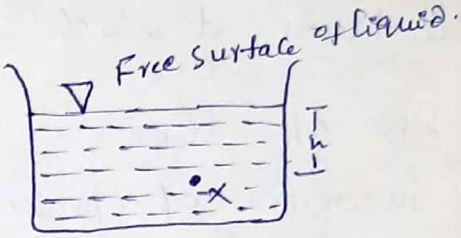
UNIT – III

MEASUREMENT OF FLUIDFLOWS

Pressure :-

When a fluid is contained in a vessel, it exerts force at all points on the sides and bottom of container. The force per unitarea is called pressure.

Pressure Head of a liquid :-



Consider a vessel containing a liquid as shown in fig.

Let ρ be mass density of liquid in kg/m^3

let h be the height of liquid above area at x in m

w be the spec weight of liquid in N/m^2

Let the area at x be A

mass of liquid above the $x = \rho \times area \times height$

$$m = \rho A h$$

Net force on area $= mg = \rho g h A$

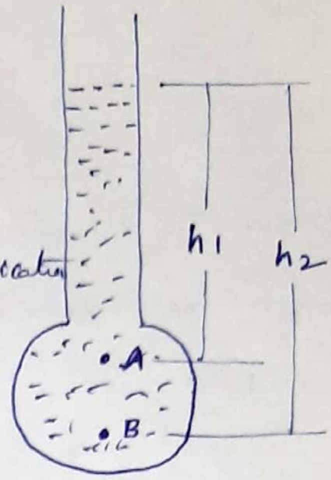
$$\text{pressure at } x = \frac{Force}{Area} = \frac{\rho g h A}{A} = \rho g h$$

$$P_x = \rho g h \Rightarrow h = \frac{P}{\rho g} = \text{Pressure head}.$$

→ Pr at any point in a body of liquid at rest is proportional to the depth of the point below the free surface of liquid, and increases in the downward direction at a rate equivalent to the density of fluid.

Measurement of pressure :-

① Piezometer :-



It is vertical transparent glass tube, the upper end of which is open to atmoshphere and lower end is incommunicating with gauge point; a point in the fluid container at which pr. is to be measured.

Rise of fluid in the tube above certain gauge point is a measure of pressure at that point.

Fluid pr at point A = Atmoshpheric pr at free surface + pressure due to a liquid column of height h_1

$$P_1 = P_a + wh_1$$ w = Spec. Gravity of liquid

at B, $P_2 = P_a + wh_2$

→ Pressures are generally prescribed with atmoshpheric pr taken as the zero pressure scale: $P_1 = wh_1$ & $P_2 = wh_2$

→ When using piezometer to measure the pr. of moving fluid, axis of tube should be absolutely normal to the direction of flow.

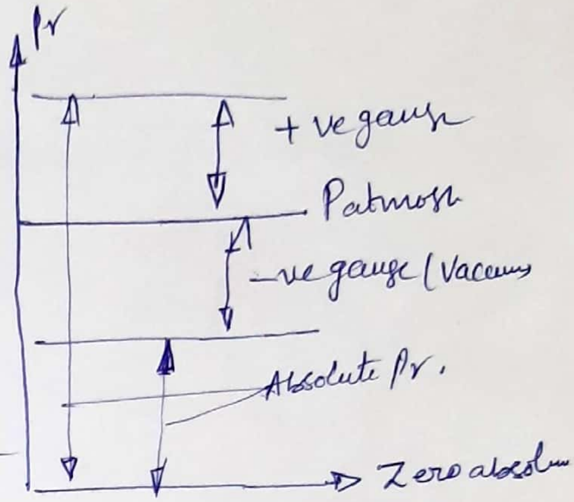
→ Piezometers cannot be used to measure pressures which are considerably excess of atmoshpheric pr.

→ Measurement of (−ve pr) Vacuum pr is not possible.

Pascals law:-

The intensity of pr at any point in liquid at rest is same in all direction.

Relation ship b/w Pressures:-



1) **Atmosphere pr:-**

The pr. exerted by air due to its weight on the surface of earth or any liquid is called atmospheric pressure.

Its value is 10.3 m of water or 10 N/cm^2
760 mm of Hg.

2) **Gauge pressure:-**

It is the Pr, measured with the help of pr. measuring instrument, in which atmospheric pr is taken as datum. The atmospheric pr on the scale is marked as zero.

It is either above or below atmospheric pr.

below atmospheric negative or gauge Vaccume pressure.

3) **Absolute pr:-**

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

Pressures are generally prescribed with atmospheric pressure taken as the zero of pressure scale. Evidently, then $p_1 = wh_1$ and $p_2 = wh_2$ and the pressures thus evaluated are the ***gauge pressures***.

When using a piezometer to measure the pressure of a moving fluid, axis of the tube should be absolutely normal to the direction of flow and its bottom end must flush smoothly with the pipe surface. Any burr or projection would cause obstruction resulting in change in the pressure head. Further, to reduce the surface tension and capillary effects, diameter of the tube must be kept at least 6 mm.

Piezometers cannot be used to measure pressures which are considerably excess of atmospheric pressure. Use of very long glass tube would be unsafe, it being both fragile and unmanageable. Further, gas pressure cannot be measured as gas does not form any free surface with atmosphere. Again measurement of negative pressure is not possible due to flow of atmospheric air into the container through the tube. These difficulties are overcome by modifying the piezometer into a U-tube manometer, also called the double column manometer.

EXAMPLE 14.3

Explain the use of a piezometer to measure the intensity of pressure in a liquid.

A closed vessel contains a liquid of mass density 1000 kg/m^3 and a piezometer tube communicates with the vessel at depth 1.5 m under the free surface. Presuming that absolute pressure on the free liquid surface is 2.5 × 10^5 N/m^2 and atmospheric pressure is 1.0135 × 10^5 N/m^2, make calculations for the height to which the liquid will rise in the piezometer.

Solution : Refer Fig. 14.10.

Write manometric equation for the point A where the piezometer communicates with the vessel

$$p + wh = p_a + wH$$

∴ Required height H is :

$$H = \frac{p + wh - p_a}{w}$$

$$= \frac{2.5 \times 10^5 + 9910 \times 1.5 - 1.0135 \times 10^5}{9810}$$

= **16.65 m**

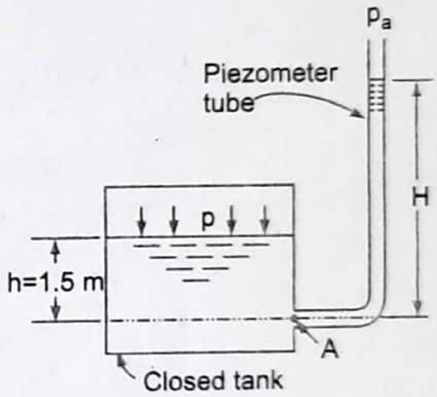


Fig. 14.10. Piezometer tube

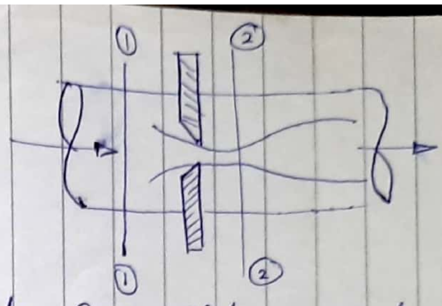
$$V_{2a} = C_v \sqrt{2gh + \left[C_c \frac{a_0}{a_1} V_{2a}\right]^2}$$

$$V_{2a} = \frac{C_v \sqrt{2gh}}{\sqrt{1 - C_v^2 C_c^2 \left(\frac{a_0}{a_1}\right)^2}}$$

$$Q_{act} = C_c a_0 V_{2a}$$

$$Q_{act} = \frac{C_c C_v a_0 \sqrt{2gh}}{\sqrt{1 - (C_c C_v)^2 \left(\frac{a_0}{a_1}\right)^2}}$$

$$Q_{act} = \frac{C_d a_0 a_1 \sqrt{2gh}}{\sqrt{a_1^2 - a_0^2}}$$



Apply Bernoulli's equ b/w ① & ②

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

$$\frac{P_1 - P_2}{\rho g} = \frac{V_2^2 - V_1^2}{2g} \Rightarrow h = \frac{V_2^2 - V_1^2}{2g} \rightarrow ①$$

$$C_c = \frac{a_2}{a_0} \quad \& \quad C_v = \frac{V_{2act}}{V_{2th}}$$

$$V_{2th} = \sqrt{V_1^2 + 2gh} \rightarrow ②$$

$$V_{2act} = C_v \cdot V_{2th} = C_v \sqrt{V_1^2 + 2gh}$$

from continuity equ

$$Q_{act} = a_1 V_{1a} = a_2 V_{2a} \Rightarrow$$

$$Q_{act} = C_c a_0 V_{2a} = a_1 V_{1a}$$

$$V_1 = \frac{C_c a_0 V_{2a}}{a_1} \rightarrow ③$$

③ in ②

$$V_{2th} = \sqrt{\left(\frac{C_c a_0 V_{2a}}{a_1}\right)^2 + 2gh} \rightarrow ④$$

$$V_{2a} = C_v \cdot V_{2th}$$

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∴ Height of liquid surface in piezometer

14.4.2. U-Tube Double Column Manometer

This simplest and useful pressure measure device consists of a transparent tube bent in the form of letter U and filled with a manometric liquid whose density is known. The choice of a particular manometric liquid depends upon the pressure range and nature of the fluid whose pressure is sought. For high ranges, mercury (specific gravity 13.6) is the manometric/balancing liquid. For low pressure ranges, liquid like carbon tetrachloride (specific gravity 1.59) or acetylene tetrabromide (specific gravity 2.59) are employed. Quite often, some colors are added to the balancing liquid so as to get clear readings.

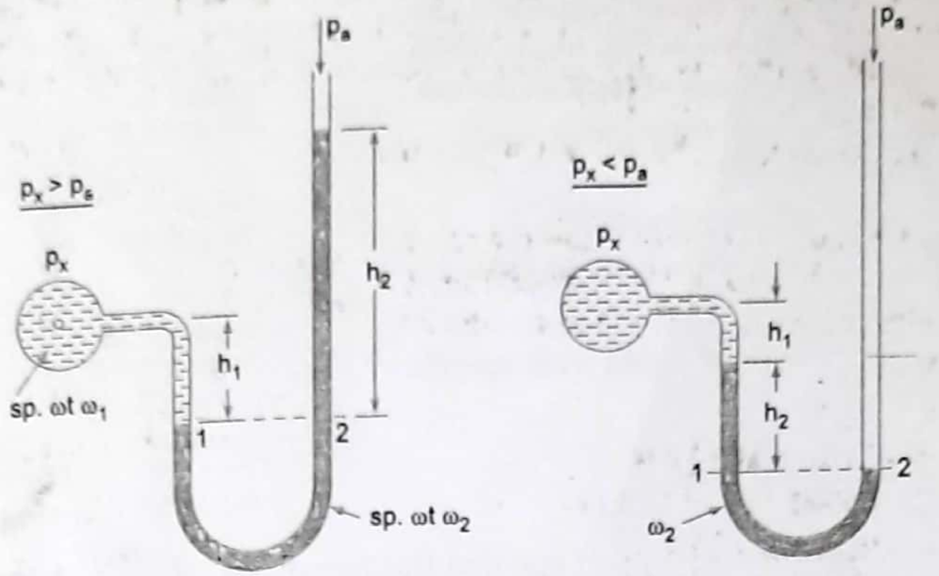

Fig. 14.12 U-tube manometers

When both the limbs are open to atmosphere, manometric liquid stands at even height. nder application of pressure p_x to one limb, manometric liquid is forced downward on the side ith a corresponding rise on the other side until the column of liquid between the two levels alances the difference between the unknown pressure p_x and the atmospheric pressure p_a. igure 14.12 shows the schematics of U-tube being employed for measurement of positive and egative pressures.

