ME 262 BASIC FLUID MECHANICS

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Lecture 2

(Atmospheric pressure, absolute and gage pressure, pressure measurement, relationship between pressure and elevation, surfaces of equal pressures, manometers)

8. ATMOSPHERIC PRESSURE

The atmosphere of earth is a thick layer (approximately 1500 km) of mixed gases.

N_2 78 %

O_2 21 % .

Other gases (water vapor, CO_2, argon etc.) 1%

Each of gasses possess a certain mass and consequently has a mass Total weight of the atmospheric column exerts a pressure on every surface. At sea level, under normal conditions;

Atmospheric pressure =1.014×10^3 $\mathrm{N/m^2}$ or 1 bar

Pressure unit = 1 N/m^2 is also known as 1 Pascal.

Vapor pressure: In the atmosphere each gas exerts a partial pressure independent of other gases. The partial pressure exerted by water vapor is called vapor pressure.

9. ABSOLUTE AND GAGE PRESSURE

A water surface in contact with the earth's atmosphere is subjected to atmospheric pressure which is approximately equal to a 10.33 m high column of water at sea level.

In still water, any object located below the water surface is subjected to a pressure greater than the atmospheric pressure.

Pressure gages are used to measure the pressure above or below the atmospheric pressure.

Gage pressure: Pressure measured using atmospheric pressure as a base (reference).

Absolute pressure (Pa): Gage pressure above atmospheric pressure + P_{atm} (+)

Absolute pressure (Pa): Gage pressure below atmospheric pressure (vacuum) + P_{atm} (-)

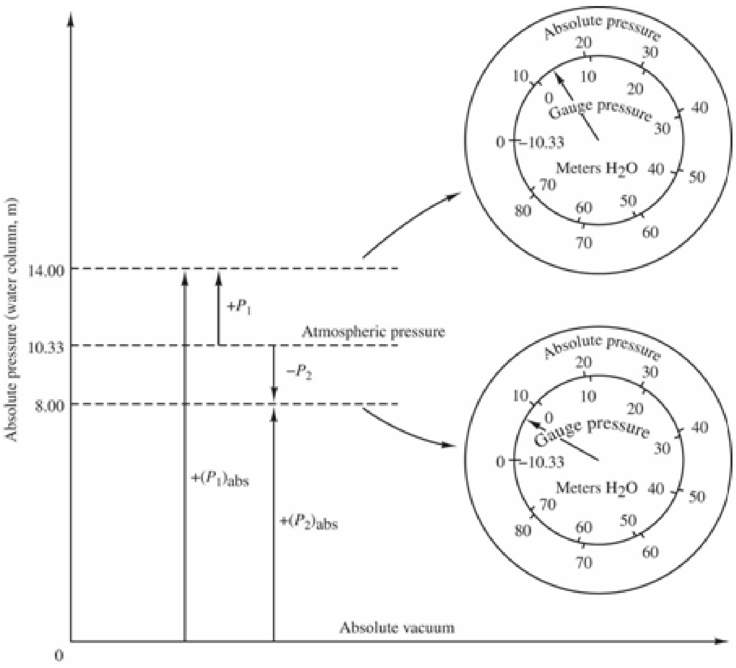


Figure 9.1 Absolute and gage pressure

Gage pressure for P_1 ➔ = 14.00 – 10.33 = + 3.67 m H_2O

Gage pressure for P_2 ➔ = - 10.33 + 8.00 = - 2.33 m H_2O

$(P_1)_{abs}$ = 3.67 + 10.33 = 14 m H_2O

$(P_2)_{abs}$ = - 2.33 + 10.33 = 8.0 m H_2O

10. PRESSURE MEASUREMENT

When making calculations involving pressure in a fluid , you must make the measurements relative to some reference pressure. Normally the reference pressure is that of atmosphere and the resulting pressure is called gage pressure.

