SREENIVASA INSTITUTE OF TECHNOLOGY AND MANAGEMENT STUDIES

(AUTONOMOUS)

DEPARTMENT OF MECHANICAL ENGINEERING

COURSE MATERIAL

Subject Name	Fluid Mechanics and Hydraulic Machines
Subject Code	23MEC241T
Semester	IV Semester
Academic Year	2025-26
Regulation	R23

Unit-I

Fluid Statics, Buoyancy and Flotation

UNIT – I

Fluid Statics:

- Dimensions and Units.
- Physical Properties of fluids- Specific gravity, viscosity, surface tension.
- Vapour pressure and their influence on fluid motion.
- Atmospheric, gauge and vaccum pressure.
- Measurement of pressure- Piezometer, U-tube and Differential manometers.

COURSE OUTLINE

UNIT -1

LECTURE	LECTURE TOPIC	KEY ELEMENTS	Learning objectives
1	Introduction to FMHM	Units and dimensions.	Remember the units (B1)
2	Physical Properties of fluid	Definition of Specific gravity, Viscosity, Surface tension	• Analyze Law of viscosity (B4) • Apply Surface tension concepts in droplet (B3)
3	Vapour pressure and their influence in fluid motion	Concepts of Vapour pressure	Understanding influence of vapour pressure due change in temperature (B2)
4	Atmospheric, gauge and vaccum pressure	Classification of Pressure	Evaluate pressure (B5)
5	Measurement of pressure	Derivation of Piezometer, U-Tube Manometer	Apply to measure pressure (B3)
6	Measurement of pressure	Derivation of Differential	Apply to measure pressure (B3)

COURSE OUTLINE

UNIT -1

LECTURE	LECTURE TOPIC	KEY ELEMENTS	Learning objectives
7	Example Problems (2/3 classes)		

TOPICS TO BE COVERED

- Introduction to Fluid Mechanics
- Application of Fluid Mechanics
- Units and Dimensions
- Definitions
- Problems

LECTURE 1

Introduction – Units and Dimensions

INTRODUCTION

- Fluid Mechanics is basically a study of:
  - ➢ Physical behavior of fluids and fluid systems and laws governing their behavior.
  - ➢ Action of forces on fluids and the resulting flow pattern.
- Fluid is further sub-divided in to liquid and gas.
- The liquids and gases exhibit different characteristics on account of their different molecular structure.

FLUID MECHANICS COVER MANY AREAS LIKE:

- Design of wide range of hydraulic structures (dams, canals, weirs etc) and machinery (Pumps, Turbines etc).
- Design of complex network of pumping and pipe lines for transporting liquids. Flow of water through pipes and its distribution to service lines.
- Fluid control devices both pneumatic and hydraulic.
- Design and analysis of gas turbines and rocket engines and air–craft.
- Power generation from hydraulic, stream and Gas turbines.
- Methods and devices for measurement of pressure and velocity of a fluid in motion.

UNITS AND DIMENSIONS:

- A dimension is a name which describes the measurable characteristics of an object such as mass, length and temperature etc. a unit is accepted standard for measuring the dimension. The dimensions used are expressed in four fundamental dimensions namely Mass, Length, Time and Temperature.
- Mass (M) – Kg
- Length (L) – m
- Time (T) – S
- Temperature (t) – ^{0}C or K (Kelvin)

UNITS AND DIMENSIONS:

- **Density:** Mass per unit volume= kg/m^3
- **Newton:** Unit of force expressed in terms of mass and acceleration, according to Newton's 2nd law motion. Newton is that force which when applied to a mass of 1 kg gives an acceleration $1 m/Sec^2$. F=Mass x Acceleration = $kg – m/sec^2$ = N.
- **Pascal:** A Pascal is the pressure produced by a force of Newton uniformly applied over an area of 1 m^2. Pressure = Force per unit area = N/ m^2 = Pascal or P_a.
- **Joule:** A joule is the work done when the point of application of force of 1 Newton is displaced Work = Force per unit = N/m = J or Joule.
- **Watt:** A Watt represents a work equivalent of a Joule done per second.
- Power = Work done per unit time = J/ Sec = W or Watt.

DEFINITIONS

Density or Mass Density:

- The density or mass density of a fluid is defined as the ratio of the mass of the fluid to its volume. Thus the mass per unit volume of the fluid is called density.
- It is denoted by ρ .
- The unit of mass density is Kg/m^3

$$\rho = \frac{\text{Mass of fluid}}{\text{Volume of fluid}}$$

- The value of density of water is $1000 Kg/m^3$.