Arrangement (*a*) *Measurement of pressure greater than atmospheric pressure*

Due to greater pressure p_x in the container, the manometric liquid is forced downward in the left limb of the U-tube and there is a corresponding rise of manometric liquid in the right limb.

For the right limb the gauge pressure at point 2 is

p_2 = atmospheric pressure *i.e.*, zero gauge pressure at the free surface + pressure due to head h_2 of manometric liquid of specific weight w_2

$$= 0 + w_2 h_2$$

For the left limb, the gauge pressure at point 1 is

p_1 = gauge pressure p_x + pressure due to height h_1 of the liquid of specific weight w_1

$$= p_x + w_1 h_1$$

Points 1 and 2 are at the same horizontal plane ; $p_1 = p_2$ and therefore

$$p_x + w_1 h_1 = w_2 h_2$$

∴ Gauge pressure in the container ,

$$p_x = w_2 h_1 - w_1 h_1 \qquad ...(14.6a)$$

or in terms of head of water column,

$$\frac{p_x}{w} = \left(\frac{w_2}{w} h_2 - \frac{w_1}{w} h_1\right) = (s_2 h_2 - s_1 h_1) \qquad ..(14.6b)$$

where w is the specific weight of water and symbol s denotes the specific gravity of a liquid.

Arrangement (*b*) *Measurement of pressure less than atmospheric pressure*

Due to negative pressure p_x in the container, the manometric liquid is sucked upwards in the left limb of the U-tube and there is a corresponding fall of manometric liquid in the right limb.

Pressure in the two legs at the same levels 1 and 2 are equal; $p_1 = p_2$ and therefore,

$$p_x + w_1 h_1 + w_2 h_2 = 0$$

∴ Gauge pressure in the container,

$$p_x = -(w_1 h_1 + w_2 h_2) \quad ...(14.7a)$$

or in terms of head of water column,

$$\frac{p_x}{w} = -(s_1 h_1 + s_2 h_2) \quad ...(14.7b)$$

U-tube manometer necessitates two readings, h_1 and h_2 and that is likely to increase the chance of error. The difficulty is circumvented by adopting a single column manometer.

EXAMPLE 14.6

One end of a U-tube manometer is connected to a piezometer opening in an air duct and the other end is left open to atmosphere. The manometer has mercury as the balancing liquid. If the mercury level in the manometer on the duct side stands 0.2 m higher than that on the open end, calculate the absolute pressure of air inside the duct. Take atmospheric pressure $p_a = 10 \times 10^4$ N/m².

Solution : Refer Fig. 14.13. Let p_x be the gauge pressure in the air duct.

Neglecting the pressure exerted by the air column above mercury in the left limb of the manometer, the governing manometric equation for the points 1 and 2 is :

$$p_x + w_m h = 0$$

$$p_x = -w_m h$$
$$= -(9810 \times 13.6) \times 0.2$$
$$= -26683.2 \text{ N/m}^2 \text{ (gauge)}$$
$$= -26683.2 + 10 \times 10^4$$
$$= \mathbf{73316.8 \text{ N/m}^2 \text{ (absolute)}}$$

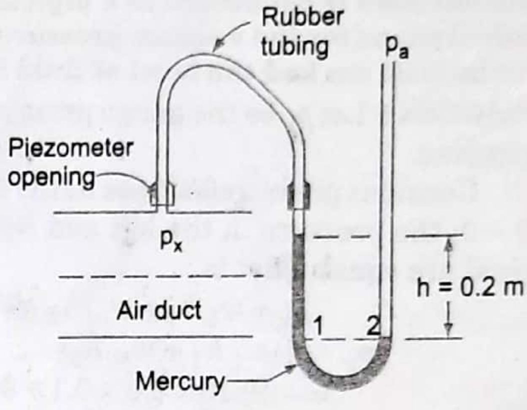

Fig. 14.13.

EXAMPLE 14.7

The right limb of a U-tube manometer containing mercury is open to the atmosphere while the left limb is connected to a pipe through which flows a fluid of specific gravity 0.85. The centre of the pipe lies 15 cm below the level of mercury in the right limb. If the difference of mercury level in the two limbs is 25 cm, determine the pressure of fluid of the pipe.

Solution : Let p_x be the gauge pressure of the fluid in the pipeline.

Consider pressure balance in the horizontal plane 0 – 0; the pressure in the left and right limbs at this plane are equal. That is :

$$p_x + w_1 h_1 = w_m h_2$$

or

$$p_x = w_m h_2 + w_1 h_1$$
$$= (9810 \times 13.6) \times 0.25 - (9810 \times 0.85) \times 0.1$$
$$= 33354 - 833.85$$
$$\approx \mathbf{32520 \text{ N/m}^2}$$

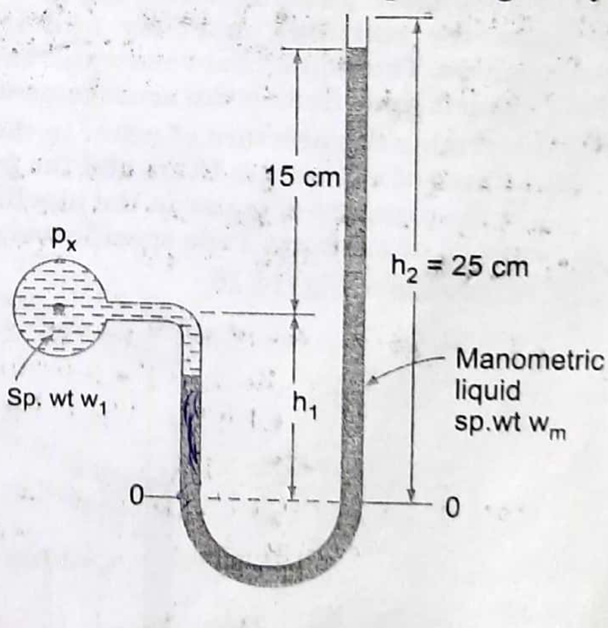

Fig. 14.14.

EXAMPLE 14.8

The right limb of a simple U-tube manometer containing mercury is open to atmosphere and the left limb is connected to a pipe through which flows a fluid of specific gravity 0.8. Make calculations for the vacuum pressure in the pipe if the difference of mercury level in the two limbs is 30 cm and the level of fluid in the left limb is 10 cm below the centre of pipe.

Solution : Let p_x be the gauge pressure of fluid in the pipeline.

Consider pressure balance in the horizontal plane 0 – 0; the pressure in the left and right limbs at this level are equal. That is :

$$p_x + w_1 h_1 + w_m h_2 = 0$$

$$p_x = -(w_1 h_1 + w_m h_2)$$

$$= -(9810 \times 0.8 \times 0.1 + 9810 \times 13.6 \times 0.3)$$

$$= -(784.8 + 40024.8) = \mathbf{-40809.6\ N/m^2}$$

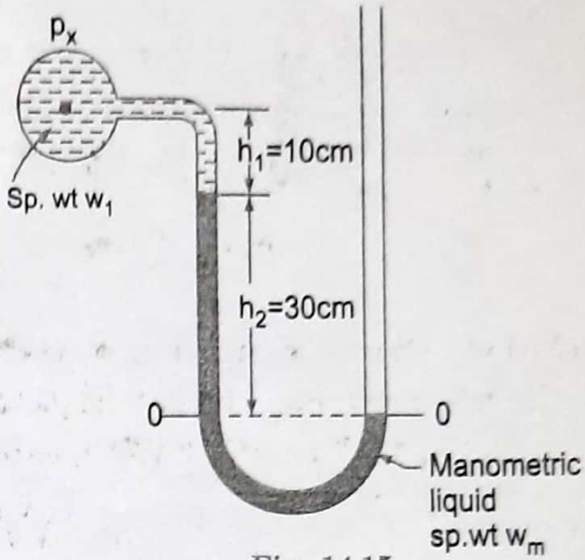

Fig. 14.15.

EXAMPLE 14.9

A U-tube manometer has been employed to measure the pressure of water in a pipeline which is in excess of atmospheric pressure. The right limb of the manometer contains mercury and is open to atmosphere. The contact between water and mercury is in the left limb. Sketch the arrangement and explain its working.

Determine the pressure of water in the mainline if the difference in the level of mercury in the limbs of a U-tube is 10 cm and the free surface of mercury is in level with the centre of pipe. If the pressure of water in the pipeline reduce to 10 kN/m², calculate the new difference in the level of mercury. Take specific weight of water as 10 kN/m³.

Solution : Refer Fig. 14.16.

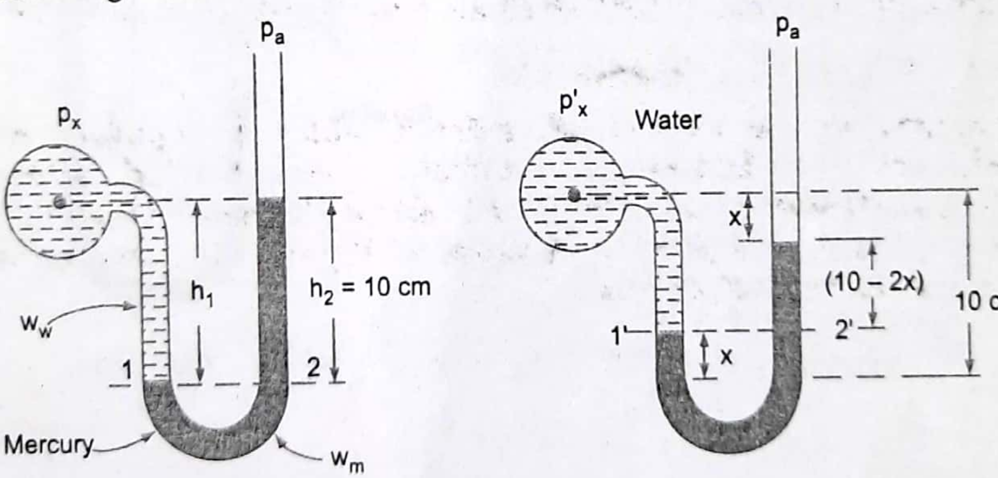

Fig. 14.16.

Let p_x be the gauge pressure of water in the mainline. Governing manometric equation for the points 1 and 2 is :

$$p_x + w_w h_1 = w_m h_2$$

where w_w and w_m are the specific weight of the water and mercury respectively. Further $h_1 = h_2 = h$

$$\therefore \qquad p_x = (w_m - w_w) h = (13.6 \times 10 - 10) \times 0.01 = 1.26 \text{ kN/m}^3$$

With reduction in the pressure of water in the mains, mercury level in the left limb will rise by a height x cm with corresponding fall in the right limb. The new manometric equation for points 1′ and 2′ is

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$$p_x + w_w(0.1 - 0.01\,x) = w_x(0.1 - 0.02\,x)$$
$$10 + 10(0.1 - 0.01\,x) = 13.6 \times 10(0.1 - 0.02\,x)$$
$$10 + 1 - 0.1\,x = 13.6 - 2.72\,x\,; \quad x = 0.922 \text{ cm}$$

∴ New difference in mercury level = $10 - 2x = 10 - 2 \times 0.922 =$ **8.156 cm**

EXAMPLE 14.10

Figure 14.17 show a conical vessel having its outlet at A to which a U-tube manometer is connected. The reading of the manometer indicated in the figure pertains to the situation when the vessel is empty, *i.e.*, the water surface is at *A*. Find the reading of the manometer when the vessel is completely filled with water.

