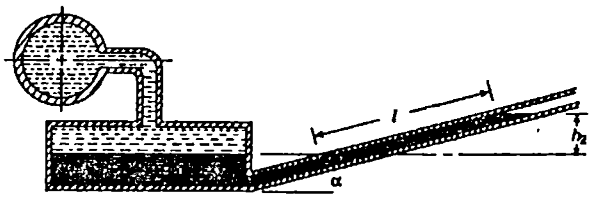


Fig. 2·11. Inclined tube micromanometer.

By substituting the value of h_2 in the micromanometer equation, we can find out the required pressure in the pipe.

Example 2·10. *In order to determine the pressure in a pipe, containing liquid of specific gravity 0·8, a micromanometer was used as shown in Fig. 2·12.*

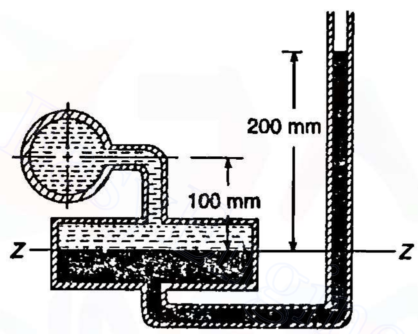


Fig. 2·12.

The ratio of area of the basin to that of the limb is 50. Find the intensity of pressure in the pipe for the manometer reading as shown in the figure.

Solution. Given : $s_1 = 0{\cdot}8$; $A/a = 50$; $h_1 = 100$ mm; $h_2 = 200$ mm and $s_2 = 13{\cdot}6$ (because of mercury).

We know that pressure head in the left limb above Z–Z

$$= h + s_1h_1 + \frac{a}{A} \times s_1h_2 = h + (0{\cdot}8 \times 100) + \frac{1}{50} \times 0{\cdot}8 \times 200$$

$$= h + 80 + 3{\cdot}2 = h + 83{\cdot}2 \text{ mm of water} \quad ...(i)$$

and pressure head in the right limb above Z–Z

$$= s_2h_2 + \frac{a}{A} \times s_2h_2 = 13{\cdot}6 \times 200 + \frac{1}{50} \times 13{\cdot}6 \times 200$$

$$= 2720 + 54{\cdot}4 = 2774{\cdot}4 \text{ mm of water} \quad ...(ii)$$

Since pressure in both the limbs above the Z–Z datum is equal, therefore equating (*i*) and (*ii*),

$$h + 83{\cdot}2 = 2774{\cdot}4$$

or $$h = 2774{\cdot}4 - 83{\cdot}2 = 2691{\cdot}2 \text{ mm} = 2{\cdot}6912 \text{ m of water}$$

and intensity of pressure in the pipe

$$p = wh = 9{\cdot}81 \times 2{\cdot}6912 = 26{\cdot}4 \text{ kN/m}^2 = 26{\cdot}4 \text{ kPa} \quad \textbf{Ans.}$$

EXERCISE 2·2

1. A simple manometer is used to measure the pressure of water flowing in a pipeline. Its right limb is open to the atmosphere and the left limb is connected to the pipe. The centre of the pipe is in level with that of the mercury in the right limb. Determine the pressue in the pipe, if the difference of mercury levels in the two limbs is 100 mm. **[Ans.** 1·26 m of water; 12·36 kPa]

2. The pressure of water in a pipeline was measured by means of a simple manometer containing mercury. The reading of the manometer is shown in Fig. 2·13. Determine the static pressure of water in the pipe in terms of (*i*) head of water in metres and (*ii*) kPa. Take usual specific gravities of mercury and water. **[Ans.** 1·05 m; 10·3 kPa]

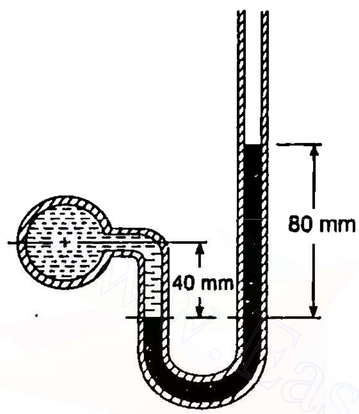


Fig. 2·13.

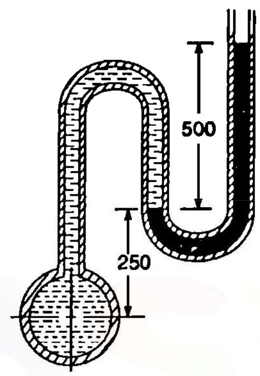


Fig. 2·14.

3. A U-tube containing mercury is used to measure the pressure of an oil (of specific gravity 0·8) as shown in Fig. 2·14. Calculate the pressure of the oil, if the difference of mercury level be 50 cm. **[Ans.** 7·0 m of water]

[Hint : Pressure in the left limb = $h - (0{\cdot}8 \times 250) = h - 200$ mm of water ...(*i*)

Pressure in the right limb = $s_2 h_2 = 13{\cdot}6 \times 500 = 6800$ mm of water ...(*ii*)

Equating the equations (*i*) and (*ii*).

$$h = 200 = 6800 \quad \text{or} \quad h = 6800 + 200 = 7000 \text{ mm} = 7 \text{ m}$$

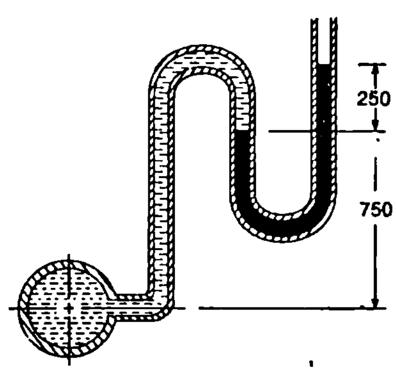


Fig. 2·15.