DEFINITIONS

- **Specific weight or Specific density:** It is the ratio between the weights of the fluid to its volume. The weight per unit volume of the fluid is called weight density and it is denoted by **w**.

$$w = \frac{\text{Weight of fluid}}{\text{Volume of fluid}} = \frac{\text{Mass of fluid} \times \text{Acceleration due to gravity}}{\text{Volume of fluid}}$$

$$= \frac{\text{Mass of fluid} \times g}{\text{Volume of fluid}} = \rho \times g$$

- **Specific volume:** It is defined as the volume of the fluid occupied by a unit mass or volume per unit mass of fluid is called Specific volume.

$$\text{Specific volume} = \frac{\text{Volume of the fluid}}{\text{Mass of fluid}} = \frac{1}{\frac{\text{Mass of fluid}}{\text{Volume of the fluid}}} = \frac{1}{\rho}$$

- Thus the Specific volume is the reciprocal of Mass density. It is expressed as m^3/kg and is commonly applied to gases.

DEFINITIONS

- **<u>Specific Gravity:</u>** It is defined as the ratio of the Weight density (or density) of a fluid to the Weight density (or density) of a standard fluid. For liquids the standard fluid taken is water and for gases the standard liquid taken is air. The Specific gravity is also called relative density. It is a dimension less quantity and it is denoted by **s**.
- **S** (for liquids) = $\frac{\text{weight density of liquid}}{\text{weight density of water}}$
- **S** (for gases) = $\frac{\text{weight density of gas}}{\text{weight density of air}}$

PROBLEMS

1. Calculate the density, specific weight and weight of one liter of petrol of specific gravity = 0.7

Sol: i) Density of a liquid = S

$$\rho = 0.7 \times 1000 = 700 \text{ kg/m}^3$$

ii) Specific weight w = $\rho \times g = 700 \times 9.81 = 6867 \text{ N/m}^3$

iii) Weight (w) Volume = 1 liter = 0.001 m^3

We know that, specific weight w = $\dfrac{\text{weight of fluid}}{\text{volume of the fluid}}$

Weight of petrol = w× volume of petrol

$= 6867 \times 0.001$

$= 6.867 \text{ N}$

TOPICS TO BE COVERED

- Properties of fluids
- Viscosity
- Kinematic Viscosity
- Newton’s Law of viscosity
- Types of Fluids
- Surface tension

LECTURE 2

Properties of Fluids

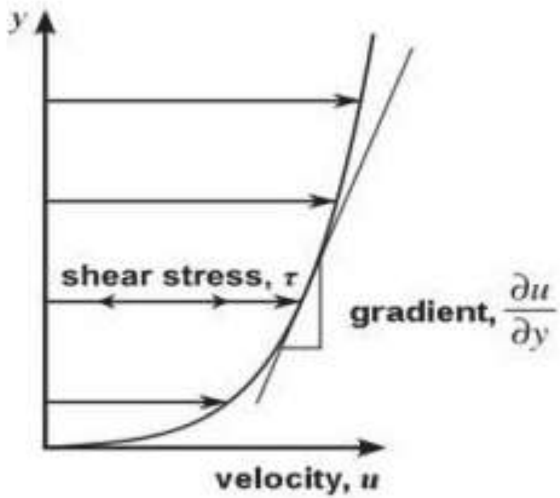
PROPERTIES OF FLUID

- Viscosity
- Surface tension
  - on liquid droplet
  - on hollow bubble
  - on liquid jet
- Capillarity
  - Capillary rise
  - Capillary fall

VISCOSITY

DEFINITION

- It is defined as the property of a fluid which offers resistance to the movement of one layer of the fluid over another adjacent layer of the fluid.
- When the two layers of a fluid, at a distance ‘dy’ apart, move one over the other at different velocities, say u and u+du.
- The viscosity together with relative velocities causes a shear stress acting between the fluid layers.



VISCOSITY

- The top layer causes a shear stress on the adjacent lower layer while the lower layer causes a shear stress on the adjacent top layer.
- This shear stress is proportional to the rate of change of velocity with respect to y. It is denoted by symbol τ (tau).

$$\tau \propto \frac{du}{dy}$$

$$\tau = \mu \frac{du}{dy}$$

- Where μ is the constant of proportionality and is known as the co-efficient of dynamic viscosity or only viscosity. $\frac{du}{dy}$ represents the rate of shear strain or rate of shear deformation or velocity gradient.
- From the above equation, we have $\mu = \frac{\tau}{\left(\frac{du}{dy}\right)}$
- Thus, viscosity is also defined as the shear stress required producing unit rate of shear strain.