Gage pressure

$$P_{abs} = P_{gage} + P_{atm} \longrightarrow \text{Atmospheric pressure}$$

10.33 m H_2O column

Absolute pressure

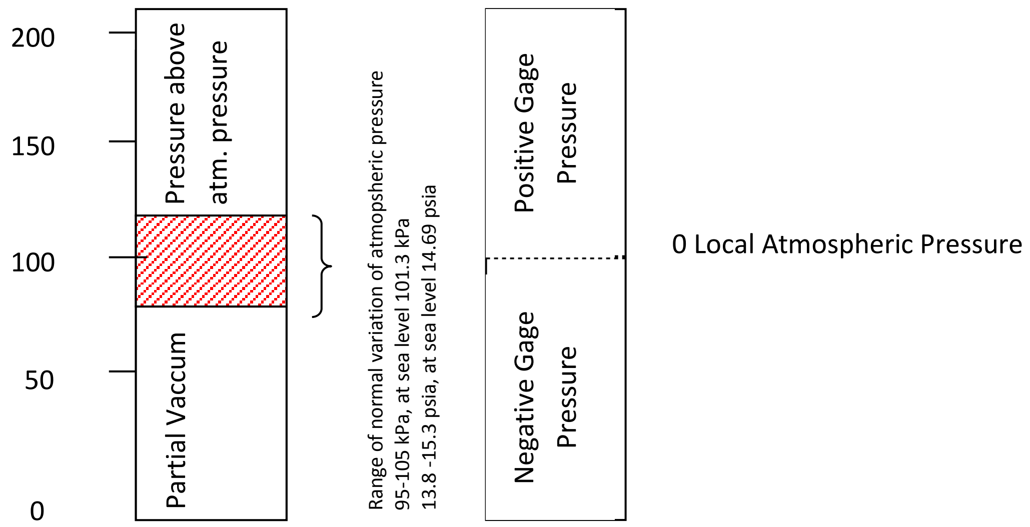
Pressure measured relative to the perfect vacuum is called absolute pressure.

1. A perfect vacuum is the lowest possible pressure. Therefore, an absolute pressure is always positive.

2. A gage pressure above atmospheric is positive

3. A gage pressure below atmospheric pressure is negative, sometimes called vacuum.

4. The actual magnitude of the atmospheric pressure varies with location and climatic conditions.



Range of normal variation of atmospheric pressure (95 – 105 kPa in SI units, 13.8 – 15.3 psia in English units, a stands for absolute pressure)

Example 10.1. : Express a pressure of 155 kPa (gage) as an absolute pressure. The local atmospheric pressure is 98 kPa.

$$P_{\text{atm local}} = 98 \text{ kPa (absolute)}$$

$$P_{\text{abs}} = 155 \text{ kPa} + 98 \text{ kPa}$$

$$= 253 \text{ kPa (abs)}$$

Example 10.2. : Express a pressure of 225 kPa (abs) as a gage pressure. The local atmospheric pressure is 101 kPa (abs) $P_{\text{gage}} = ?$

$$P_{\text{atm}} = 101 \text{ kPa (abs)}$$

$$225 \text{ kPa} = P_{\text{gage}} + 101 \text{ kPa}$$

$$P_{\text{gage}} = 124 \text{ kPa (abs)}$$

Example 10.3.: Express a pressure of 10.9 psia as a gage pressure. The local atmospheric pressure is 15 psia.