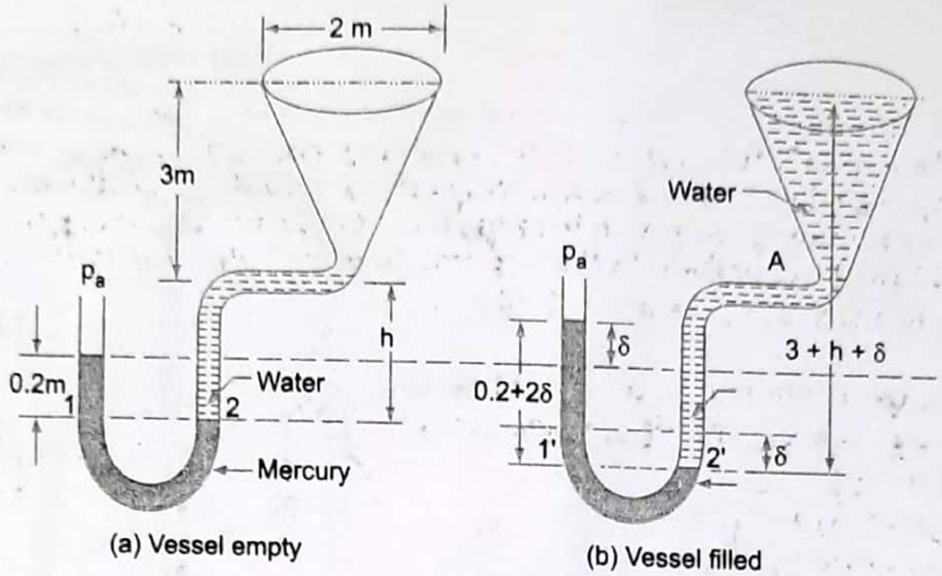


Fig. 14.17.

Solution : *Case (a) When the vessel is empty :*

Equating pressure values at the points 1 and 2 which lie at the same horizontal plane ;

$$p_a + (13.6 \times 9810 \times 0.2) = 9810 \times h + p_a$$

$$\therefore \qquad h = \frac{13.6 \times 9810 \times 0.2}{9810} = 2.72 \text{ m}$$

Case (b) When the vessel in full of water :

Let the mercury level fall by a distance δ in the right limb with a corresponding rise δ in the left limb. Again writing the governing manometric equation for the points 1′ and 2′ :

$$p_a + 13.6 \times 9810 \times (0.2 + 2\delta) = 9810\,(3 + 2.72 + \delta) + p_a$$

Solution gives : $\delta = 0.1145$ m

Hence the manometer reading would be $0.20 + 2 \times 0.1145 = 0.429$ m **42.90 cm**

14.5.3. U-tube Differential Manometer

A differential manometer is a device used to find the difference in pressure between two points in a pipeline or in two different pipes or containers. In general, a differential manometer consists of a U-tube field with a manometric liquid and with its ends connected to the points between which the pressure difference is to be measured. Figure 14.18 shows the two common arrangements of a differential manometer.

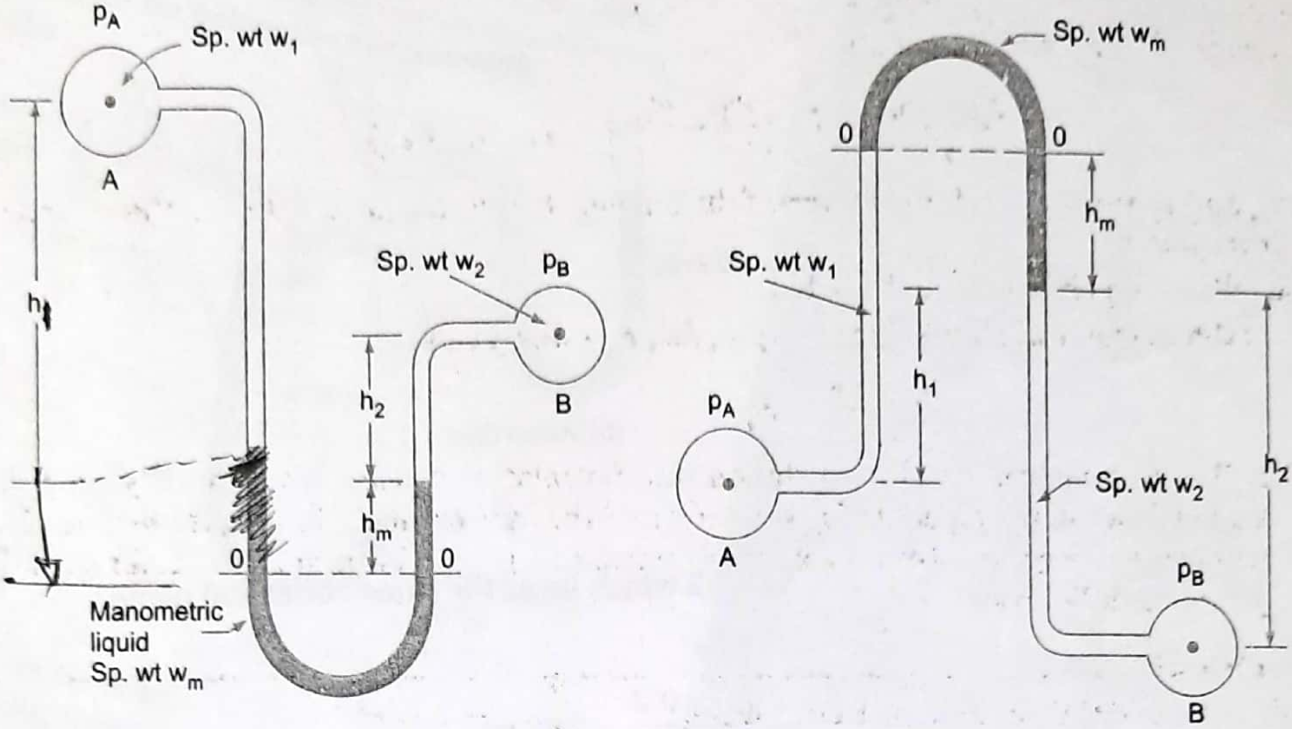


Fig. 14.18.

In the ***upright configuration*** of U-tube differential manometer, the manometric liquid contained in the U-tube is a heavier liquid, *i.e.*, its specific weight w_m is greater than that of the liquids in the containers.

Consider the pressure balance in the horizontal plane 0 – 0; the pressure in the left and right limbs at his plane are equal. That is :

$$p_A + w_1 (h_1 + h_m) = p_B + w_2 h_2 + w_m h_m$$

or

$$p_A - p_B = h_m (w_2 - w_1) + w_2 h_2 - w_1 h_1$$

For the special and frequently encountered case of pipes A and B at the same level ($h_1 = h_2$) and carrying the same fluid ($w_1 = w_2$).

$$p_A - p_B = h_m (w_m - w_1)$$

In terms of head of water column

$$\frac{p_1 - p_2}{w} = h_m \left[\frac{w_m}{w} - \frac{w_1}{w}\right] = h_m (s_m - s_1)$$

If water is the fluid in the two pipes and mercury is the manometric liquid, then $s_1 = 1$ and $s_m = 13.6$ and therefore, for the mercury-water differential manometer,

$$\frac{p_A - p_B}{w} = 12.6\, h_m$$

i.e., the pressure difference measured as a head of water column is 12.6 times the difference in height of mercury column. Sensitivity of such a gauge may be defined as the ratio of the observed difference in levels h_m to the difference of pressure head $\frac{(p_A - p_B)}{w}$ of water being measured.

$$\text{Sensitivity} = \frac{h_m}{\frac{(p_A - p_B)}{w}} = \frac{h_m}{h_m (s_m - 1)} = \frac{1}{s_m - 1}$$

With mercury (relative density 13.6) sensitivity is $\frac{1}{12.6}$ and with paraffin (relative density 0.85) the sensitivity is $-\frac{1}{0.15}$ · Negative sensitivity implies that a paraffin-water differential manometer must be used in the inverted position.

In the ***inverted differential manometer***, the manometric liquid is lighter than the fluid whose pressure difference is to be ascertained.

Consider the pressure balance in the horizontal place 0 – 0; the pressure in the left and right limbs of the inverted U-tube at this place are equal. That is :

$$p_A - w_1 h_1 - w_1 h_m = p_B - w_2 h_2 - w_m h_m$$

or

$$p_A - p_B = w_1 h_1 - w_2 h_2 + h_m (w_1 - w_m)$$

If the pipes A and B are the same level ($h_1 = h_2$) and carry the same fluid ($w_1 = w_2$)

$$p_A - p_B = h_m (w_1 - w_m)$$

In terms of head of water column,

$$\frac{p_A - p_B}{w} = h_m \left(\frac{w_1}{w} - \frac{w_m}{w}\right) = = h_m (s_1 - s_m)$$

where s_m and s_1 are the specific gravities of the manometric liquid and the fluid in the pipelines of the flow system.

The following points need to be noted :

(*i*) If the manometric liquid is very light, *i.e.*, $s_m <<< s_1$, then

$$\frac{p_A - p_B}{w} = h_m$$

(*ii*) If the manometric liquid is so chosen that its relative density is very nearly equal to that of fluids in the pipelines ($s_m \approx s_1$) and that the fluids do not intermix, the manometer will become very sensitive. A sensitive manometer gives a large value of h_m for a small pressure difference.

EXAMPLE 14.11

A U-tube differential manometer containing mercury is connected on one side to pipe A containing carbon tetrachloride (sp. gr. 1.6) under a pressure of 120 kPa, and on the other side to pipe B containing oil (sp. gr. 0.8) under a pressure of 200 kPa. The pipe A lies 2.5 m above pipe B and the mercury level in the limb communicating with pipe A lies 4 m below the pipe A. Determine the difference in the levels of mercury in the two limbs of the manometer. Take specific weight of water = 9.81 kN/m³.

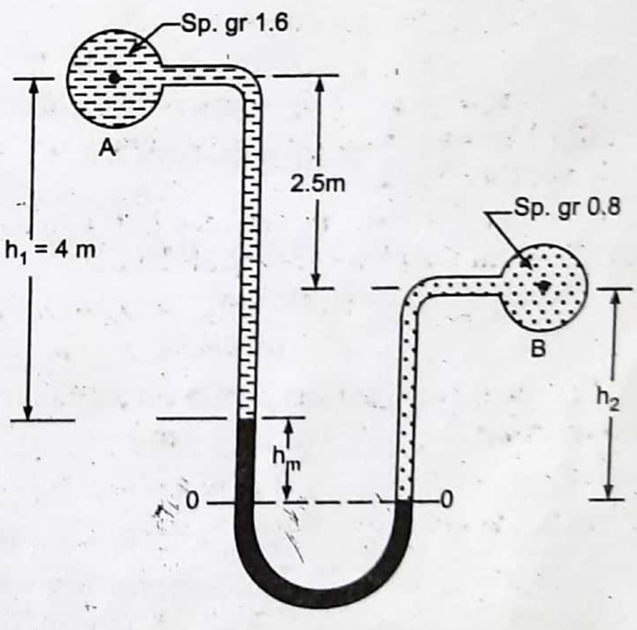


Fig. 14.19.