KINEMATIC VISCOSITY

- It is defined as the ratio between dynamic viscosity and density of fluid.
- It is denoted by symbol ϑ (nu)

$$\vartheta = \frac{\text{viscosity}}{\text{density}} = \frac{\mu}{\rho}$$

- The unit of viscosity in CGS is called poise and is equal to dyne-see/ cm^2
- The unit of kinematic viscosity is m^2 /sec
- Thus one stoke = cm^2/sec = $\left(\frac{1}{100}\right)^2$ m^2/sec= 10^{-4} m^2/sec

NEWTON'S LAW OF VISCOSITY

- It states that the shear stress (τ) on a fluid element layer is directly proportional to the rate of shear strain.
- The constant of proportionality is called the co- efficient of viscosity.
- It is expressed as:

$$\tau = \mu \frac{du}{dy}$$

- Fluids which obey above relation are known as NEWTONIAN fluids and fluids which do not obey the above relation are called NON-NEWTONIAN fluids.

TYPES OF FLUIDS

- The fluids may be classified in to the following five types.

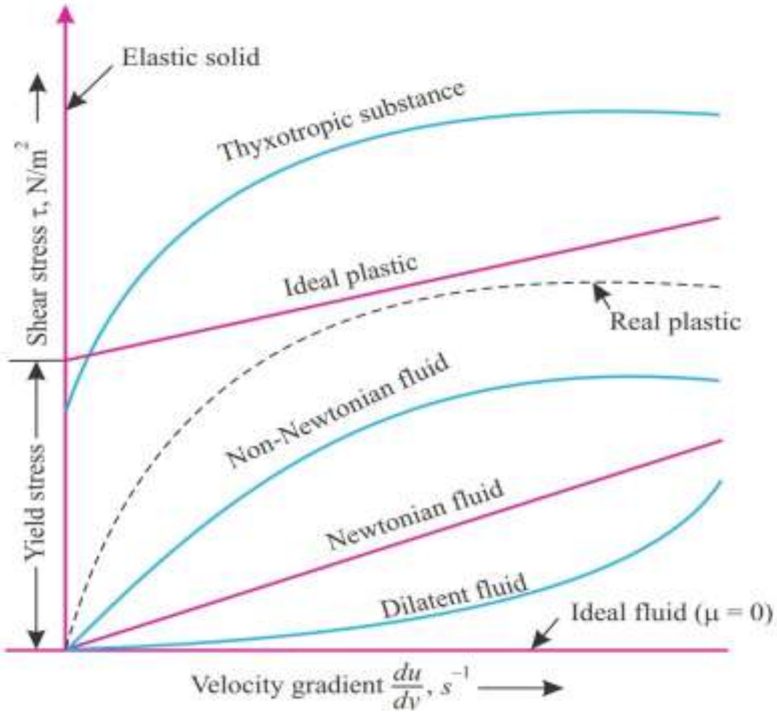
➢ Ideal fluid

➢ Real fluid

➢ Newtonion fluid

➢ Non-Newtonion fluid

➢ Ideal plastic fluid



TYPES OF FLUIDS

- **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.
- **Real fluid**: A fluid possessing a viscosity is known as real fluid. All fluids in actual practice are real fluids.
- **Newtonian fluid**: A real fluid, in which the stress is directly proportional to the rate of shear strain, is known as Newtonian fluid.
- **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.
- **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

SURFACE TENSION ON LIQUID DROPLET

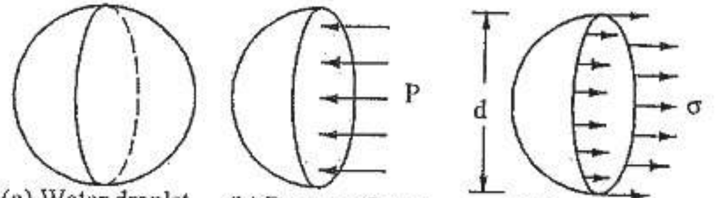
- Consider a small spherical droplet of a liquid of radius ‘r’ on the entire surface of the droplet, the tensile force due to surface tension will be acting
- Let σ = surface tension of the liquid

p = pressure intensity inside the droplet (In excess of outside pressure intensity)

d = Diameter of droplet

- Let, the droplet is cut in to two halves. The forces acting on one half (say left half) will be