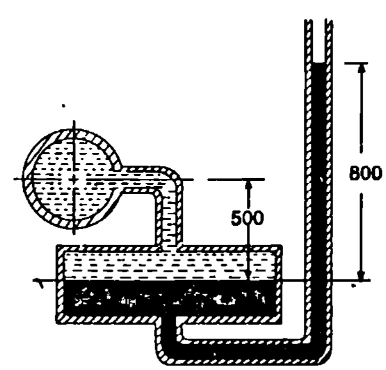


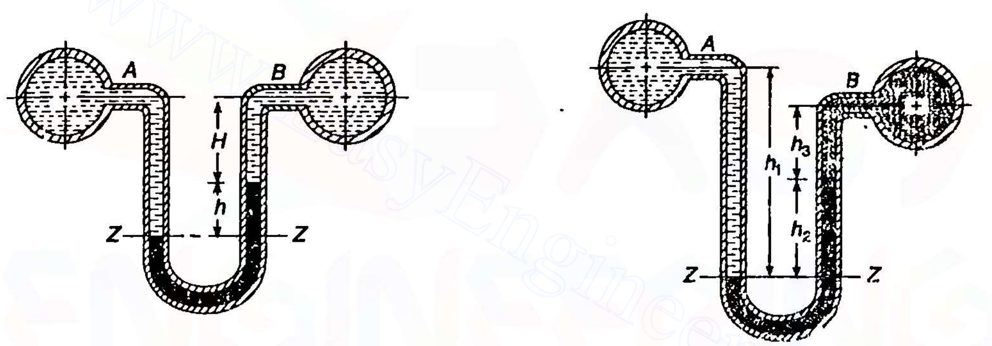
Fig. 2·16.

4. Fig. 2·15 shows a manometer connected to a pipeline, containing an oil of specific gravity 0·8. Find the pressure of oil in the pipe. **[Ans. 39·4 kPa]**
5. A micromanometer, having ratio of basin to limb areas as 40, was used to determine the pressure in a pipe containing water. Determine the pressure in the pipe for the manometer reading shown in Fig. 2·16. **[Ans. 104 kPa]**

2·13 Differential Manometer

It is a device used for measuring the difference of pressures, between two points in a pipe, or in two different pipes. A differential manometer, in its simplest form, consists of a U-tube containing a heavy liquid, whose two ends are connected to the points, whose difference of pressures is required to be found out.

Now consider a differential manometer whose two ends are connected with two different points *A* and *B* as shown in Fig. 2·17 (*a*) and (*b*). Let us assume that the pressure at point *A* is more than that at point *B*. A little consideration will show, that the greater pressure at *A* will force the heavy liquid in the U-tube to move downwards. This downward movement of the heavy liquid, in the left limb, will cause a corresponding rise of the heavy liquid in the right limb as shown in Fig. 2·17 (*a*).



(*a*) *A* and *B* at the same level and containing same liquid.

(*b*) *A* and *B* at different levels an containing different liquids

Fig. 2·17.

Let us take the horizontal surface *Z–Z*, at which the heavy liquid and light liquid meet in the left limb, as the datum line.

Let h = Difference of the levels of the heavy liquid in the right and left limb (also known as the reading of the differential manometer) in mm,

h_A = Pressure head in pipe *A*,

h_B = Pressure head in pipe *B*

s_1 = Specific gravity of the light liquid in the pipes and

s_2 = Specific gravity of the heavy liquid.

We know that the pressure head in the left limb above *Z–Z*

$$= h_A + s_1 (H + h) = h_A + s_1 H + s_1 h \text{ m of water} \quad ...(i)$$

and pressure head in the right limb above *Z–Z*

$$= h_B + s_1 h + s_2 h \text{ m of water} \quad ...(ii)$$

Since the pressure heads in both the limbs above *Z–Z* datum are equal, therefore equating the equations (*i*) and (*ii*),

$$h_A + s_1 H + s_1 h = h_B + s_1 H + s_2 h$$

$$\therefore \quad h_A - h_B = s_2 h - s_1 h = h(s_2 - s_1)$$

Sometimes, the two pipes or the two points, whose difference of pressures is required to be found out are not at the same level. And at the same time, the liquids flowing in the two pipes are different. In such a case, the same principle is applied to obtain the difference of pressure heads.

Now consider a differential manometer, whose two ends are connected to two different pipes *A* and *B* and containing different liquids at different levels as shown in Fig. 2·17 (*b*). Let us assume that the pressure at the point *A* is more than that at the point *B*. A little consideration will show that the greater pressure at *A* will force the heavy liquid to move downwards. This downward movement of the liquid, in the left limb, will cause a corresponding rise of the heavy liquid in the right limb as shown in Fig. 2·17 (*b*).

The horizontal surface at which the heavy and light liquids meet in the left limb is taken as a datum line. In this case, let *Z–Z* be the datum line, as shown in Fig. 2·17 (*b*).