$$P_{atm} = 15 \text{ psia}$$

$$10.9 \text{ psia} = P_{gage} + 15 \text{ psia}$$

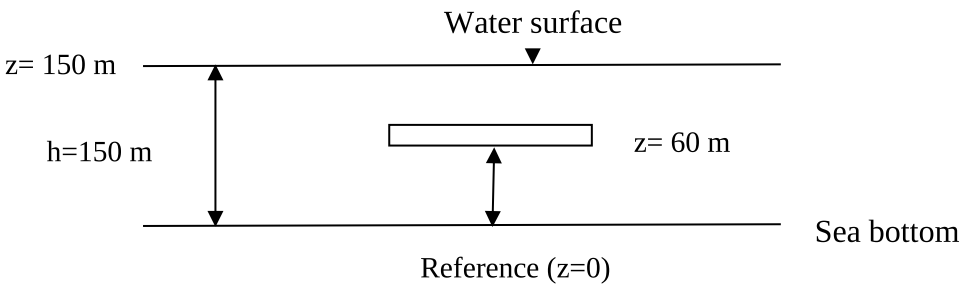
$$P_{gage} = -4.1 \text{ psig}$$

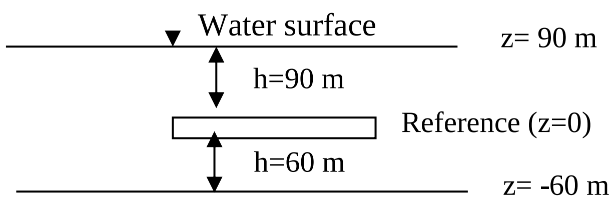
4.1 psi below atmospheric pressure or 4.1 psi vacuum.

11. RELATIONSHIP BETWEEN PRESSURE AND ELEVATION

Elevation : Vertical distance from some reference level to a point of interest and is called z.

h : a change in elevation between two points.





The change in pressure in a homogenous liquid at rest due to a change in elevation.

$$\Delta P = \gamma \times h$$

h → Change in elevation

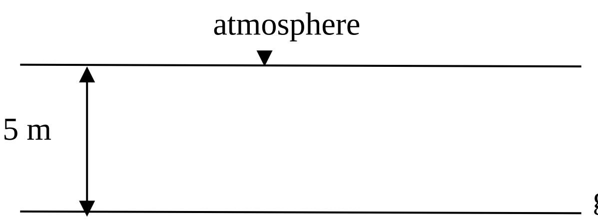
ΔP → Pressure Change

γ → Specific weight of Liquid

The above equation does not apply to gases because the specific weight changes with pressure.

1. The equation is valid only for a homogeneous liquid at rest
2. Points on the same horizontal level have the same pressure
3. The change of pressure is directly proportional to specific weight (γ) of the liquid
4. Pressure varies linearly with change in elevation or depth
5. A decrease in elevation causes an increase in pressure.
6. An increase in elevation causes a decrease in pressure

Example 11.1 : Calculate the change in water pressure (Dfrom the surface to the depth of 5 m.



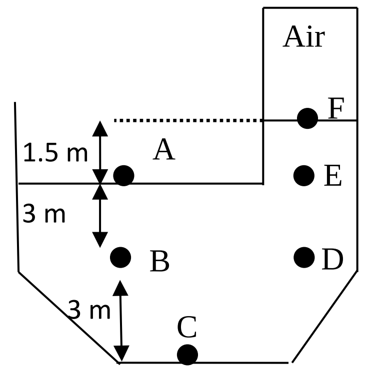
$$\Delta P = \gamma \times h$$

$$\gamma = 9.81 \text{ kN/m}^3$$

$$\Delta P = (9.81 \text{ kN/m}^3).(5 \text{ m}) = 49.05 \text{ kPa}$$

Decreasing elevation produces an increase in pressure.

Example 11.2: Figure shows a tank of oil with one side open to the atmosphere and other side sealed with air above oil. The oil has a specific gravity of 0.9. Calculate the gage pressures at A, B, C, D, E and air pressure at right hand side of the tank.



At point A : The oil is exposed to the atmosphere $P_a = 0 \; P_a$ (gage)

Point B : $\gamma_{oil} = (s.g)_{oil} \times \gamma_{water}$ N/m^3=$0.90 \times 9.81 = 8.83 \text{ kN/m}^3$

$$\Delta P_{A-B} = \gamma_{oil} \times h = \quad 8.83 \frac{kN}{m^3} \times 3 \text{ m} \qquad = 26.5 \text{ kPa}$$