FORCES ON DROPLET



(a) Water droplet (b) Pressure forces (c) Surface tension

SURFACE TENSION ON LIQUID DROPLET

- Tensile force due to surface tension acting around the circumference of the cut portion = σ ×circumference = σ × πd
- Pressure force on the area $\frac{\pi}{4}d^2 = p \times \frac{\pi}{4}d^2$
- These two forces will be equal to and opposite under equilibrium conditions i.e.

$$p \times \frac{\pi}{4}d^2 = \sigma \pi d$$

$$p = \frac{\sigma \pi d}{\frac{\pi}{4}d^2}$$

$$p = \frac{4\sigma}{d}$$

SURFACE TENSION ON HOLLOW BUBBLE

- A hallows bubble like soap in air has two surfaces in contact with air, one inside and other outside.
- Thus, two surfaces are subjected to surface tension.

$$p \times \frac{\pi}{4} d^2 = 2(\sigma \pi d)$$

$$p = \frac{8\sigma}{d}$$

SURFACE TENSION ON LIQUID JET

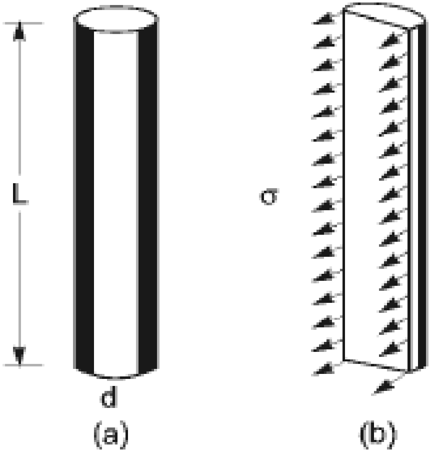
- Consider a liquid jet of diameter ‘d’ length ‘L’
- Let, p = pressure intensity inside the liquid jet above the outside pressure

  σ = surface tension of the liquid
- Consider the equilibrium of the semi- jet .
- Force due to pressure = p × area of the semi-jet = p × L × d
- Force due to surface tension = σ × 2L

Equating above forces we get,

$$p \times L \times d = \sigma \times 2L$$

$$p = \frac{2\sigma}{d}$$



TOPICS TO BE COVERED

- Capillarity
- Expression for Capillary rise
- Expression for Capillary fall
- Vapor pressure
- Variation of vapor pressure with temperature

LECTURE 3

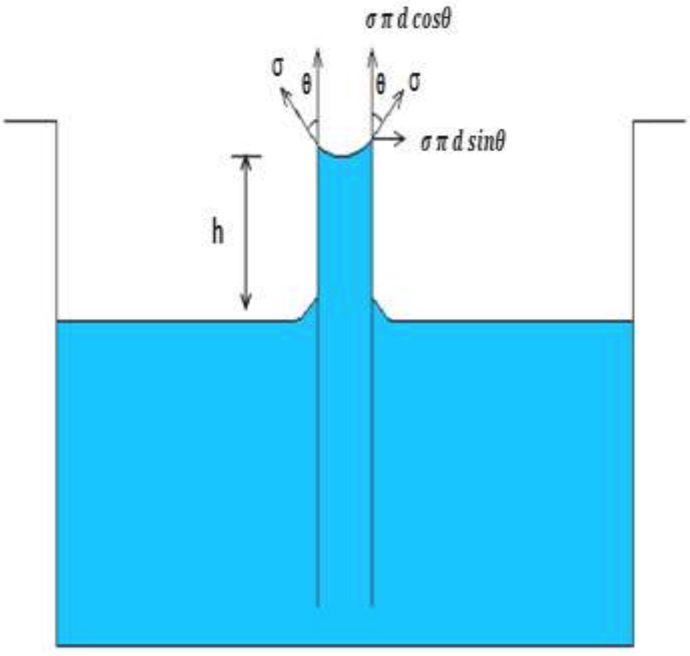
Concept of Vapor pressure & its variation

CAPILLARITY

- Capillarity is defined as a phenomenon of rise or fall of a liquid surface in a small tube relative to the adjacent general level of liquid when the tube is held vertically in the liquid.
- The rise of liquid surface is known as capillary rise, while the fall of the liquid surface is known as capillary depression.
- It is expressed in terms of ‘cm’ or ‘mm’ of liquid.
- Its value depends upon the specific weight of the liquid, diameter of the tube and surface tension of the liquid.