Let h_1 = Height of liquid in the left limb above the datum line in mm,
h_2 = Difference of levels of the heavy liquid in the right and left limb (also known as reading of the differential manometer) in mm,
h_3 = Height of the liquid in the right limb above the datum line in mm,
h_A = Pressure head in the pipe *A*,
h_B = Pressure head in the pipe *B*,
s_1 = Specific gravity of the liquid in the left pipe (*A*),
s_2 = Specific gravity of the heavy liquid, and
s_3 = Specific gravity of the liquid in the right pipe (*B*).

We know that pressure in the left limb above the datum *Z–Z*

$$= h_A + s_1 h_1 \text{ m of water} \qquad ...(i)$$

and pressure in the right limb above the datum *Z–Z*

$$= s_2 h_2 + s_3 h_3 + h_B \text{ m of water} \qquad ...(ii)$$

Since pressure in both the limbs above the *Z–Z* datum is equal, therefore equating these two pressures,

$$h_A + s_1 h_1 = s_2 h_2 + s_3 h_3 + h_B$$

From the above equation, the value of h_A, h_B or their difference may be found out.

Note : If a differential manometer has got readings other than those assumed in the above equation (*i.e.*, pressure in pipe *A* is more than that in *B*), then it is advisable to start the problem from the fundamentals.

Example 2·10. *A differential manometer connected at the two points A and B at the same level in a pipe containing an oil of specific gravity 0·8, shows a difference in mercury levels as 100 mm. Determine the difference in pressures at the two points.*

Solution. Given : s_1 = 0·8; h = 100 mm and s_2 = 13·6 (because of mercury)

We know that pressure head in the left limb above *Z–Z*

$$= h_A + s_1 (H + 100) \text{ mm of water}$$

$$= h_A + s_1 H + 100 s_1 \text{ mm of water} \qquad ...(i)$$

and pressure in the right limb above *Z–Z*

$$= h_B + s_1 H + s_2 \times 100 \text{ mm of water}$$

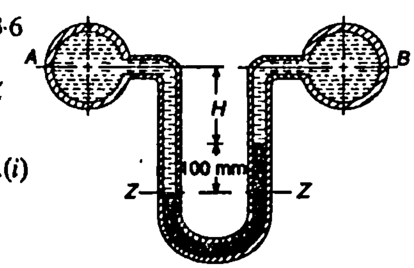


Fig. 2·18.

Since pressure heads in both the limbs above the *Z–Z* datum are equal, therefore equating (*i*) and (*ii*),

$$h_A + s_1 H + 100 s_1 = h_B + s_1 H + 100 s_2$$

$$\therefore \quad h_A - h_B = 100\, s_2 - 100\, s_1 = 100\,(s_2 - s_1) = 100\,(13{\cdot}6 - 0{\cdot}8)$$

$$= 100 \times 12{\cdot}8 = 1280 \text{ mm} = 1{\cdot}28 \text{ m of water}$$

and difference of pressures,

$$p = w(h_A - h_B) = 9{\cdot}81 \times 1{\cdot}28 = 12{\cdot}56 \text{ kN/m}^3 = 12{\cdot}56 \text{ kPa} \quad \textbf{Ans.}$$

Example 2·11. *A manometer containing mercury is connected to two points 15 m apart, on a pipeline conveying water. The pipeline is straight and slopes at an angle of 15° with the horizontal. The manometer gives a reading of 150 mm. Determine the pressure difference between the two points of the pipeline. Take specific gravity of mercury as 13·6 and that of water as 1·0.*

Solution. Given : Pipe length (l) = 15 m; Inclination of pipe, $\alpha = 15°$; $h = 150$ mm $= 0{\cdot}15$ m; $s_2 = 13{\cdot}6$ and $s_1 = 1{\cdot}0$.

Let x = Height of water in the right limb.

We know that difference between the points A and B due to inclination

$$AC = 15 \sin 15° = 15 \times 0{\cdot}2588 \text{ m}$$

$$= 3{\cdot}882 \text{ m}$$

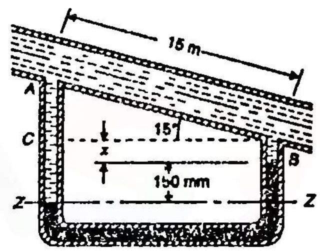


Fig. 2.19.

We also know that pressure head in the left limb above Z–Z datum

$$= h_A + 0{\cdot}15 \times s_1 + x.s_1 + 3{\cdot}882\, s_1$$

$$= h_A + (0{\cdot}15 \times 1) + (x \times 1) + 3{\cdot}882 \times 1$$

$$= h_A + x + 4{\cdot}032 \text{ m of water} \qquad ...(i)$$

and pressure head in the right limb above Z–Z datum

$$= h_B + 0{\cdot}15\, s_2 + x.s_1$$

$$= h_B + (0{\cdot}15 \times 13{\cdot}6) + x_1 \times 1$$

$$= h_B + 2{\cdot}04 + x \text{ m of water} \qquad (ii)$$

Since the pressure heads in both the limbs are equal, therefore equating (i) and (ii),

$$h_A + x + 4{\cdot}032 = h_B + 2{\cdot}04 + x$$

$$\therefore \quad h_B - h_A = 4{\cdot}032 - 2{\cdot}04 = 1{\cdot}992 \text{ m of water}$$

and difference of pressures,

$$p = w\,(h_B - h_A) = 9{\cdot}81 \times 1{\cdot}992 = 19{\cdot}54 \text{ kN/m}^2 = 19{\cdot}54 \text{ kPa} \quad \textbf{Ans.}$$