Point C : $\Delta P_{A-C} = \gamma_{oil} \times 6 \text{ m} = 8.83 \frac{kN}{m^3} \times 6 \text{ m} = 53 \text{ kPa}$

$$P_C = P_A + \Delta P_{A-C} = 0 \text{ Pa (gage)} + 53 = 53 \text{ kPa}$$

Point D : = Since point D is the same level as point B, the pressure is same

$$P_D = P_B = 26.5 \text{ kPa (gage)}$$

Point E: Since point E is at the same level as point A

$$P_A = P_E = 0 \text{ kPa (gage)}$$

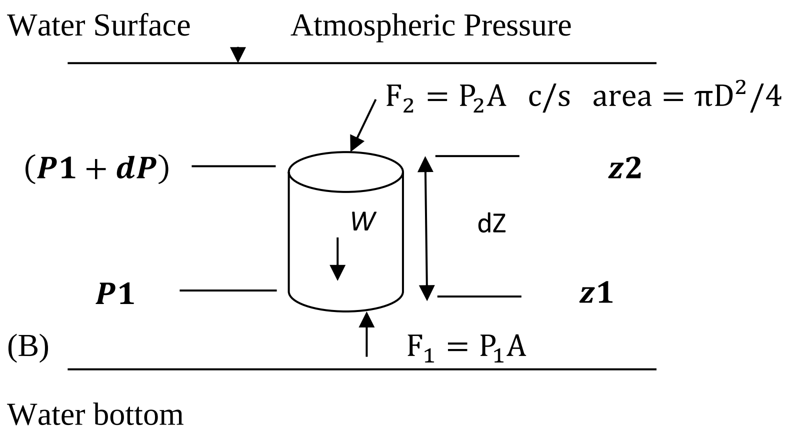
Point F: The change in elevation between point A & point F is 1.5 m with F higher than A.

$$\Delta P_{A-F} = \gamma_{oil} \times (-1.5 \text{ m}) = 8.83(-1.5) = -13.2 \text{ kPa}$$

$$P_F = P_A + \Delta P_{A-F} = 0 \text{ kPa (gage)} + (-13.2) = -13.2 \text{ kPa}$$

Air Pressure: Since the air in the right hand side of the tank is exposed to the surface of the oil where $P_{F=}$- 13.2 kPa, the air pressure is also -13.2 kPa or 13.2 kPa below atmospheric pressure.

12. DEVELOPMENT OF THE PRESSURE ELEVATION RELATION



Fluid-specific weight = γ

$$dV = A\,(dz)$$

$$W = \gamma \forall = \gamma A(dz)$$ $\forall$ = Volume, m^3

W = the force acting on the cylinder in the downward direction through the center.

Apply the principle of static equilibrium, if there is no motion,

Fluid is static, acceleration = 0, Net force on the fluid layer = 0

$$\sum F_V = 0 = F_1 - F_2 - w = 0$$

$$P_1A - (P_1 + dP)A - \gamma A dz = 0$$

Area can be eliminated by dividing all terms by area (A);

$$\frac{P_1A}{A} - \frac{(P_1 + dP)A}{A} - \frac{\gamma A dz}{A} = \frac{0}{A}$$

$$P_1 - P_1 - dP - \gamma dz = 0$$

$$dP = -\gamma \times dz$$

$$(1)\quad \frac{dP}{dz} = -\gamma = -\rho g \text{ (For all liquids)}$$

For gases specific weight (γ) changes with pressure, hence equation 1 cannot be applied.

$$\int_{P_1}^{P_2} dP = -\gamma \int_{z_1}^{z_2} dz$$

$$P_2 - P_1 = -\gamma \times (z_2 - z_1)$$

$\Delta P = P_2 - P_1$

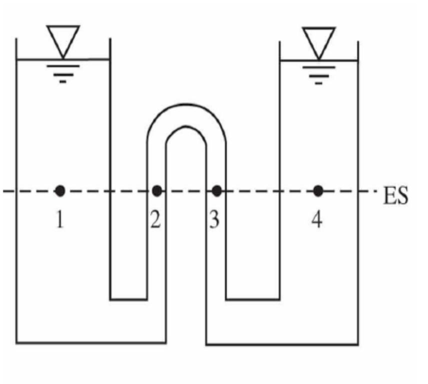
h=$z_2 - z_1$

$$\Delta P = \gamma \times h = \rho \times g \times h$$

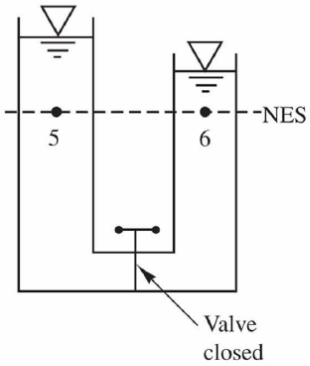
A pressure applied at any point in a liquid at rest is transmitted equally and undiminished in all directions to every point in the liquid. This principle, also known as Pascal’ s law, has been made use of in the hydraulic jacks that lift heavy weights by applying relatively small forces.

