MODULE 1: PROPERTIES OF FLUIDS AND PRESSURE MEASUREMENT

General: The branch of science deals with study of fluids in statics, kinematics and dynamics is known as fluid mechanics. Fluid Mechanics is basically a study of:

1) Physical behavior of fluids and fluid systems and laws governing their behavior.

2) Action of forces on fluids and the resulting flow pattern.

A fluid is defined as substance which is capable of flowing under the action of stress. In general fluids are classified into ideal and real fluids.

Fluids can be categorized into liquids and gases, each displaying distinct characteristics owing to their unique molecular structures. Gases have large molecular spacing and latitude of motion, liquids have comparatively smaller spacing and motion, while solids are very compact and rigid due to strong molecular forces. Solids maintain a fixed form, liquids adapt to the shape of their container, and gases occupy the entire volume of the vessel they are in, influenced by these molecular traits.

The various properties of fluids are

- Mass density
- Specific weight
- Specific volume
- Specific gravity
- Viscosity
- Surface tension
- Capillarity
- Compressibility
- Vapour pressure

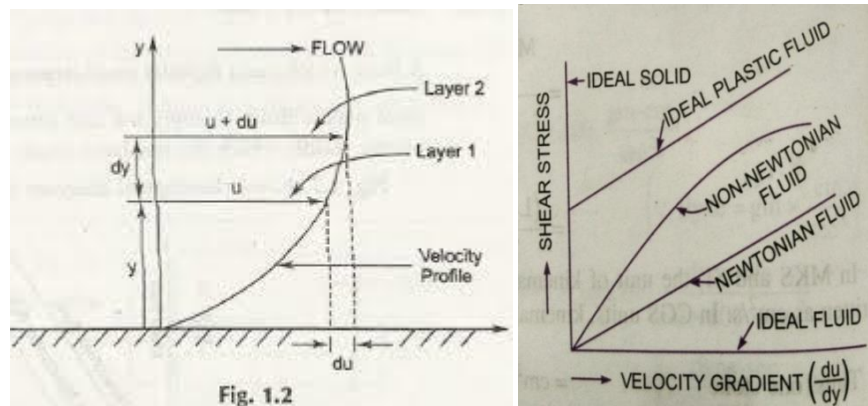Mass density is defined as the ratio of mass of fluid to volume of fluid. The density of water is 1000 kg/m^3.

Specific weight is defined as the ratio of weight of fluid to volume of fluid. The specific weight of water is 9810N/ m^3.

Specific volume is defined as reciprocal of specific weight ie ratio of volume of fluid to weight of fluid.

Specific gravity is defined as density of fluid to density of standard fluid (water). The specific gravity of water is 1.

Viscosity is defined as the resistance offered between movement of one layer over another layer. The shear stress developed is directly proportional to the velocity gradient which is known as Newton's law of viscosity.

Based on Newton's law of viscosity, the fluids are classified into Newtonian and Non Newtonian fluid.

Fig. 1.2

Also viscosity is defined as the shear stress developed under unit velocity gradient.

TYPES of FLUIDS: The fluids may be classified in to the following five types.

1. Ideal fluid 2. Real fluid 3.Newtonian fluid 4. Non-Newtonian fluid 5. Ideal plastic fluid

1**. Ideal fluid**: A fluid which is compressible and is having no viscosity is known as ideal fluid. It is only an imaginary fluid as all fluids have some viscosity.

2**. Real fluid**: A fluid possessing a viscosity is known as real fluid. All fluids in actual practice are real fluids.

3**. Newtonian fluid**: A real fluid, in which the stress is directly proportional to the rate of shear strain, is known as Newtonian fluid.

4. **Non-Newtonian fluid**: A real fluid in which shear stress is not Proportional to the rate of shear strain is known as Non- Newtonian fluid.

5**. Ideal plastic fluid:** A fluid, in which shear stress is more than the yield value and shear stress is proportional to the rate of shear strain is known as ideal plastic fluid.