Example 2·12. *A U-tube differential manometer connects two pressure pipes A and B. The pipe A contains carbon tetrachloride having a specific gravity 1·6 under a pressure of 120 kPa. The pipe B contains oil of specific gravity 0·8 under a pressure of 200 kPa. The pipe A lies 2·5 m above pipe B. Find the difference of pressures measured by mercury as fluid filling U tube.*

Solution. Given : $s_A = 1{\cdot}6$; $p_A = 120$ kPa, $s_B = 0{\cdot}8$; $p_B = 200$ kPa; $h_A = 2{\cdot}5$ m and $s = 13{\cdot}6$ (because of mercury).

Let h = Difference of pressure measured by mercury in terms of head of water.

We know that pressure head in pipe A,

$$\frac{p_A}{w} = \frac{120}{9{\cdot}81} = 12{\cdot}2 \text{ m of water}$$

and pressure head in pipe B, $\dfrac{p_B}{w} = \dfrac{200}{9{\cdot}81} = 20{\cdot}4$ m of water

We also know that pressure head in pipe A above Z–Z

$$= 12{\cdot}2 + (s_A \,.\, h_A) + s.h$$
$$= 12{\cdot}2 + (1{\cdot}6 \times 2{\cdot}5) + 13{\cdot}6 \times h$$
$$= 16{\cdot}2 + 13{\cdot}6\,h \quad ...(i)$$

and pressure head in pipe B above Z–Z

$$= 20{\cdot}4 + s_B\,h = 20{\cdot}4 + (0{\cdot}8 \times h) \quad ...(ii)$$

Since the pressure heads in both the pipes above the Z–Z datum are equal, therefore equating (*i*) and (*ii*)

$$16{\cdot}2 + 13{\cdot}6\,h = 20{\cdot}4 + 0{\cdot}8\,h \quad \text{or} \quad 12{\cdot}8\,h = 4{\cdot}2$$

$$\therefore \quad h = 4{\cdot}2/12{\cdot}8 = 0{\cdot}328 \text{ m} = 328 \text{ mm} \quad \textbf{Ans.}$$

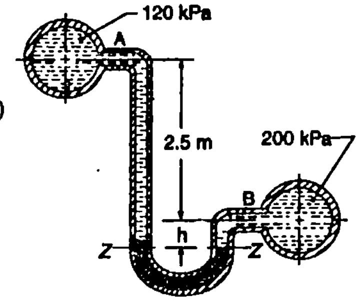


Fig. 2·20.

2·14 Inverted Differential Manometer

It is a particular type of differential manometer, in which an inverted U-tube is used. An inverted differential manometer is used for measuring difference of low pressures, where accuracy is the prime consideration. It consists of an inverted U-tube, containing a light liquid whose two ends are connected to the points whose difference of pressures is to be found out.

Now consider an inverted differential manometer, whose two ends are connected to two different points A and B as shown in Fig. 2·21. Let us assume that the pressure at point A is more than that at point B. A little consideration will show, that the greater pressure at A will force the light liquid in the inverted U-tube to move upwards. This upward movement of liquid in the left limb will cause a corresponding fall of the light liquid in the right limb as shown in Fig. 2·21. Let us take Z–Z as the datum line in this case.

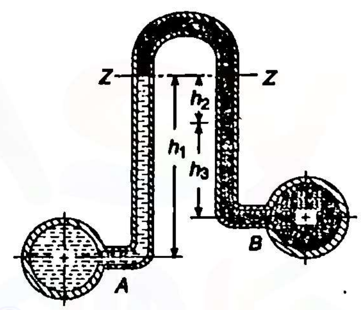


Fig. 2·21. Inverted differential manometer.

Let h_1 = Height of liquid in the left limb below the datum line in mm,

h_2 = Difference of levels of the light liquid in the right and left limbs (also known as manometer reading) in mm,

h_3 = Height of liquid in the right limb below the datum line in mm,

h_A = Pressure in the pipe A, expressed in terms of head of the liquid in mm,

h_B = Pressure in the pipe B, expressed in terms of head of the liquid in mm,

s_1 = Specific gravity of the liquid in the left limb,

s_2 = Specific gravity of the light liquid, and

s_3 = Specific gravity of the liquid in the right limb.

We know that pressure head in the left limb below the datum line

$$= h_A - s_1 h_1 \quad ...(i)$$

and pressure head in the right limb below the datum line

$$= h_B - s_2 h_2 - s_3 h_3 \quad ...(ii)$$

Since pressure heads in both the limbs below the Z–Z detum are equal, therefore equating (*i*) and (*ii*)

$$h_A - s_1 h_1 = h_B - s_2 h_2 - s_3 h_3$$

From the above equation, the value of h_A, h_B or their difference may be found out as usual.

Example 2·13. *An inverted differential manometer having an oil of specific gravity 0·75 was connected to two different pipes carrying water under pressure as shown in Fig. 2·22.*

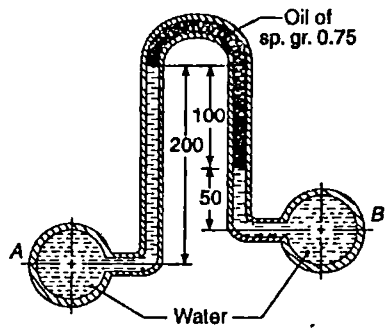


Fig. 2·22.