Solution : Consider pressure balance in the horizontal plane 0 – 0 ; the pressures in the left and right limbs at this plane are equal. That is :

$$p_A + w_c h_1 + w_m h_m = p_B + w_0 h_2$$

$$120 + 9.81 \times 1.6 \times 4 + 9.81 \times 13.6\, h_m$$
$$= 200 + 9.81 \times 0.8\,(1.5 + h_m)$$

$$120 + 62.78 + 133.42\, h_m = 200 + 11.77 + 7.85\, h_m$$

$$h_m = \frac{200 + 11.77 - 120 - 62.78}{133.42 - 7.85}$$

$$= 0.231 \text{ m} = \mathbf{23.1 \text{ cm}}$$

EXAMPLE 14.12

Determine the difference of pressure between pipes A and B when connected to an inverted U-tube differential manometer containing oil of specific gravity 0.8 as the manometric liquid. The pipe A conveys water and a fluid of sp. gr. 0.9 flows through the pipe B. The position of manometric liquid in the manometer limbs is as indicated in Fig. 14.20. If p_B = 5×10^4 N/m² and the barometer reading is 730 mm of mercury, find the pressure in pipe A in metres of water absolute.

Solution : Consider pressure balance in the horizontal plane 0 – 0 ; the pressure in the left and right limbs at this plane are equal. That is :

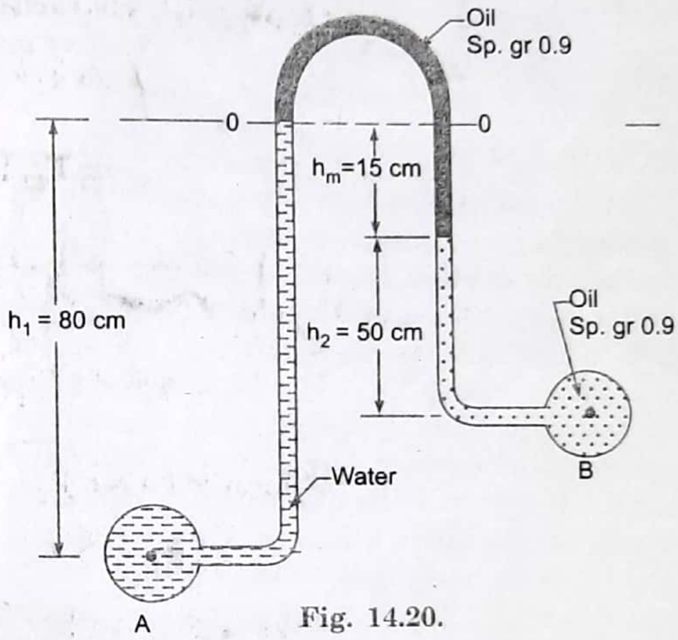


Fig. 14.20.

$$p_A - w_1 h_1 = p_B - w_2 h_2 - w_m h_m$$

$$p_A - 9810 \times 0.8 = p_B - 9810 \times 0.9 \times 0.5 - 9810 \times 0.8 \times 0.15$$

$$p_A - p_B = 9810\,(0.8 - 0.9 \times 0.5 - 0.8 \times 0.15)$$

$$= 9810\,(0.8 - 0.45 - 0.12)$$

$$= 2256 \text{ N/m}^2$$

Given : $p_A = 5 \times 10^4$ N/m²

and $p_{at} = 9810 \times 13.6 \times 0.73$

$= 9.74 \times 10^4$ N/m²

Pressure intensity in pipe *A*

$$p_A = p_B + 2256 = 5 \times 10^4 + 2256 = 52256 \text{ N/m}^2 \text{ (gauge)}$$

Absolute pressure = gauge pressure + atmospheric pressure

$$p_A \text{ (absolute)} = 52256 + 9.74 \times 10^4 = 149656 \text{ N/m}^2$$

$$= \frac{149656}{9810} = \mathbf{15.25 \text{ m of water absolute}}$$

EXAMPLE 14.13

When pressure at a point is so large that the manometric fluid cannot be contained within the height of a single U-tube manometer, use is made of a compound U-tube manometer which essentially consists of a number of simple U-tube manometers arranged in series. For one such unit illustrated in Fig. 14.21, calculate the pressure difference between the points A and B. Take w_w = 10 kN/m³ for water w_m = 136 kN/m³ for mercury and w_0 = 8.5 kN/m³ for oil.

Solution : Starting from point A, the governing manometric equation is :

$$p_A + 10 \times 0.9 - 136 \times 0.6 + 8.5 \times 0.4 - 136 \times 0.5 - 10\,(0.8 - 0.5) = p_B$$

$$p_A - p_B = -9 + 81.6 - 3.4 + 68 + 3 = \mathbf{140.2 \text{ kN/m}^2}$$

$A\delta h = ah_2$, which gives $\delta h = \frac{a}{A} h_2$

For the left limb, the gauge pressure at point 1 is :

$$p_1 = p_x + w_1 h_1 + w_1 \delta h$$

For the right limb, the gauge pressure at point 2 is:

$$p_2 = 0 + w_2 h_2 + w_2 \delta h$$

Points 1 and 2 are at the same horizontal plane ; $p_1 = p_2$ and therefore,

$$p_x + w_1 h_1 + w_1 \delta h = w_2 h_2 + w_2 \delta h$$

∴ Gauge pressure p_x in the container is :

$$p_x = (w_2 h_2 - w_1 h_1) + \delta h (w_2 - w_1)$$

Inserting the value of δh,

$$p_x = (w_2 h_2 - w_1 h_1) + \frac{a}{A} h_2 (w_2 - w_1)$$

$$= w_2 h_2 \left[1 + \frac{a}{A}\right] - w_1 \underline{\left[h_1 + h_2 \left(\frac{a}{A}\right)\right]}$$

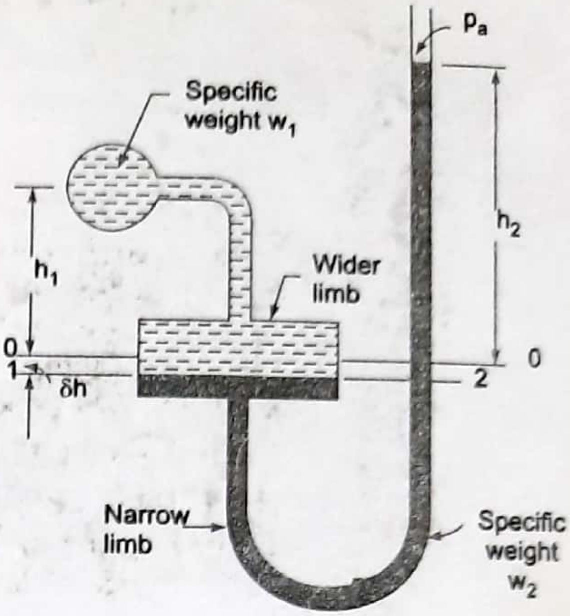


Fig. 14.28.

The underlined term represents pressure due to liquid column in the reservoir and in the pipe connecting the reservoir to the source p_x. If it is neglected then :

$$p_x = w_2 h_2 \left[1 + \frac{a}{A}\right] \quad \text{...(14.8 a)}$$

If the area ratio $\left(\frac{a}{A}\right)$ is made so small that it can be neglected, then

$$p_x = w_2 h_2 \quad \text{...(14.8 b)}$$

When the area ratio $\left(\frac{a}{A}\right)$ is not negligible, the scale may be calibrated in contracted units, *i.e.*, normal length units multiplied by $\left[\frac{A}{A + a}\right]$.

Single column manometers are used as primary standards for calibrating other pressure gauges, and are more sensitive than simple U-tube manometers.

To expand the scale and thereby increase sensitivity, the narrow limb of the single column manometer is not set vertically but is kept inclined to the horizontal axis by an angle θ as shown in Fig. 14.29. Gauge pressure p_x is then given by :

$$p_x = w_2 \times \text{(net change in the liquid level due to change in the pressure)}$$

Let l be the rise of liquid in the inclined tube. Corresponding vertical rise in the tube and fall of liquid in the well are $l \sin\theta$ and $l \left(\frac{a}{A}\right)$ respectively. Net change in the vertical liquid level then becomes equal to $l \left[\sin\theta + \frac{a}{A}\right]$.

$$\therefore \quad p_x = w_2 \, l \left(\sin\theta + \frac{a}{A}\right) \quad \text{...(14.9)}$$

ROTAMETER:

A rotameter consists of a tapered tube, typically made of glass with a 'float' (a shaped weight, made either of anodized aluminum or a ceramic), inside that is pushed up by the drag force of the flow and pulled down by gravity

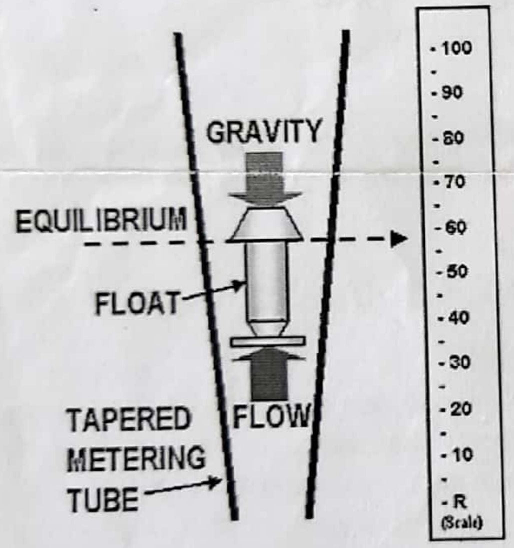
A higher volumetric flow rate through a given area increases flow speed and drag force, so the float will be pushed upwards.

However, as the inside of the rotameter is cone shaped (widens), the area around the float through which the medium flows increases, the flow speed and drag force decrease until there is mechanical equilibrium with the float's weight.

The float may be diagonally grooved so that it rotates axially as the fluid passes.

The "float" must not float in the fluid: it has to have a higher density than the fluid, otherwise it will float to the top even if there is no flow.

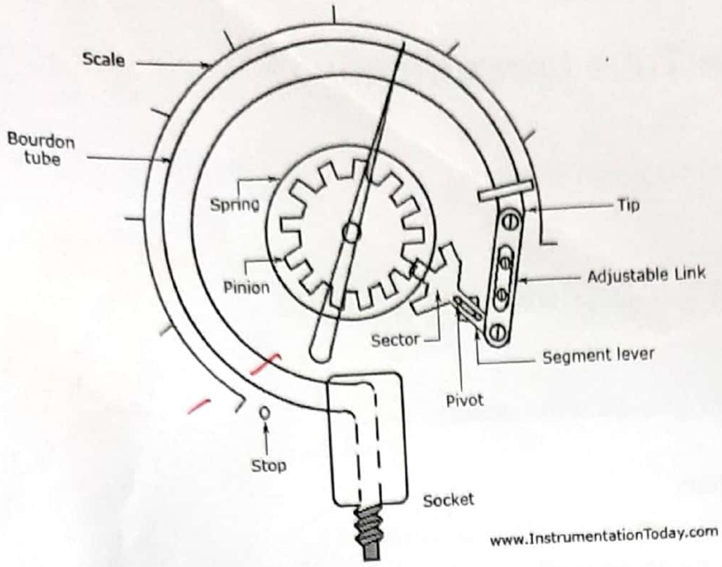
The mechanical nature of the measuring principle provides a flow measurement device that does not require any electrical power.



Hot Wire Anemometer (HWA)

The hot wire anemometer is used to measure fluid velocities by measuring heat loss by convection from a very fine wire which is exposed to the fluid stream. The wire is electrically heated by passing an electrical current through it. When the heated wire is cooled by a fluid stream its electrical resistance decreases, because the resistance of metal wire varies linearly with its temperature.