SURFACE TENSION:

Surface tension is defined as the tensile force acting on the surface of a liquid is contact with a gas or on the surface behaves like a membrane under tension. The magnitude of this force per unit length of free surface will have the same value as the surface energy per unit area. It is denoted by σ (sigma). In MKS units it is expressed as Kg f/m while in SI units as N/m.

Capillarity is defined as the rise or fall of liquid with respect to the adjacent level. If the value is positive then capillary rise and if it is negatives then it is capillary fall.

Compressibility is defined as reciprocal of bulk modulus and it is defined as ratio of compressive stress to volumetric strain.

Vapour pressure is defined as the partial pressure exerted at the free surface of the liquid.

Problem 1

15 cm diameter vertical cylinder rotates concentrically inside another cylinder of diameter 15.10 cm. Both cylinders are 25 cm high. The space between the cylinders is filled with a liquid whose viscosity is unknown. If a torque of 12.0 Nm is required to rotate the inner cylinder at 100 rpm determine the viscosity of the fluid.

Solution:

Diameter of cylinder = 15 cm = 0.15 m

Diameter of outer cylinder = 15.10 cm = 0.151 m

Length of cylinder $\Rightarrow$ L = 25 cm = 0.25 m

Torque T= 12 Nm ; N = 100 rpm.

Viscosity = μ

Tangential velocity of cylinder $u = \dfrac{\pi \, DN}{60} = \pi \, \dfrac{0.15 \times 100}{60} = 0.7854 \quad m/s$

Surface area of cylinder $A = \pi D \times L = \pi \times 0.15 \times 0.25$

$= 0.1178 \ m^2$

$$du = u - 0 = u = 0.7854 \ m/s$$

$$T = \dfrac{\mu \times 0.7854}{0.0005}$$

Shear force, $F = Shear\ Stress \times Area = \dfrac{\mu \times 0.7854}{0.0005} \times 0.1178$

PRESSURE MEASUREMENT

Pressure is defined as the ratio of force to area. The units for pressure is Pascal/bar/KPa.

The pressure at a point is calculated using $p = \rho g h$.

Pascal's law is defined as the intensity of pressure is same in all directions when the fluid is at static condition.

$$p_y = p_x = p_s$$

ABSOLUTE, GAUGE, ATMOSPHERIC and VACCUM PRESSURES

Fluid pressure is measured using two distinct systems. In one system, known as Absolute pressure, measurements are taken above absolute zero or complete vacuum. In the other system, Gauge pressure is measured above atmospheric pressure.

1. ABSOLUTE PRESSURE: It is described as the pressure measured in relation to absolute vacuum pressure.

2. GAUGE PRESSURE: It is characterized as the pressure measured using a pressure measuring instrument, with atmospheric pressure serving as the reference point. The atmospheric pressure is designated as zero on the scale of the instrument.