Determine the pressure in the pipe B in terms of kPa, if the manometer reads as shown in the figure. Take pressure in the pipe A as 1·5 metre of water.

Solution. Given : $h_1 = 200 \text{ mm} = 0{\cdot}2$ m; $h_2 = 100 \text{ mm} = 0{\cdot}1$ m; $s_2 = 0{\cdot}75$, $h_3 = 50$ mm $= 0{\cdot}05$ m ; $h_A = 1{\cdot}5$ m and $s_1 = s_3$ (because of water).

Let h_B = Pressure in pipe B in terms of head of water.

We know that pressure head in the left limb below Z–Z

$$= h_A - s_1 h_1 = 1{\cdot}5 - (1 \times 0{\cdot}2) = 1{\cdot}3 \text{ m of water} \quad ...(i)$$

and pressure head in the right limb below Z–Z

$$= h_B - s_2 h_2 - s_3 h_3 = h_B - (0{\cdot}75 \times 0{\cdot}1) - (1 \times 0{\cdot}05)$$

$$= h_B - 0{\cdot}125 \text{ m of water} \quad ...(ii)$$

Since the pressures in both the limbs below Z–Z are equal, therefore equating (*i*) and (*ii*),

$$1{\cdot}3 = h_B - 0{\cdot}125$$

or $$h_B = 1{\cdot}3 + 0{\cdot}125 = 1{\cdot}425 \text{ m of water}$$

and pressure in the pipe B,

$$p_B = w.h_B = 9{\cdot}81 \times 1{\cdot}425 = 13{\cdot}98 \text{ kN/m}^2 = 13{\cdot}98 \text{ kPa} \quad \textbf{Ans.}$$

2·15 Mechanical Gauges

Whenever a very high fluid pressure is to be measured, a mechanical gauge is best suited for the purpose. A mechanical gauge is also used for the measurement of pressure in boilers or other pipes, where tube gauges cannot be conveniently used.

There are many types of gauges available in the market. But the principle, on which all these gauges work, is almost the same. Following three types of gauges are important from the subject point of view :

1. Bourdon's tube pressure gauge,
2. Diaphragm pressure gauge, and
3. Dead weight pressure gauge.

2·16 Bourdon's Tube Pressure Gauge

The pressure, above or below the atmospheric pressure, may be easily measured with the help of a Bourdon's tube pressure gauge. A Bourdon's tube pressure gauge, in its simplest form, consists of an elliptical tube *ABC* ; bent into an arc of a circle as shown in Fig. 2·23. This bent-up tube is called Bourdon's tube.

When the gauge tube is connected to the fluid (whose pressure is required to be found out) at *C*, the fluid under pressure flows into the tube. The Bourdon's tube, as a result of the increased pressure, tends to straighten itself. Since the tube is encased in a circular cover, therefore it tends to become circular instead of straight. With the help of a simple pinion and sector arrangement, the elastic deformation of the Bourdon's tube rotates the pointer. This pointer moves over a calibrated scale, which directly gives the pressure as shown in Fig. 2·23.

Note : A Bourdon's tube pressure gauge is generally used for measuring high pressures.

2·17 Diaphgram Pressure Gauge

The Pressure, above or below the atmospheric pressure, is also found out with the help of diaphragm pressure gauge. A diaphragm pressure gauge, in its simplest form, consists of a corrugated diaphragm (instead of Bourdon's tube as in Art. 2·16) as shown in Fig. 2·24.

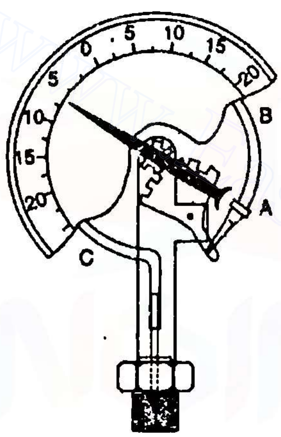


Fig. 2·23. Bourdon's tube pressure gauge.

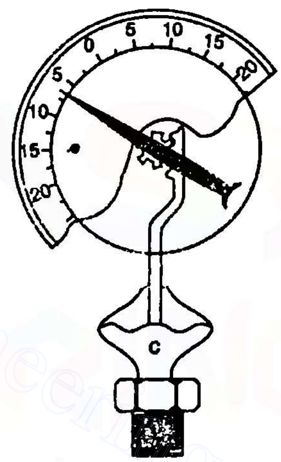


Fig. 2·24. Diaphragm pressure gauge.

When the gauge is connected to the fluid (whose pressure is required to be found out) at *C*, the fluid under pressure causes some deformation of the diaphragm. With the help of some pinion arrangement, the elastic deformation of the diaphragm rotates the pointer. This pointer moves over a calibrated scale, which directly gives the pressure as shown in Fig. 2·24.

A diaphragm pressure gauge is, generally, used to measure relatively low pressures.

2·18 Dead Weight Pressure Gauge

It is the most accurate pressure gauge, which is generally used for the calibration of the other pressure gauges in a laboratory. A dead weight pressure gauge, in its simplest form, consists of a piston and a cylinder of known area, which is connected to a fluid through a tube as shown in Fig. 2·25.