The material of the hot wire is Tungsten, Platinum or Platinum Rhodium



Bourdon Tube Pressure Gauge

Basic Principle of Bourdon tube pressure gauge:

when an elastic transducer (bourdon tube in this case) is subjected to a pressure, it deflects. This deflection is proportional to the applied pressure when calibrated.

Description of Bourdon tube Pressure Gauge:

The main parts of this instruments are as follows: An elastic transducer, that is bourdon tube which is fixed and open at one end to receive the pressure which is to be measured. The other end of the bourdon tube is free and closed. The cross-section of the bourdon tube is eliptical. The bourdon tube is in a bent form to look like a circular arc. To the free end of the bourdon tube is attached an adjustable link, which is inturn connected to a sector and pinion as shown in diagram. To the shaft of the pinion is connected a pointer which sweeps over a pressure calibrated scale.

Operation of Bourdon tube:

The pressure to be measured is connected to the fixed open end of the bourdon tube. The appilied pressure acts on the inner walls of the bourdon tube. Due to the appilied pressure, the bourdon tube tends to change in cross – section from ellipitcal to circular. This tends to straighten the bourdon tube causing a displacement of the free end of the bourdon tube.

This displacement of the free closed end of the bourdon tube is proportional to the applied pressure. As the free end of the bourdon tube is connected to a link – section – pinion arrangement, the displacement is amplified and converted to a rotary motion of the pinion.

As the pinion rotates, it makes the pointer to assume a new posistion on a pressure calibrated scale to indicate the appilied pressure directly. As the pressure in the case containing the bourdon tube is usually atmospheric, the pointer indicates gauge pressure.

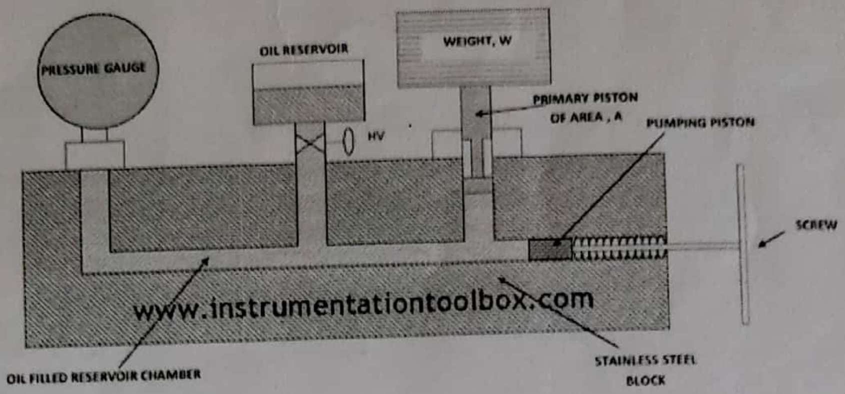
Applications of Bourdon Tube pressure gauge:

They are used to measure medium to very high pressures.

Advantages of Bourdon tube pressure gauge:

These Bourdon tube pressure gauges give accurate results.
Bourdon tube cost low.
Bourdon tube are simple in construction.
They can be modified to give electrical outputs.
They are safe even for high pressure measurement.
Accuracy is high especially at high pressures.

DEAD WEIGHT TESTER:



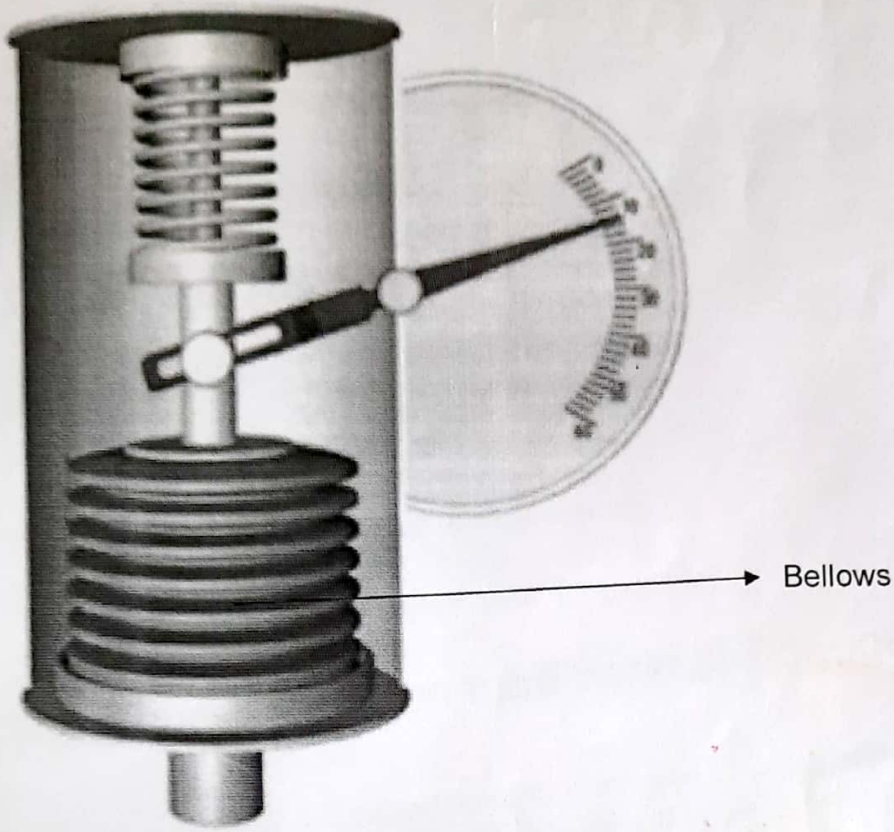
Schematic of Dead Weight Tester

A dead weight tester is a very handy piece of instrument for calibrating a pressure gauge or other pressure transducers in an industrial plant. But how does this device work? Lets find out:

A deadweight tester consists of a pumping piston with a screw that presses it into the reservoir containing a fluid like oil, a primary piston that carries the dead weight, W, and the pressure gauge or transducer to be calibrated as shown in the schematic above. It works by loading the primary piston (of cross sectional area A), with the amount of weight (W) that corresponds to the desired calibration pressure ($P = W/A$). The pumping piston then pressurizes the whole system by pressing more fluid into the reservoir cylinder.

When the screw is turned the increase in fluid pressure is applied to both the gauge and the weights. When the weights start to lift the gauge pressure should be the same as the pressure indicated by the weights. You can calibrate pressure gauges and pressure transducers very accurately if the weights are correct and there is minimum friction between the weight piston and the cylinder.

BELLOWS PRESSURE GAUGE:



The basic way of manufacturing bellows is by fastening together many individual diaphragms. The bellows element, basically, is a one piece expansible, collapsible and axially flexible member. It has many convolutions or fold. It can be manufactured form a single piece of thin metal.

It is the one of the pressure measuring device.

The applied pressure makes the bellows expand. The expansion causes the bellows to get longer. When pressure is removed, the bellows get shorter.

The movement of the bellows will be transmitted by a link connected to a pointer. The pointer indicates the pressure applied to the bellows.

Then $h = y\left[\frac{S_{hl}}{S_p} - 1\right]$ ...(6.7)

Case. II. *Differential manometer containing a liquid lighter than the liquid flowing through the pipe.*

Let, S_{ll} = sp. gravity of lighter liquid,

S_p = sp. gravity of liquid flowing through pipe, and

y = difference of lighter liquid column in *U*-tube.

Then, $h = y\left[1 - \frac{S_{ll}}{S_p}\right]$ ...(6.8)

Example 6.28. *A horizontal venturimeter with inlet diameter 200 mm and throat diameter 100 mm is used to measure the flow of water. The pressure at inlet is 0.18 N/mm² and the vacuum pressure at the throat is 280 mm of mercury. Find the rate of flow. The value of C_d may be taken as 0.98.*

Solution. Inlet diameter of venturimeter, D_1 = 200 mm = 0.2 m

∴ Area of inlet, $A_1 = \frac{\pi}{4} \times 0.2^2 = 0.0314 \text{ m}^2$

Throat diameter, D_2 = 100 mm = 0.1 m

∴ Area of throat, $A_2 = \frac{\pi}{4} \times 0.1^2 = 0.00785 \text{ m}^2$

Pressure at inlet, $p_1 = 0.18 \text{ N/mm}^2 = 180 \text{ kN/m}^2$

∴ $\frac{p_1}{w} = \frac{180}{9.81} = 18.3 \text{ m}$

Vacuum pressure at the throat,

$\frac{p_2}{w} = -280$ mm of mercury

$= -0.28$ m of mercury $= -0.28 \times 13.6 = -3.8$ m of water

Co-efficient of discharge, $C_d = 0.98$

∴ Differential head, $h = \frac{p_1}{w} - \frac{p_2}{w} = 18.3 - (-3.8) = 22.1$ m

Rate of flow, Q:

Using the relation,

$$Q = C_d \times \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \times \sqrt{2gh}$$, we have

$$= 0.98 \times \frac{0.0314 \times 0.00785}{\sqrt{(0.031^2 - (0.00785)^2}} \times \sqrt{2 \times 9.81 \times 22.1}$$

$$= \frac{0.000241}{0.0304} \times 20.82$$

or $Q = \mathbf{0.165 \text{ m}^3\text{/s}}$ **(Ans.)**

Example 6.29. *A horizontal venturimeter with inlet diameter 200 mm and throat diameter 100 mm is employed to measure the flow of water. The reading of the differential manometer connected to the inlet is 180 mm of mercury. If the co-efficient of discharge is 0.98 determine the rate of flow.*

Solution. Inlet diameter of venturimeter, D_1 = 200 mm = 0.2 m

∴ Area at inlet $A_1 = \frac{\pi}{4} \times 0.2^2 = 0.0314 \text{ m}^2$

Throat diameter, $D_2 = 100$ mm $= 0.1$ m

∴ Area of throat $A_2 = \frac{\pi}{4} \times 0.1^2 = 0.00785$ m²

Reading of differential manometer, $y = 180$ mm ($= 0.18$ m) of mercury

Co-efficient of discharge, $C_d = 0.98$

Rate of flow, Q:

To find difference of pressure head (h) using the relation,

$$h = \left[\frac{S_{hl}}{S_p} - 1\right], \text{ we have}$$

where, S_{hl} = Sp.gr. of mercury (heavy liquid) = 13.6, and

S_p = Sp. gr. of liquid through the pipe *i.e.*, water = 1

$$h = 0.18\left[\frac{13.6}{1} - 1\right] = 2.268 \text{ m}$$

To find Q, using the relation,

$$Q = C_d \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \times \sqrt{2gh}, \text{ we get}$$

$$Q = 0.98 \times \frac{0.0314 \times 0.00785}{\sqrt{(0.0314)^2 - (0.00785)^2}} \times \sqrt{2 \times 9.81 \times 2.268}$$

or $$Q = \frac{0.000241}{0.0304} \times 6.67 = \mathbf{0.0528\ m^3/s\ (Ans.)}$$

Example 6.30. *A horizontal venturimeter with inlet and throat diameters 300 mm and 100 mm respectively is used to measure the flow of water. The pressure intensity at inlet is 130 kN/m² while the vacuum pressure head at the throat is 350 mm of mercury. Assuming that 3 per cent of head is lost in between the inlet and throat, find:*

(*i*) *The value of C_d (co-efficient of discharge) for the venturimeter, and*

(*ii*) *Rate of flow.*

Solution. Inlet diameter of the venturimeter, $D_1 = 300$ mm $= 0.3$ m

∴ Area at inlet, $A_1 = \frac{\pi}{4} \times 0.3^2 = 0.07$ m²

Throat diameter, $D_2 = 100 = 0.1$

∴ Area of throat, $A_2 = \frac{\pi}{4} \times 0.1^2 = 0.00785$ m²

Pressure at inlet, $p_1 = 130$ kN/m²

∴ Pressure head, $\frac{p_1}{w} = \frac{130}{9.81} = 13.25$ m

Similarly, pressure head at throat,

$$\frac{p_2}{w} = -350 \text{ mm of mercury} = -0.35 \times 13.6 \text{ m of water} = -4.76 \text{ m}$$