13. SURFACES OF EQUAL PRESSURES

Hydrostatic pressure in a body of water varies with the vertical distance measured from the water surface. All points on a horizontal surface in a static body of water are subjected to the same hydrostatic pressure.

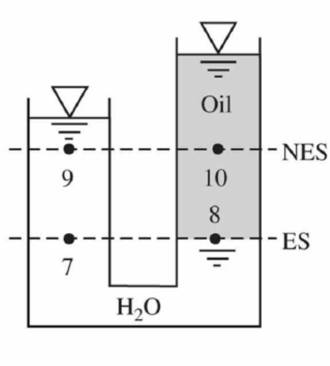


P1=P2=P3=P4



P5≠P6

Water in the two tanks are not connected and overlying depths to the free surfaces are different



P7=P8

P9≠P10

Point 9 and 10 reside in different liquids

Figure 12.1 Hydraulic Pressure in vessels

ES= equal pressure surface, NES=nonequal pressure surface

1. The points on the surface be in the same liquid

2. The points be at the same elevation

3. The liquid containing the points be connected.

14. MANOMETERS

Manometer: is a pressure measurement device uses relationship between pressure change and elevation change in a static liquid. Basically there are two types of manometers.

Open manometer

U-Tube Manometer

Differential manometer

14.1 U-Tube Manometer: has one end open to atmospheric pressure and is capable of measuring the gage pressure in a vessel.

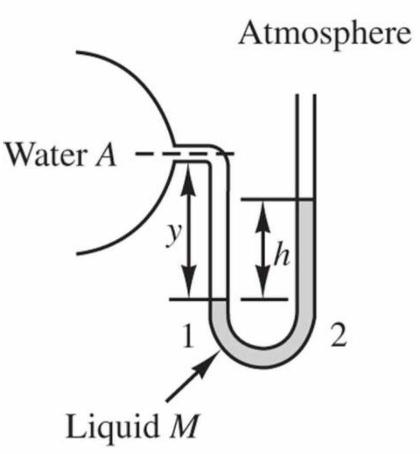


Figure 14.1 U-tube manometer

The liquid used in manometer is usually heavier than the fluids to be measured. It must form a distinct interface-that is, it must not mix with the adjacent liquids. The most frequently used manometer liquids are mercury (sp. gr. = 13.6), water (sp. gr. =1.00), alcohol (sp. gr. =0.9), and other commercial manometers oils of various specific gravities.

14.2 Differential Manometer: has each end connected to a different pressure tap and is capable of measuring the pressure difference between the two taps.