3. VACUUM PRESSURE: It is defined as the pressure below the atmospheric pressure

i) Absolute pressure = Atmospheric pressure+ gauge pressure

$p_{ab} = p_{atm} + p_{guage}$

ii) Vacuum pressure = Atmospheric pressure - Absolute pressure

The atmospheric pressure at sea level at 150C is 10.13N/cm^2 or

101.3KN/m^2 in S I Units and 1.033 Kg f/cm^2 in M K S System.
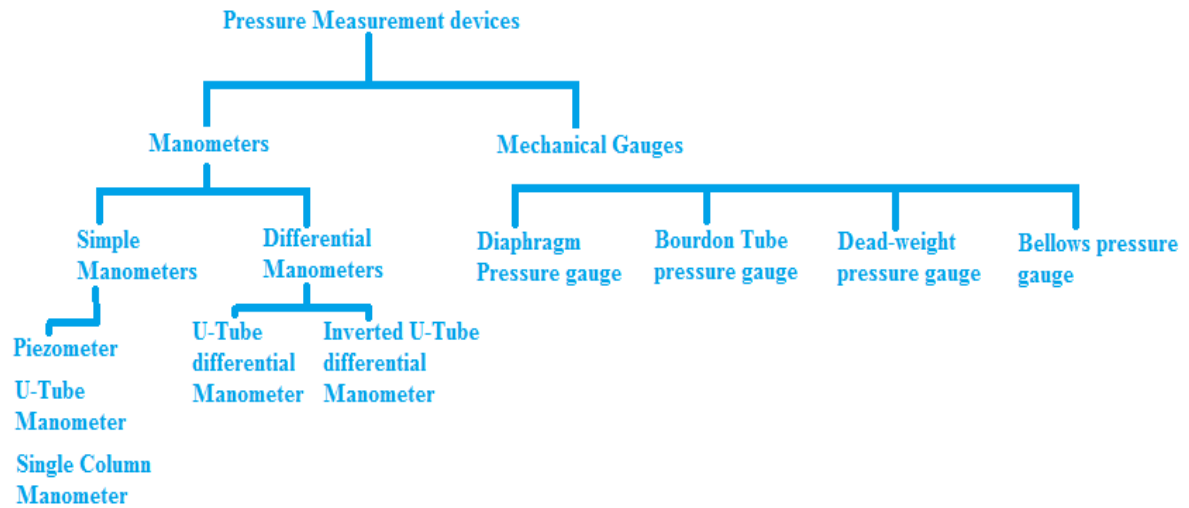
The atmospheric pressure head is 760mm of mercury or 10.33m of water.

MEASUREMENT OF PRESSURE

The pressure of a fluid is measured by the fallowing devices.

1. Manometers 2.Mechanical gauges.

1. Manometers: Manometers are devices employed to measure the pressure at a specific point in a fluid by balancing the fluid column with either the same or another column of fluid. They are categorized into two types: a) Simple Manometers and b) Differential Manometers.

Pressure Measurement devices
- Manometers
  - Simple Manometers
    - Piezometer
    - U-Tube Manometer
    - Single Column Manometer
  - Differential Manometers
    - U-Tube differential Manometer
    - Inverted U-Tube differential Manometer
- Mechanical Gauges
  - Diaphragm Pressure gauge
  - Bourdon Tube pressure gauge
  - Dead-weight pressure gauge
  - Bellows pressure gauge

2. Mechanical Gauges: are defined as the devices used for measuring the pressure by balancing the

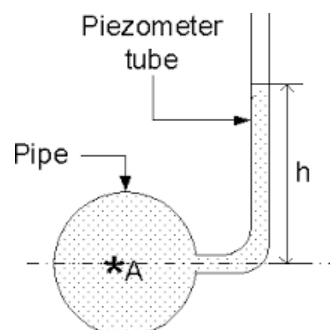fluid column by the spring or dead weight. The commonly used Mechanical pressure gauges are:

a) Diaphragm pressure gauge b) Bourdon tube pressure gauge

c) Dead – Weight pressure gauge d) Bellows pressure gauge.

Simple Manometers: A simple manometer comprises a glass tube, with one end connected to the location where pressure is to be measured, while the other end is left open to the atmosphere.
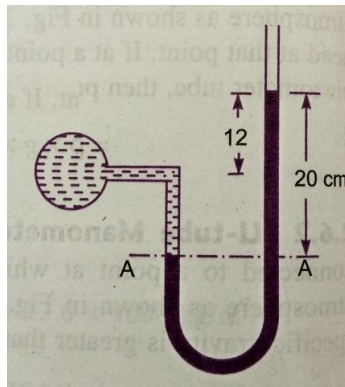
The common types of simple manometers are:

1. Piezo meter.

2. U-tube manometer.

3. Single column manometer.

1. Piezometer: This device, known as a Piezometer, represents the simplest form of a manometer employed to measure gauge pressure. One end of the Piezometer is connected to the location where pressure is being measured, while the other end is left open to the atmosphere. The elevation of the liquid in the Piezometer indicates the pressure head at that specific point (point A).

Q1.The right limb of a simple U – tube manometer containing mercury is open to the atmosphere, while the left limb is connected to a pipe in which a fluid of sp.gr.0.9 is flowing. The centre of pipe is 12cm below the level of mercury in the right limb. Find the pressure of fluid in the pipe, if the difference of mercury level in the two limbs is 20 cm.