(*i*) **Co-efficient of discharge, C_d:**

Differential head, $h = \frac{p_1}{w} - \frac{p_2}{w} = 13.25 - (-4.76) = 18.01$ m

Head lost, $h_f = 3\%$ of $h = \frac{3}{100} \times 18.01 = 0.54$ m

$\therefore$ $$C_d = \sqrt{\frac{h - h_f}{h}} = \sqrt{\frac{18.01 - 0.54}{18.01}} = 0.985$$

(*ii*) **Rate of flow, Q:**

Using the relation,

$$Q = C_d \times \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \times \sqrt{2gh}\text{ , we have}$$

$$Q = 0.985 \times \frac{0.07 \times 0.00785}{\sqrt{0.07^2 - 0.00785^2}} \times \sqrt{2 \times 9.81 \times 18.01}$$

$$= \frac{0.000541}{0.0956} \times 18.79 = \mathbf{0.146\ m^3/s\ (Ans.)}$$

Example 6.31. *A venturimeter (throat diameter = 10.5 cm) is fitted to a water pipeline (internal diameter = 21.0 cm) in order to monitor flow rate. To improve accuracy of measurement, pressure difference across the venturimeter is measured with the help of an inclined tube manometer, the angle of inclination being 30° (Fig. 6.30). For a manometer reading of 9.5 cm of mercury, find the flow rate. Discharge co-efficient of venturimeter is 0.984.*

(GATE)

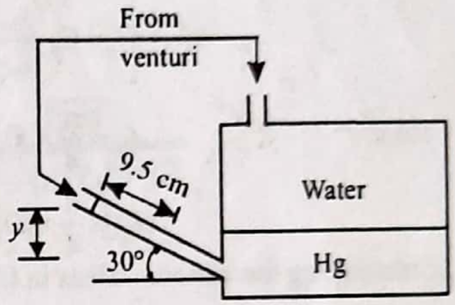


Fig. 6.30

Solution. Internal dia., $D_1 = 21.0$ cm $= 0.21$ m;

Area of inlet, $A_1 = \frac{\pi}{4} D_1^2 = \frac{\pi}{4} \times (0.21)^2 = 0.0346\ m^2$

Throat dia, $D_2 = 10.5$ cm $= 0.105$ m

$\therefore$ Area at throat, $A_2 = \frac{\pi}{4} \times D_2^2 = \frac{\pi}{4} \times (0.105)^2 = 0.00866\ m^2$

Discharge co-efficient of venturimeter, $C_d = 0.984$

Pressure head, $$h = y\left[\frac{S_{Hg}}{S_{water}} - 1\right] = (9.5 \sin 30°)\left[\frac{13.6}{1} - 1\right]$$

$$= 59.85 \text{ cm} = 0.5985 \text{ m}$$

Discharge (Q) through a venturi-meter is given by:

$$Q = C_d \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \times \sqrt{2gh}$$

$$= 0.984 \times \frac{0.0346 \times 0.00866}{\sqrt{(0.0346)^2 - (0.00866)^2}} \times \sqrt{2 \times 9.81 \times 0.5985}$$

$$= 0.984 \times 0.008945 \times 3.427 = \mathbf{0.0302\ m^3/s\ (Ans.)}$$

Example 6.32. *Water at the rate of 30 litres/sec is flowing through a 0.2 m. I.D. pipe. A venturimeter of throat diameter 0.1 m is fitted in the pipeline. A differential manometer in the pipe-line has an indicator liquid M and the manometer reading is 1.16 m. What is the relative density of the manometer liquid M? Venturi co-efficient = 0.96; density of water = 998 kg/m³.*

(AMIE Summer, 2001)

Solution. *Given*: $Q = 30$ litres/sec $= 30 \times 10^{-3}$ m³/s $= 0.03$ m³/s $= D_1 = 0.2$ m; $D_2 = 0.1$ m; $C_d = 0.96$; $\rho_w = 998$ kg/m³; $y = 1.16$ m

Assume venturimeter to be *horizontal*. The flow rate is given by,

$$Q = C_d \times \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \times \sqrt{2gh} \qquad ...(i)$$

Here,
$$A_1 = \frac{\pi}{4} \times D_1^2 = \frac{\pi}{4} \times 0.2^2 = 0.03141 \text{ m}^2, \text{ and}$$

$$A_2 = \frac{\pi}{4} \times D_2^2 = \frac{\pi}{4} \times 0.1^2 = 0.007854 \text{ m}^2$$

Substituting the various values in (*i*), we get

$$0.03 = 0.96 \times \frac{0.03141 \times 0.007854}{\sqrt{0.03141^2 - 0.007854^2}} \times \sqrt{2 \times 9.81} \times \sqrt{h}$$

or
$$0.03 = 0.96 \times 0.008112 \times 4.43 \times \sqrt{h}$$

or
$$h = \left(\frac{0.03}{0.96 \times 0.008112 \times 4.43}\right)^2 = 0.756 \text{ m}$$

Also,
$$h = y\left(\frac{S_{hl}}{S_{ll}} - 1\right) \qquad \text{[Eqn. (6.7)]}$$

$$0.756 = 1.16\left(\frac{S_{hl}}{0.998} - 1\right)$$

$$\therefore \quad S_{hl} = \left(\frac{0.756}{1.16} + 1\right) \times 0.998 = 1.648$$

Hence specific gravity/relative density of the manometer fluid $M =$ **1.648 (Ans.)**

Example 6.33. *A venturimeter is installed in a pipeline carrying water and is 30 cm in diameter. The throat diameter is 12.5 cm. The pressure in pipeline is 140 kN/m², and the vacuum in the throat is 37.5 cm of mercury. Four percent of the differential head is lost between the gauges. Working from first principles find the flow rate in the pipeline in l/s assuming the venturimeter to be horizontal.*

(AMIE Summer, 2000)

Solution. Refer to Fig. 6.29. *Given*: $D_1 = 30$ cm $= 0.3$ m; $D_2 = 12.5$ cm; $= 0.125$ m; $p_1 = 140$ kN/m² $p_2 = -37.5$ cm of mercury

$$= -\frac{37.5 \times 13.6}{100} = -5.1 \text{ m of water}; \; h_f = 4\% \text{ of differential head.}$$

Flow rate in pipeline, Q:

$$\frac{p_1}{w} = \frac{140 \times 10^3}{9810} = 14.27 \text{ m of water}$$

$$\frac{p_2}{w} = -5.1 \text{ m of water (Calculated above)}$$

$$h_f = 4\% \text{ of differential head}$$

$$= \frac{4}{100}\left(\frac{p_1}{w} - \frac{p_2}{w}\right) = \frac{4}{100}\,[(14.27 - (-5.1)] = 0.775 \text{ m of water.}$$

Applying Bernoulli's equation to the entrance (1) and throat (2) of the venturimeter, we get

$$\frac{p_1}{w} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{w} + \frac{V_2^2}{2g} + z_2 + h_f$$

venturimeter.

Difference between a venturimeter and an orificemeter:

A **venturimeter** is *a device which is inserted into pipeline to measure incompressible fluid flow rates*. It consists of a convergent section which reduces the diameter to between one half to one-fourth of the pipe diameters. This is followed by a divergent section. The pressure difference between the position just before the venturi and at the throat of the venturi is measured by a differential manometer. The *working of the venturi is based on the Bernoulli's principle,* that is *when the velocity head increases in an accelerated flow, there is a corresponding reduction in the piezometric head.*

The **orificemeter** *is opening, usually round, located in the side wall of the tank or reservoir, for measuring the flow of a liquid.* The main feature of the orificemeter is that *most of the potential energy of the liquid is converted into kinetic energy of the free jet issuing through the orifice.*

The main points of *difference* between a venturimeter and orificemeter are:

1. The venturimeter can be used for *measuring the flow rates of all incompressible flows.* (gases with low pressure variations, as well as liquids), whereas orifice meters are generally used for measuring the *flow rates of liquids.*

2. Venturimeter is installed *in pipeline only*, and the accelerated flow through the apparatus, is subsequently decelerated to the original velocity at the outlet of the venturimeter. The flow continues through the pipeline. In the orificemeter the entire potential energy of the fluid is converted to kinetic energy, and the jet *discharges freely into the open atmosphere.*
3. In venturimeter, the flow velocity is *measured by noting the pressure difference between the inlet and the throat of the venturimeter,* whereas in the orificemeter the discharge velocity is measured by using *Pitot tube* or by *trajectory method.*

Example 6.39. *The following data relate to an orificemeter:*

Diameter of the pipe = 240 mm

Diameter of the orifice = 120 mm

Sp. gravity of oil = 0.88

Reading of differential manometer = 400 mm of mercury

Co-efficient of discharge of the meter = 0.65.

Determine the rate of flow of oil.

Solution. Diameter of the pipe $D_1 = 240\text{ mm} = 0.24\text{ m}$

∴ Area of the pipe, $A_1 = \frac{\pi}{4} \times 0.24^2 = 0.0452\text{ m}^2$

Diameter of the orifice, $D_0 = 120\text{ mm} = 0.12\text{ m}$

∴ Area of the orifice, $A_0 = \frac{\pi}{4} \times 0.12^2 = 0.0113\text{ m}^2$

Co-efficient of discharge, $C_d = 0.65$

Sp. gravity of oil, $S_0 = 0.88$

Reading of differential manometer, $y = 400$ mm of mercury = 0.4 m of mercury

∴ Differential head, $h = y\left[\frac{S_{hl}}{S_o} - 1\right]$

[where S_{hl} = sp. gravity of heavier liquid = 13.6 (for mercury)]

$$= 0.4\left[\frac{13.6}{0.88} - 1\right] = 5.78\text{ m of oil}$$

Discharge Q:

Using the relation, $Q = C_d \dfrac{A_0 . A_1 . \sqrt{2gh}}{\sqrt{A_1^2 - A_0^2}}$, we have

$$Q = 0.65 \times \frac{0.0113 \times 0.0452 \times \sqrt{2 \times 9.81 \times 5.78}}{\sqrt{(0.0452)^2 - (0.0113)^2}}$$

$$= \frac{0.000353}{0.0437} = \mathbf{0.08\ m^3/s}\ \textbf{(Ans.)}$$

Example 6.40. *Water flows at the rate of 0.015 m³/s through a 100 mm diameter orifice used in a 200 mm pipe. What is the difference of pressure head between the upstream section, and the vena contracta section? Take co-efficient of contraction C_c = 0.60 and C_v = 1.0.* **(AMIE Winter, 2001)**

Solution. *Given*: $Q = 0.015\text{ m}^3/\text{s}$; $D_0 = 100\text{ mm} = 0.1\text{ m}$; $D_1 = 200\text{ mm} = 0.2\text{ m}$; $C_c = 0.60$; $C_v = 1.0$

Difference in pressure head *h*: Refer to Fig. 6.35.

$$A_1 = \frac{\pi}{4} D_1^2 = \frac{\pi}{4} \times 0.2^2 = 0.03142\text{ m}^2$$

$$A_0 = \frac{\pi}{4} D_0^2 = \frac{\pi}{4} \times 0.1^2 = 0.007854 \text{ m}^2$$

$$C_d = C_c \times C_v = 0.60 \times 1.0 = 0.6$$

the relation: $$Q = C_d \frac{A_0 A_1 \sqrt{2gh}}{\sqrt{A_1^2 - A_0^2}}$$

$$0.015 = 0.6 \times \frac{0.007854 \times 0.03142 \sqrt{2 \times 9.81 \times h}}{\sqrt{(0.03142)^2 - (0.007854)^2}} \quad \text{...[Eqn. (6.9)]}$$

$$0.015 = 0.6 \times \frac{0.001093 \sqrt{h}}{0.03042}$$

$$h = \left(\frac{0.015 \times 0.03042}{0.6 \times 0.001093}\right)^2 = \textbf{0.484 m of water (Ans.)}$$

mple 6.41. (*a*) *Derive an expression for the volumetric flow rate of a fluid flowing through emeter. Write down the advantage and disadvantages of using orificemeter over a venturimeter.*

Water is flowing through a pipeline of 50 cm ID at 30°C. An orifice is placed in the pipeline to measure the flow rate. Orifice diameter is 20 cm. If the manometer reads 30 cm of Hg, calculate the water flow rate and velocity of the fluid through the pipe.