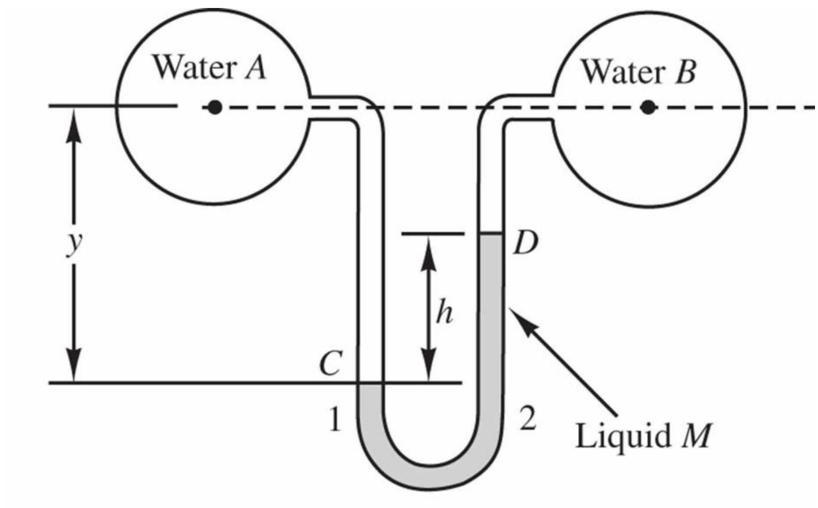
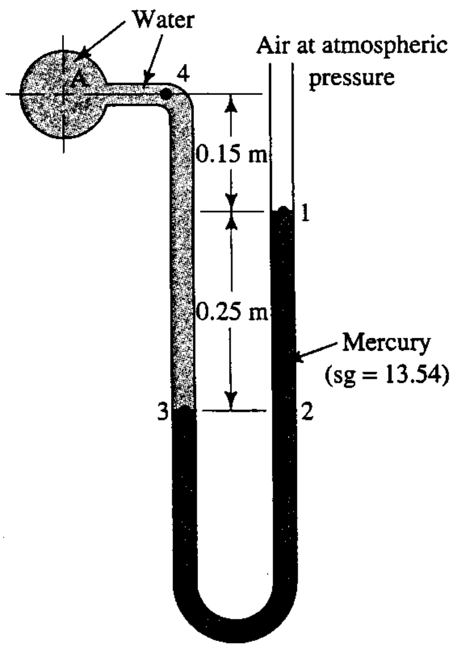


Figure 14.2 differential manometer [Hwang et al., 4th edition]

$\gamma_{\text{liquid}}\ \text{M} > \gamma_{\text{liquid}}$ (whose pressure is measured)

Example 14.1 Calculate the pressure at point A.



Pressure at point 1: Atmospheric pressure: P_{atm}

Pressure at point 2: $P_1 + \gamma_{mercury}\ (0.25\ m)$

Pressure at point 3 : Pressure at point 2, same level & same liquid ➔ they are same

$P_3 = P_1 + \gamma_{mercury}\ (0.25\ m)$**Pressure at point 4** : P_3 or $P_2\ - \gamma_w(0.25\ m) - \gamma_w(0.15\ m\ )$

$$P_4 = P_1 + \gamma_{mercury}\ (0.25\ m) - \gamma_w(0.25\ m + 0.15\ m\ )$$

Pressure at point A: same level & same liquid with point 4

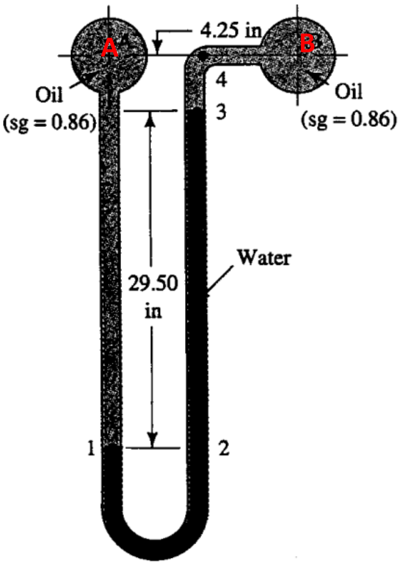
$$P_A = P_1 + \gamma_{mercury}\ (0.25\ m) - \gamma_w(0.40\ m\ )$$

Specific weight of mercury➔ $\gamma_{mercury} = (s.g) \times 9.81 = 13.54 \times 9.81 = 132.8\ \ kN/m^3$

$$P_A = 0 + \left(\ 132.8\ \ \frac{kN}{m^3}\right)(\ 0.25\ ) - \left(\ 9.81\ \ \frac{kN}{m^3}\right)(\ 0.40\ )$$

$$= 29.28\ kN/m^2 = 29.28\ \ kPa\ (\ gage\ )$$

Example 14.2 Calculate the pressure difference between points A and B.



It could be started either at point A or point B.