The pressure on the fluid, in the pipe, is calculated from the relation,

$$p = \frac{\text{Weight}}{\text{Area of the piston}}$$

A pressure gauge, to be calibrated, is fitted on the other end of the tube as shown in Fig. 2·25. By changing the weight, on the piston, the pressure on the fluid is calculated and marked on the gauge at the respective points, indicated by the pointer. A small error due to frictional resistance to the motion of the piston may come into play. But the same may be avoided by taking adequate precautions.

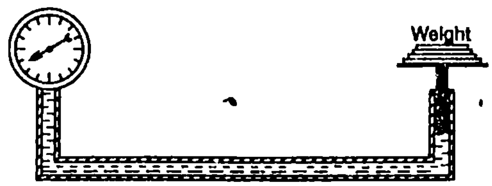


Fig. 2·25. Dead weight pressure gauge.

Example 2·14. *A closed tank fitted with a gauge and a manometer contains water as shown in Fig. 2·26.*

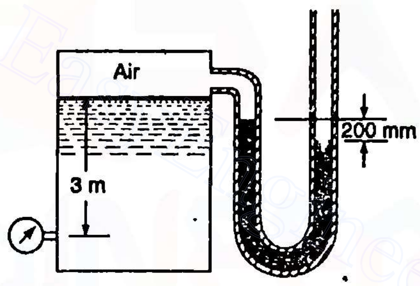


Fig. 2·26.

Find the gauge reading if the manometer, containing mercury, shows a reading of 200 mm.

Solution. Given : Manometer reading = 200 mm = 0·2 m.

Since the space above the water in the tank is full of air, therefore pressure of the air will be the same as that obtained from the manometer reading. Moreover, as the heavy liquid level in the right limb is below the liquid level in the left limb, therefore there is a negative pressure of the air.

We know that pressure of air in terms of head of water

$$= -0{\cdot}2 \times 13{\cdot}6 = -2{\cdot}72 \text{ m}$$

Minus sign has been used for negative pressure in the tank. It has been done as the surface of heavy liquid in the right limb is lower than that in the left limb.

Now the gauge reading will be the pressure of air plus pressure due to water under a head of 3 m. Therefore gauge reading in terms of head of water,

$$h = -2{\cdot}72 + 3{\cdot}0 = 0{\cdot}28 \text{ m}$$

and gauge reading, $= wh = 9{\cdot}81 \times 0{\cdot}28 = 2{\cdot}75 \text{ kN/m}^2 = 2{\cdot}75 \text{ kPa}$ **Ans.**

Example 2 15. *A closed vessel is divided into two compartments. These compartments contain oil and wa er as shown in Fig. 2·27.*

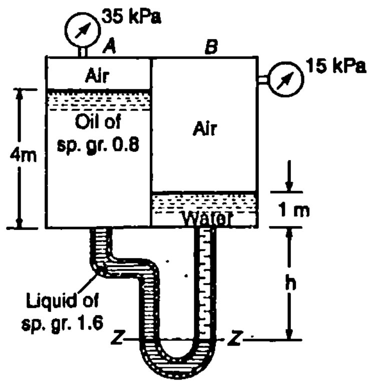


Fig. 2·27.

Determine the value of h, if the gauges show the readings as shown in the figure.

Solution. Given : Gauge reading in A = 35 kPa and gauge reading in B = 15 kPa.

Since the space above the oil in tank A and above water in tank B is full of air, therefore the pressure of the air will be the same as obtained from the gauge readings. Moreover, as the level of liquid of sp. gr. 1·6 in the right limb is below the liquid level in the left limb, therefore there is a negative pressure in the tank A. We know that the gauge reading at A in terms iof head of water,

$$h_A = -\frac{35}{w} = -\frac{35}{9 \cdot 81} = -3 \cdot 57 \text{ m of water}$$

Similarly, gauge reading at B in terms of head of water,

$$h_B = +\frac{15}{w} = \frac{15}{9 \cdot 81} = 1 \cdot 53 \text{ m of water}$$

From the geometry of the figure, we find that the pressure in the left limb above the datum line Z–Z

$$= -3 \cdot 57 + (4 \times 0 \cdot 8) + h \times 1 \cdot 6 \quad \text{m of water}$$

$$= 1 \cdot 6h - 0 \cdot 37 \quad \text{m of water} \qquad ...(i)$$

and pressure in the right limb above the datum line Z–Z

$$= 1 \cdot 53 + (1 \times 1) + h \times 1 \text{ m of water}$$

$$= h + 2 \cdot 53 \text{ m of water} \qquad ...(ii)$$

Since pressures in both the limbs above the Z–Z datum are equal, therefore equating (*i*) and (*ii*),

$$1 \cdot 6h - 0 \cdot 37 = h + 2 \cdot 53 \quad \text{or} \quad 0 \cdot 6h = 2 \cdot 53 + 0 \cdot 37 = 2 \cdot 9$$

$$\therefore \quad h = 2 \cdot 9/0 \cdot 6 = 4 \cdot 83 \text{ m} \quad \textbf{Ans.}$$

Example 2·16. *A container with fluids, vacuum gauge, piezometers and manometer as shown in Fig. 2·8 is to be used in an experiment.*

Find the elevation of liquids in columns E and F and deflection of mercury in U-tube. Gauge reading in A = – 20·6 kPa.

Solution. Given : Gauge reading = – 20·6 kPa.