Given,   Sp.gr. of liquid S_1= 0.9
           Density of fluid $\rho_1 = S_1 \times 1000 = 0.9 \times 1000 = 900$ kg/ m³
           Sp.gr. of mercury S_2 = 13.6
           Density of mercury $\rho_2 =13.6\times 1000 = 13600$ kg/m³
Difference of mercury level h_2 = 20cm = 0.2m
Height of the fluid from A – A h_1= 20 – 12 = 8cm = 0.08 m
Let 'P' be the pressure of fluid in pipe
Equating pressure at A – A, we get
        $p + \rho_1 gh_1 = \rho_2 gh_2$
        p + 900 × 9.81 × 0.08 = 13.6 × 1000 × 9.81 × 0.2
        p = 13.6 × 1000 × 9.81 × 0.2 – 900 × 9.81 × 0.08
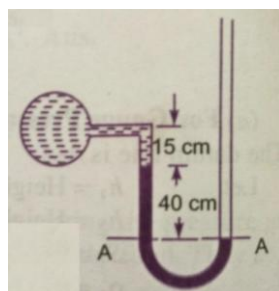   p = 26683 – 706
        p = 25977 N/m²
        p = 2.597 N/cm²
        <u>Pressure of fluid   = 2.597 N/ cm²</u>
.

Q2.A simple U – tube manometer containing mercury is connected to a pipe in which a fluid of sp.gr. 0.8 And having vacuum pressure is flowing. The other end of the manometer is open to atmosphere. Find the vacuum pressure in pipe, if the difference of mercury level in the two limbs is 40cm. and the height of the fluid in the left tube from the centre of pipe is 15cm below.

Given,

Sp.gr of fluid $S_1 = 0.8$

Sp.gr. of mercury $S_2 = 13.6$

Density of the fluid $= S_1 \times 1000 = 0.8 \times 1000 = 800$

Density of mercury $= 13.6 \times 1000$

Difference of mercury level $h_2 = 40cm = 0.4m$

Height of the liquid in the left limb $= 15cm = 0.15m$

Let the pressure in the pipe $= p$

Equating pressures above datum line   A-- A

$$\rho_2 g h_2 + \rho_1 g h_1 + P = 0$$

$$P = - [\rho_2 g h_2 + \rho_1 g h_1]$$

$$= - [13.6 \times 1000 \times 9.81 \times 0.4 + 800 \times 9.81 \times 0.15]$$

$$= 53366.4 + 1177.2$$

$$= -54543.6 \ N/m^2$$

$$\underline{P = - 5.454 \ N/cm^2}$$

Tutorial Questions

1. A piston with a diameter of 9.95 cm operates in a cylinder of 10 cm diameter and 12 cm length. The space between them is filled with a lubricating oil having a viscosity of 0.65 poise. Determine the piston speed when subjected to an axial force of 5 N.

2. Calculate the height to which water rises through capillary action in a glass tube with a 2 mm bore, given the surface tension at the current temperature is 0.075 N/m.

3. A plate positioned 0.05 mm away from a fixed plate moves at a velocity of 1.2 m/s and requires a force of 2.2 N/m to maintain this speed. Find the viscosity of the fluid between the plates.

4. The gap between two parallel square plates, each with a side length of 0.8 m, is filled with an oil having a specific gravity of 0.8. With a plate moving at 1.25 m/s and requiring a force of 51.2 N, determine (i) the dynamic viscosity of the oil in poise and (ii) the kinematic viscosity in stokes.

5. In a U-tube differential manometer connecting two pressure pipes, Pipe A contains carbon tetrachloride with a specific gravity of 1.594 under a pressure of 11.772 N/cm², while Pipe B contains oil with a specific gravity of 0.8 under the same pressure. Pipe A is positioned 2.5 m above Pipe B. Calculate the pressure difference measured by mercury in the U-tube.

6. Enumerate all the properties of fluids and derive Newton's law of viscosity.

7. Illustrate atmospheric, gauge, and vacuum pressure with a clear diagram.

8. Elaborate on differential manometers, outlining how they can be utilized to measure pressure differences.