Pressure at point 1 $= P_A + \gamma_{oil}(4.25 + 29.5\ in\ )$

$$= P_A + \gamma_{oil}(33.75\text{ in}) - \gamma_w(29.5\text{ in}) - \gamma_{oil}(4.25\text{ in})$$

$$= P_A + \gamma_{oil}(29.5\text{ in}) - \gamma_w(29.5\text{ in})$$

$$= P_A + 29.5\text{in}\ (\gamma_{oil} - \gamma_w)$$

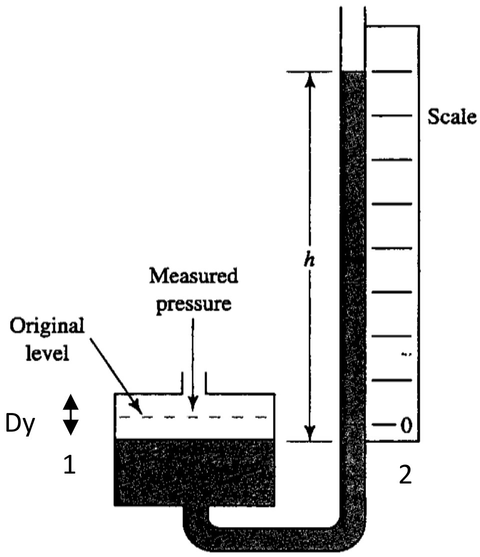
$\gamma_{oil} = (0.86)(62.4\ \text{Ib/ft}^3) = 53.7\ \ \text{Ib/ft}^3$

$\gamma_w = 62.4\ \ \text{Ib/ft}^3$

$$P_B - P_A = P_4 - P_A$$
$$= P_A + 29.5\ (\gamma_{oil} - \gamma_w)$$
$$= 29.5(\gamma_{oil} - \gamma_w)$$
$$= 29.5(53.7 - 62.4)\ \ \text{Ib/ft}^3 \times \frac{1\ \text{ft}^3}{1728\ \text{in}^3}$$
$$P_B - P_A = -0.15\ \text{Ib/in}^2$$

Negative sign indicates that magnitude of $P_A > P_B$

14.3 Single – Reading Manometers (Well type manometer): The open manometer or U-tube manometer requires reading of liquid levels at two points. A well-type manometer can be made by introducing a reservoir with a larger c/s area than that of the tube into one leg of the manometer (Figure 13.3**).**



If there is an increase in pressure, DPa will cause the liquid surface in the reservoir to drop by a small amount Dy, while the level in the right leg rises a larger amount in proportion to the ratio of the areas of the well and the tube.

A. Dy =a. h

A= Cross sectional area of the well

a= cross sectional area of the tube

$\frac{A}{a}$ is a large

$\Delta y = \text{Height}$

$$\underbrace{\Delta y \times A}_{\text{Volume change in reservoir}} = \underbrace{a \times h}_{\text{Volume change in tube}}$$

Pressure at point 1 = Pressure at point 2

$$P_A + \gamma_A(y + \Delta y) = \gamma_B(h + \Delta y)$$

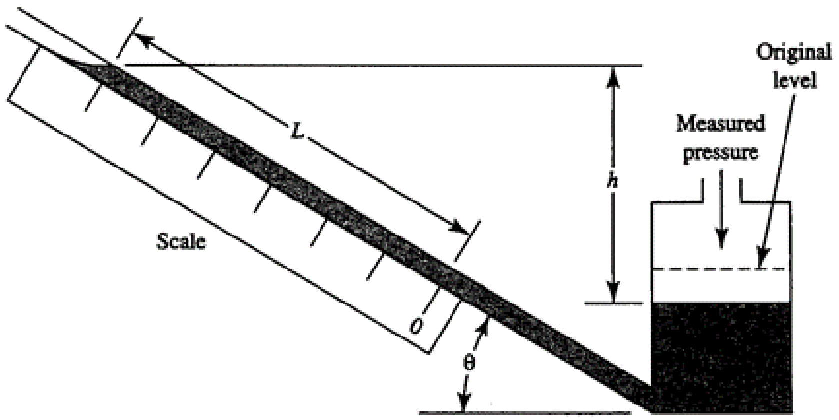
Because Δy can be made negligible by introducing a large $\frac{A}{a}$

$$\gamma_A y + P_A = \gamma_B h$$

Height of the reading h is a measure of the pressure in the vessel

14.4 Inclined Well Type Manometer

It has the same features as the well-type but offers a great sensitivity by placing the scale along the inclined tube.



Sensitivity is higher