Elevation of liquid in column E

We know that pressure head due to gauge reading

$$= -\frac{20 \cdot 6}{9 \cdot 81} = -2 \cdot 1 = 2 \cdot 1 \text{ m (vacuum) of water}$$

Since the space above the elevation 20·7 m is full of air, therefore the pressure at elevation 20·7 will be the same as that of the gauge. The pressure in the column E will be the same as the bottom of the oil. *i.e.*, at elevation 17·4 m.

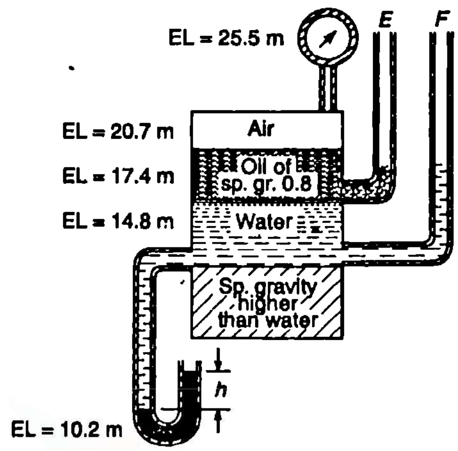


Fig. 2·28.

∴ Pressure at elevation 17·4 m

= Pressure at elevation 20·7 m

+ Weight of oil between 20·7 m and 17·4 m

$= -2 \cdot 1 + (20 \cdot 7 - 17 \cdot 4) \times 0 \cdot 7 = 0 \cdot 21$ m of water

$= 0 \cdot 21 / 0 \cdot 7 = 0 \cdot 3$ m of oil

and elevation of oil in column E $= 17 \cdot 4 + 0 \cdot 3 = 17 \cdot 7$ m **Ans.**

Elevation of liquid in column F

From the geometry of the figure, we find that the pressure at elevation 14·8 m

= Weight of water between 17·4 m and 14·8 m

+ Pressure at elevation 17·4

$= 0 \cdot 21 + (17 \cdot 4 - 14 \cdot 8) = 2 \cdot 81$ m of water

∴ Elevation of water in column F

$= 14 \cdot 8 + 2 \cdot 81 = 17 \cdot 61$ m **Ans.**

Deflection of mercury in U-tube

Let h = Deflection of mercury in U-tube.

Now let us consider the datum line at elevation 10·2 m. We know that the pressure head in the left limb above the datum line

= Pressure at elevation 14·8 m

+ Weight of water between 14·8 m and 10·2 m

$= 2 \cdot 81 + (14 \cdot 8 - 10 \cdot 2) = 7 \cdot 41$ m of water ...(*i*)

and pressure head in the right limb above the common surface

$= h$ m of mercury $= h \times 13 \cdot 6$ m of water ...(*ii*)

Since pressure heads in both the limbs above the elevation 10·2 m are equal, therefore equating (*i*) and (*ii*),

$7 \cdot 41 = 13 \cdot 6h$ or $h = 7 \cdot 41 / 13 \cdot 6 = 0 \cdot 545$ m = 545 mm **Ans.**

EXERCISE 2·3

1. A differential manometer was connected with two points at the same level in a pipe containing liquid of specific gravity 0·85 as shown in Fig. 2·29. Find the difference of pressures at the two points, if the difference of mercury levels be 150 mm [**Ans.** 18·5 kPa]

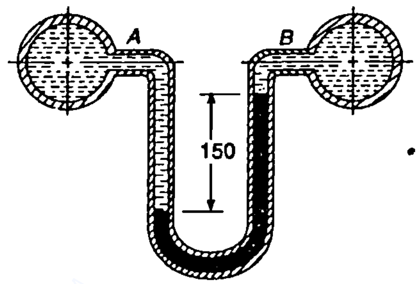


Fig. 2·29.

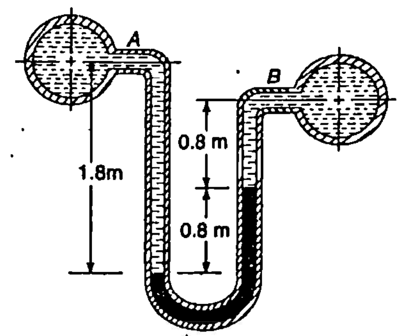


Fig. 2·30

2. A differential manometer containing mercury was used to measure the difference of pressures in two pipes containing water as shown in Fig. 2·30. Find the difference of pressures in the pipes, if the manometer reading is 0·8 m. [**Ans.** 9·88 m]
3. A differential manometer is connected to two pipes as shown in Fig. 2·31. The pipe *A* is containing water and the pipe *B* is containing an oil of specific gravity 0·8. Find the difference of mercury levels, the pressure difference in the two pipes be 80 kPa. [**Ans.** 426 mm]

   [**Hint :** Pressure in the pipe *B* is more than that in pipe *A*.]
4. An inverted differential manometer containing an oil of sp. gr. 0·8 is connected to find the difference

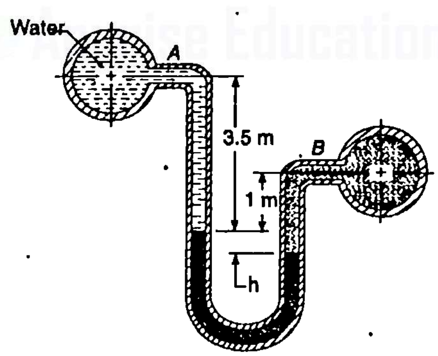


Fig. 2·31.