ρ_{water} *at 30°C = 987 kg/m³*

ρ_{Hg} *= 13600 kg/m³*

Orifice co-efficient. = 0.6

Sol. (*a*) Refer Article 6.6.2.

Advantage of orificemeter over venturimeter is that its *length is short and hence it can be used in a wide variety of application. Venturimeter has excessive length.*

The **disadvantage** of orificemeter is that a *sizeable pressure loss is increased because of the separation downstream of the plate. In a venturimeter the expanding section keeps boundary layer separation to a minimum, resulting in good pressure recovery across the meter.*

(*b*) *Given*: D_1 = 50 cm = 0.5 m; D_0 = 20 cm = 0.2; y = 30 cm of Hg = 0.3 m of Hg

ρ_{water} at 30°C = 981 kg/m³, ρ_{Hg} = 13600 kg/m³;

$C_0 = 0.6.$

Water flow rate, Q:

$$A_1 = \frac{\pi}{4} D_1^2 = \frac{\pi}{4} \times 0.5^2 = 0.1963 \text{ m}^2$$

$$A_0 = \frac{\pi}{4} D_0^2 = \frac{\pi}{4} \times 0.2^2 = 0.0314 \text{ m}^2$$

$$h = y\left(\frac{\rho_{Hg}}{\rho_{H_2O}} - 1\right) = 0.3\left(\frac{13600}{987} - 1\right) = 3.834 \text{ m}$$

Using the relation; $$Q = C_d \frac{A_0 A_1 \sqrt{2gh}}{\sqrt{A_1^2 - A_0^2}}, \text{ we get}$$

$$Q = 0.6 \times \frac{0.0314 \times 0.1963 \times \sqrt{2 \times 9.81 \times 3.834}}{\sqrt{(0.1963)^2 - (0.0314)^2}} = 0.1655 \text{ m}^3/\text{s}$$

$$V_1 = \frac{Q}{A_1} = 0.843 \text{ m/s}$$

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Pitot tube:-

$$V = \sqrt{2g(h_s - h_o)}$$

h_s = stagnation pressure head

h_o = static pr. head

→ A submarine fitted with a pitot tube moves horizontally in sea. Its axis is 12m below the surface of water. The pitot tube fixed infront of the submarine and along its axis is connected to the 2 limbs of U-tube containg Hg, the reading of which is found to be 200mm. find the speed of submarine. take spec. gravity of sea water = 1.025 times fresh water

Sol: $y = 200\text{ mm} = 0.2\text{m of Hg}$

$S_{hl} = 13.6$

$S_{pl} = 1.025$

$$h = y\left[\frac{S_{hl}}{S_{ll}} - 1\right] = 2.45$$

$$\therefore V = \sqrt{2gh} = 6.93\text{ m/s or } 24.9\text{ km/hr}$$

→ A petroleum oil (s.g = 0.9 & viscosity = 13 C.P) flows isothermally through a horizontal 5cm pipe. A pitot tube is inserted at the centre of a pipe & its leads are filled with the same oil and attached to a U-tube containing water. The reading of the manometer is 10cm, cal. volumetric flow of oil in m^3/s. coefficient of pitot tube = 0.98

Sol: $S_{oil} = 0.9$, $\mu = \frac{13}{100} \times 0.1 \frac{Ns}{m^2}$

$y = 10\text{ cm of Hg} = 0.1\text{m of Hg}$

$C_V = 0.98$

$$h = 0.1\left[\frac{13.6}{0.9} - 1\right] = 1.411$$

Act. vel = $V = C_V\sqrt{2gh} = 5.156\text{ m/s}$

$q = A \times V = 0.01\text{ m}^3/s$.

Scanned with CamScanner

14.5.2. Hot Wire Anemometer (Non-conducting fluids)

Hot wire anemometry has been considered as a satisfactory approach to the measurement of mean and fluctuating velocity components in a flow field. The sensor is a 5 micron diameter platinum-tungston wire welded between the two prongs of the probe and heated electrically as a part of wheat stone bridge circuit (Fig. 14.37). When the probe is introduced into the flowing fluid, it tends to be cooled by the instantaneous velocity and consequently there is a tendency for the electrical resistance to diminish. The rate of cooling of wire depends upon the (*i*) dimensions and physical properties of the wire, (*ii*) difference of the temperature between the wire and the fluid, (*iii*) physical properties of the fluid, and (*iv*) stream velocity under measurement. For a simple hot wire anemometer, the first three conditions are effectively constant and the instrument response is then a direct measure of the flow velocity.

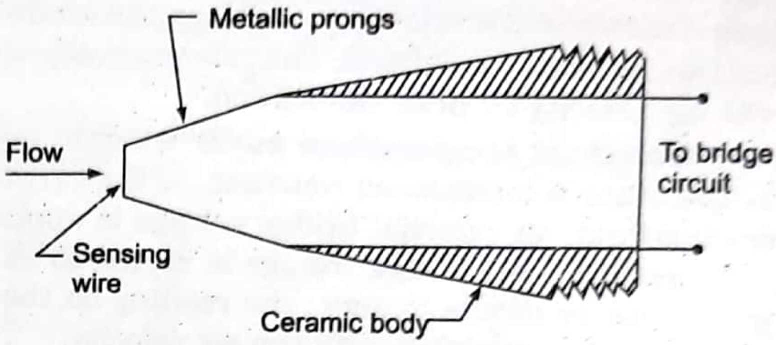

Fig. 14.37. Hot wire probe

Depending on the associated electronic equipment, a hot wire set may be operated in two ways (Fig. 14.38).

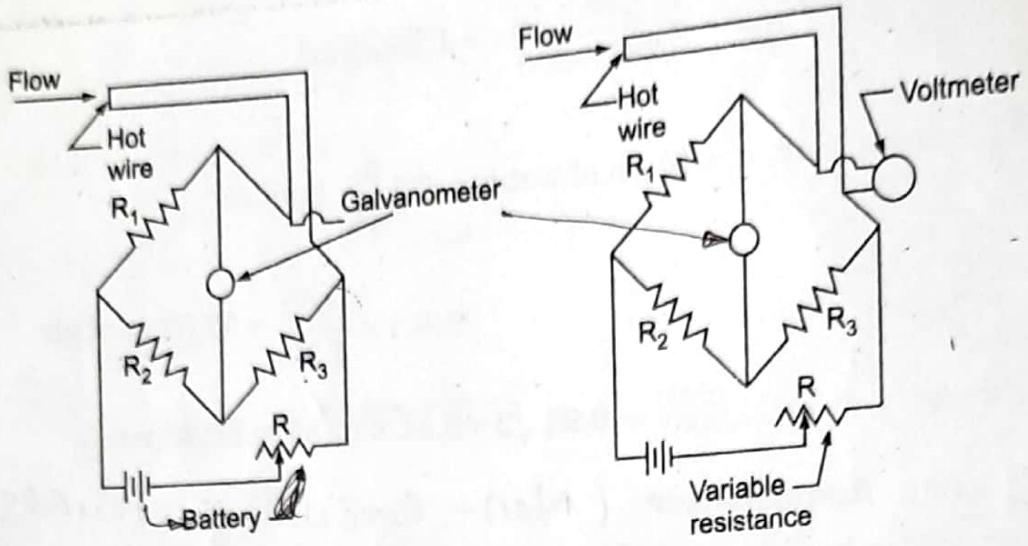

Fig. 14.38. Hot wire anemometer bridge circuits

* ***Constant current mode*** wherein the heating current *i.e.*, voltage across the bridge is kept constant. Initially the circuit is adjusted such that the galvanometer reads zero when the heated wire lies in stationary air. When the air flows, the hot wire cools, the resistance changes and the galanometer deflects. The galvanometer deflection is amplified, measured and correlated with air velocity by prior calibration.

* ***Constant temperature mode*** wherein operating resistance of the wire and hence its temperature is maintained constant. In the event of the tendency of the hot wire to cool by the flowing fluid, an external bridge voltage is applied to the wire to maintain sensibly constant temperature. The bridge voltage is varied so as to bring the galvanometer needle to zero ; the reading on the voltmeter is recorded and correlated with the air velocity.

Response of hot wire placed normal to flow stream with velocity V is known to be described by :

$$E^2 = E_0^2 + BV^n \qquad ...(14.19)$$

where E is the instantaneous value of the bridge voltage. E_0 and B are constants depending on the cold resistance of the wire and on the properties of the fluid medium. The values of these constants for a given wire are found by calibrating the wire in a uniform flow field against a standard pitot static probe. Generally with exponent $n = 0.5$, the response of hot wire in the form of a plot between E^2 and V^n is a straight line.

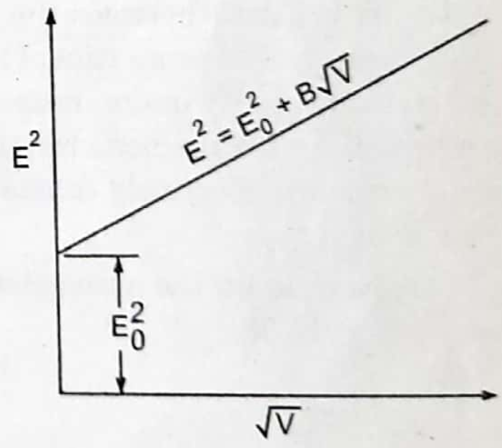

Fig. 14.39. Response of a hot wire

14.5.3. Cup and Vane Anemometers

Cup and vane anemometers are the devices which measure the speed of air movement. The device consists essentially of a rotating element whose speed of rotation varies with the velocity of flow ; the relation between these variables is determined by appropriate calibration data.

In a cup anemometer cups are attached to radial arms mounted on a shaft. Drag forces are set up on these cups when a flow stream in the plane of rotation approaches the unit from any direction. For the arrangement depicted in Fig. 14.40 (*a*), the drag on the cup A (cup with its open end facing towards the stream) is greater than that on cup B (cup with rounded face towards the stream). The resultant torque rotates the assembly in the anticlockwise direction. The number of revolutions is read from a dial for a given period of

From continuity considerations : $A_2 V_2 = A_3 V_3$ or $\frac{A_3}{A_2} = \frac{V_2}{V_3}$

$$\therefore \quad \text{Ratio of diameters} = \sqrt{\frac{V_2}{V_3}} = \sqrt{\frac{14.58}{6.84}} = \mathbf{1.459}$$

14.9 NOTCHES AND WEIRS

A notch or weir is geometrical opening in the side of a reservoir with upstream liquid level below the upper edge of the opening. It may be regarded s a large orifice where the upper edge is eliminated and it has a variable area depending on the level of the free surface. Essentially, a weir is a part obstruction built across the flow; this obstruction causes the upstream level to rise until the flow occurs.

Fig. 14.70 illustrates an opening which functions as an orifice and a weir with level of head relative to top edge of the opening, and mentions some terms associated with weir flow.

— liquid flows through an orifice but it flows over the weir

— stream of liquid issuing from an orifice is called a jet, and the overflowing stream of liquid in a weir is called nappe, sheet or vein

— top surface over which the liquid flows in a weir is called the ***sill*** or ***crest*** of the weir. Head h on the weir is prescribed by the vertical distance between the weir crest and the liquid surface taken far enough upstream of the weir; the recommended distance from the weir is between four to six times the height of the weir. Head over the weir is called the crest height. Upstream from the weir, the flow is rendered calm by stilling screens, and height of the level above the weir crest is measured by a float gauge.

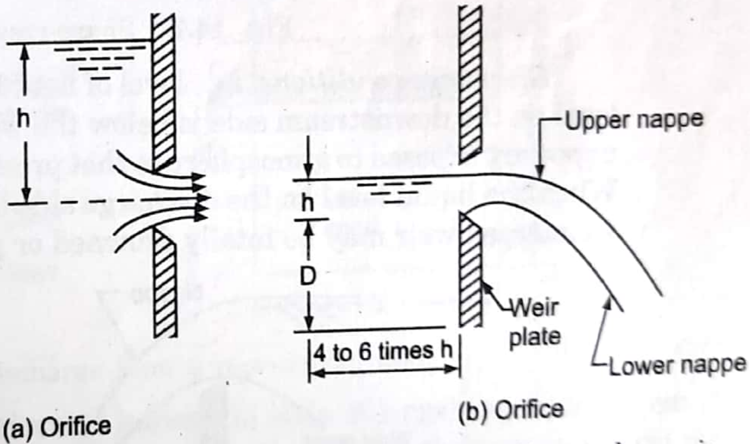

Fig. 14.70. Distinction between an orifice and a weir

Between a notch and a weir, the distinguishing features are :

- notch is a small structure with sharp edge. Weir is made on a much larger scale ; it has a substantial crest in the direction of flow.
- notch is usually made in a smooth, plane, vertical plate and its edges are leveled on the downstream side. Weir is generally of concrete or masonry construction.
- notch measure the small flow rates from a reservoir; weir measures large discharges from a river or from an open channel.

Geometry of the flow section : A weir may be of rectangular, triangular or trapezoidal section. Further it may be straight or curved in the plan shape.

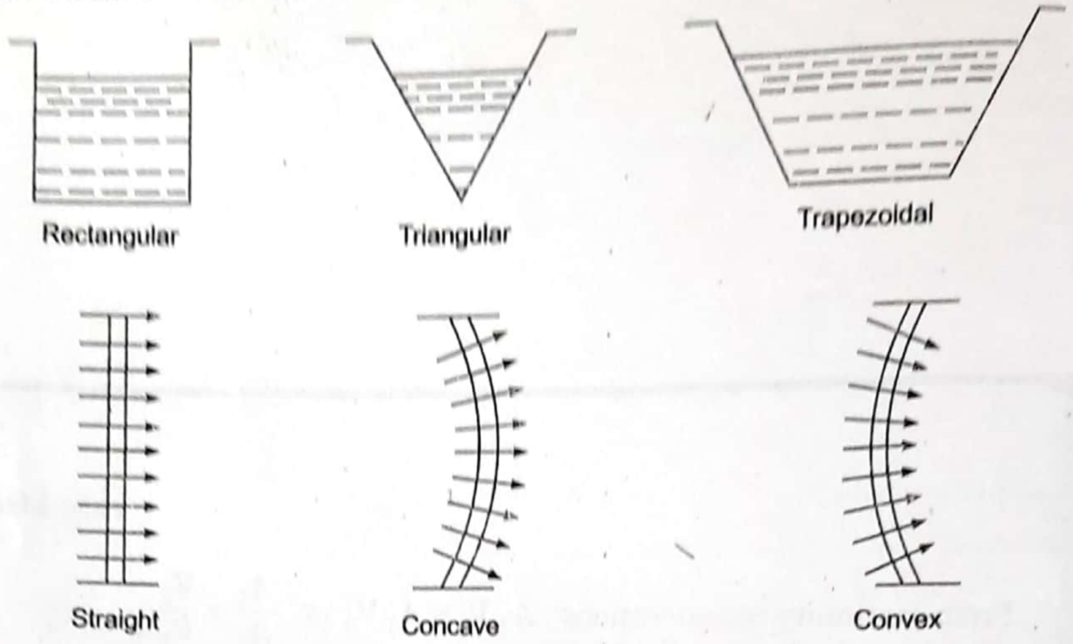

Fig. 14.71. Geometry of a weir

**Form of crest* : Sharp crested or broad crested weir. A *sharp crested weir* has sharp upstream edge; thickness of weir crest is less than half the head on the weir, *i.e.*, $b < 0.5\ h$. Jet of water touches only the upstream edge and flows clear of the downstream edge. Evidently, the liquid flowing over a sharp crested weir has only a line contact with the weir. *A broad crested weir* has a broad crest and the flowing liquid has a surface contact with the weir crest. Flow of liquid over the crest may then be compared to a channel flow.

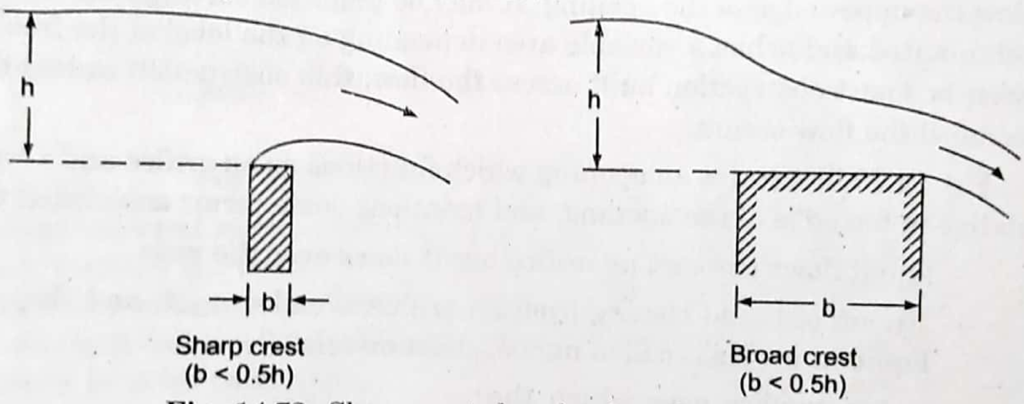

Fig. 14.72. Sharp-crested and a broad-crested weir

**Discharge conditions, i.e.*, level of liquid on discharge side of the weir. In a *free weir*, liquid level on the downstream side is below the weir crest. Both the upper and lower surfaces of the nappe are exposed to atmosphere so that pressure distribution throughout is near to atmospheric. When the liquid level on the discharge side is above the weir crest, a *submerged weir* results. A submerged weir may be totally drowned or partially drowned.

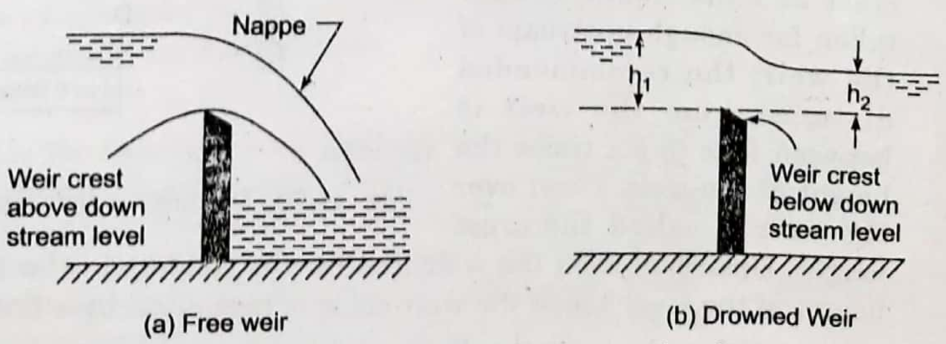

Fig. 14.73. Free and a submerged weir

* *End conditions :* A weir with side contractions or a *contracted weir* is narrower than the channel in which it is installed. A *suppressed weir* is as wide as the channel and the width of the nappe is same as the length of crest. There are no lateral contractions of the flow stream, *i.e.*, end contractions are suppressed.

* *Utility and application :* A weir may be installed to measure the flow rate of liquid (gauging weir) or it may just serve to discharge the surplus quantity of liquid from the reservoir (waste weir).

14.9.1. Discharge Over a Rectangular Weir

Consider a sharp-edged rectangular notch/weir with crest horizontal and normal to direction of flow. To establish a discharge equation for the weir, let it be assumed that :

— fluid particles move horizontally as they pass the weir crest; streamline curvature effects are neglected

— negligible velocity of approach

— atmospheric pressure exists throughout the nappe

— no end effects or lateral contractions

— viscosity, turbulence, secondary flows and surface tension have negligible influence on the flow pattern/behaviour.

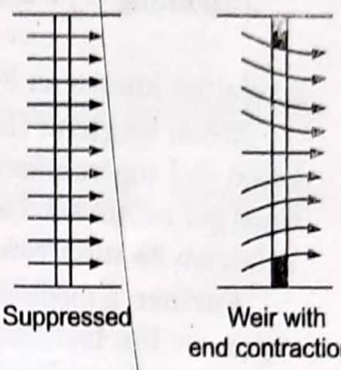

Fig. 14.74. Contracted and a suppressed weir

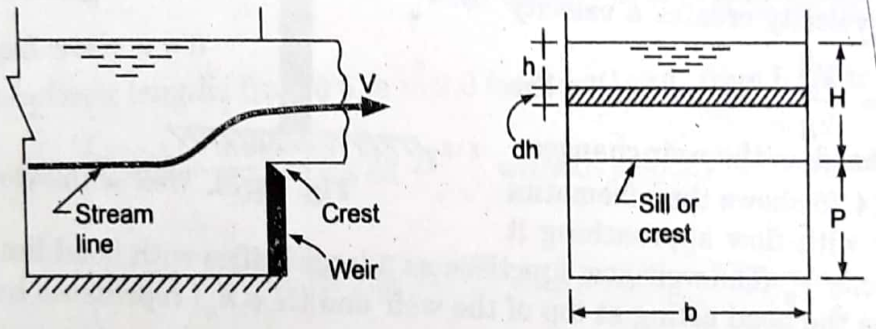

Fig. 14.75. Discharge from a rectangular weir

Let attention be focussed on an elemental horizontal strip of length b and thickness dh at depth h below the free surface of water. Velocity of fluid particles through this strip can be assumed to be uniform and constant.

Theoretical velocity of water through strip $= \sqrt{2gH}$

Area of strip $= b\, dh$

Discharge through strip = velocity × area $= \sqrt{2gH} \times b\, dh$

For the whole notch or weir, the total discharge Q can be determined by integrating the above expression between limits 0 and H.

$$Q = b\sqrt{2g}\int_0^H h^{1/2}\, dh = \frac{2}{3} b\sqrt{2g}\; H^{3/2} \qquad ...(14.41)$$

which is the basic equation for flow through a rectangular notch. Into this equation must be inserted an experimentally determined discharge coefficient C_d which accounts for the effects of flow phenomenon, particularly marked contraction of the nappe and curvature of streamlines. Thus

$$\text{Actual discharge } Q = \frac{2}{3} C_d\, b\sqrt{2g}\; H^{3/2} \qquad ...(14.42)$$