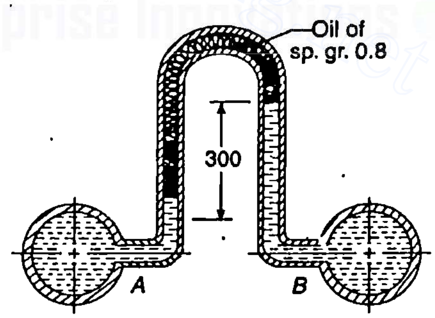


Fig. 2·32.

of pressures at two points of a pipe containing water as shown in Fig. 2·32. Find the difference of pressures, if the manometer reading be 300 mm. [**Ans.** 60 mm of water]

5. With the manometer reading as shown in Fig. 2·33, calculate the difference of pressures in the two tubes *A* and *B* containing water. [**Ans.** 9·07 kPa]

6. An inverted differential manometer, when connected to two pipes A and B, gives the readings as shown in Fig. 2·34. Determine the pressure in the tube B, if the pressure in the pipe A be 50 kPa.

[**Ans.** 47·74 kPa]

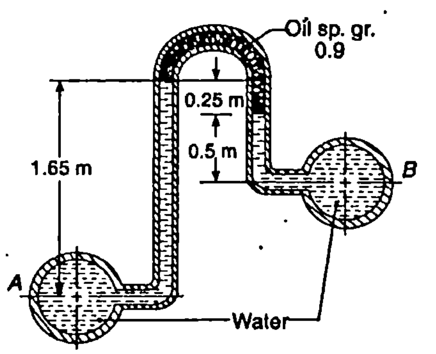


Fig. 2·33.

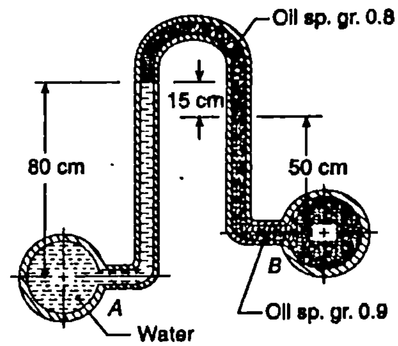


Fig. 2·34.

7. The compartments of the two tanks are closed and filled as shown in Fig. 2·35.
Find the value of h, if the pressure in the left hand tank air is 0·2 m of mercury. [**Ans.** 5·2 m]
[**Hint :** Pressure in the left hand tank above Z–Z datum

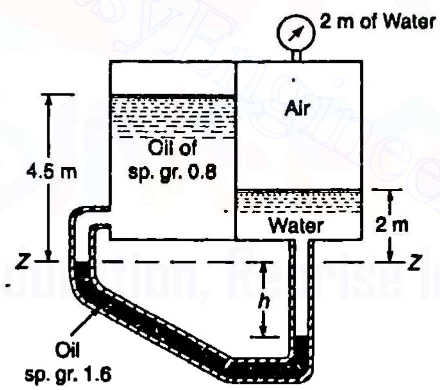


Fig. 2·35.

$$= (-0{\cdot}2 \times 13{\cdot}6) + (0{\cdot}8 \times 4{\cdot}5) + 1{\cdot}6 \times h \text{ m of water} \quad ...(i)$$

and pressure in the right hand tank

$$= 2 + 2 + 1 \times h = h + 4 \text{ m of water} \quad ...(ii)$$

Equating equations (i) and (ii),

$$h = 5{\cdot}2 \text{ m}$$

QUESTIONS

1. What do you understand by the term intensity of pressure ? State its units.
2. What is meant by pressure head ? Derive an expression for it.
3. State and prove Pascal's Law.
4. Distinguish between gauge pressure and absolute pressure.
5. State the different principles of measurement of pressure.

6. Distinguish between piezometer and pressure gauge. When and where are they used ?

7. Describe the different types of manometers.

8. Distinguish between a simple manometer and a differential manometer.

9. What are inclined manometers ? For what purpose are they used in the laboratory ?

10. What are mechanical gauges ? In what circumstance they are used ?

11. Write short notes on :

(*a*) Bourdon's tube pressure gauge.

(*b*) Diaphragm pressure gauge.

(*c*) Dead weight pressure gauge.

OBJECTIVE TYPE QUESTIONS

1. The numerical value of 1 Pa of pressure is equal to

(*a*) 1 N/m^2 (*b*) 1 kN/m^2 (*c*) 1 MN/m^2 (*d*) none of these

2. The absolute pressure is equal to

(*a*) Gauge pressure – Atmospheric pressure

(*b*) Gauge pressure + Vacuum pressure

(*c*) Atmospheric pressure + Gauge pressure

(*d*) Atmospheric pressure – Gauge pressure

3. The pressure measured with the help of a piezometer tube is

(*a*) atmospheric pressure (*b*) gauge pressure

(*c*) absolute pressure (*d*) vacuum pressure

4. A manometer is used to measure

(*a*) positive pressure (*b*) negative pressure

(*c*) atomspheric pressure (*d*) both '*a*' and '*b*'

5. The liquid used in an inverted differential manometer should be of

(*a*) low density (*b*) high density

(*c*) low surface tension (*d*) high surface tension

ANSWERS

1. (*a*) 2. (*c*) 3. (*b*) 4. (*d*) 5. (*a*)