EXPRESSION FOR CAPILLARY RISE

- Consider a glass tube of small diameter 'd' opened at both ends and is inserted in a liquid.
- The liquid will rise in the tube above the level of the liquid outside the tube.
- Let 'h' be the height of the liquid in the tube.
- Under a state of equilibrium, the weight of the liquid of height 'h' is balanced by the force at the surface of the liquid in the tube.



EXPRESSION FOR CAPILLARY RISE

- But, the force at the surface of the liquid in the tube is due to surface tension.
- Let σ = surface tension of liquid

θ = Angle of contact between the liquid and glass tube

- The weight of the liquid of height ‘h’ in the tube

$$= (\text{area of the tube} \times h) \times \rho \times g = \frac{\pi}{4} d^2 \times h \times \rho \times g$$

Where ‘ρ’ is the density of the liquid.

- The vertical component of the surface tensile force = (σ × circumference) × cosθ = σ × πd × cosθ

EXPRESSION FOR CAPILLARY RISE

For equilibrium, $\frac{\pi}{d} d^2 \times h \times \rho \times g = \sigma\, \pi d \cos\theta$,

$$h = \frac{\sigma\, \pi\, d \cos\theta}{\frac{\pi}{d} d^2 \times \rho \times g}$$

$$h = \frac{4\sigma\cos\theta}{\rho g d}$$

The value of θ is equal to ‘0’ between water and clean glass tube, then cos θ = 1, then

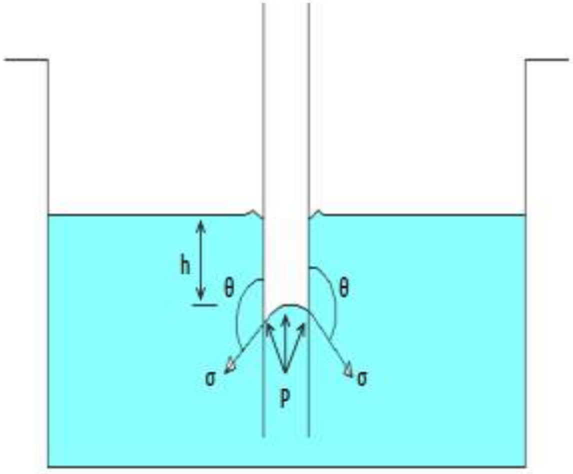
$$h = \frac{4\sigma}{\rho g d}$$

EXPRESSION FOR CAPILLARY FALL

- If the glass tube is dipped in mercury, the Level of mercury in the tube will be lower than the general level of the outside liquid.

$$h = \frac{4\sigma\cos\theta}{\rho g d}$$

- The value θ of for glass & mercury 128^0



VAPOUR PRESSURE

- A change from the liquid state to the gaseous state is known as Vaporizations.
- The vaporization (which depends upon the prevailing pressure and temperature condition) occurs because of continuous escaping of the molecules through the free liquid surface.
- Consider a liquid at a temp. of 20°C and pressure is atmospheric is confined in a closed vessel.
- This liquid will vaporize at 100°C, the molecules escape from the free surface of the liquid and get accumulated in the space between the free liquid surface and top of the vessel.
- These accumulated vapours exert a pressure on the liquid surface. This pressure is known as vapour pressure of the liquid or pressure at which the liquid is converted in to vapours.

VAPOUR PRESSURE

- Consider the same liquid at 20° C at atmospheric pressure in the closed vessel and the pressure above the liquid surface is reduced by some means; the boiling temperature will also reduce.
- If the pressure is reduced to such an extent that it becomes equal to or less than the vapour pressure, the boiling of the liquid will start, though the temperature of the liquid is 20°C.
- Thus, the liquid may boil at the ordinary temperature, if the pressure above the liquid surface is reduced so as to be equal or less than the vapour pressure of the liquid at that temperature.

VARIATION OF VAPOUR PRESSURE WITH TEMPERATURE

- The vapour pressure of a liquid varies with its temperature.
- As the temperature of a liquid or solid increases its vapour pressure also increases.
- Conversely, vapour pressure decreases as the temperature decreases.

TOPICS TO BE COVERED

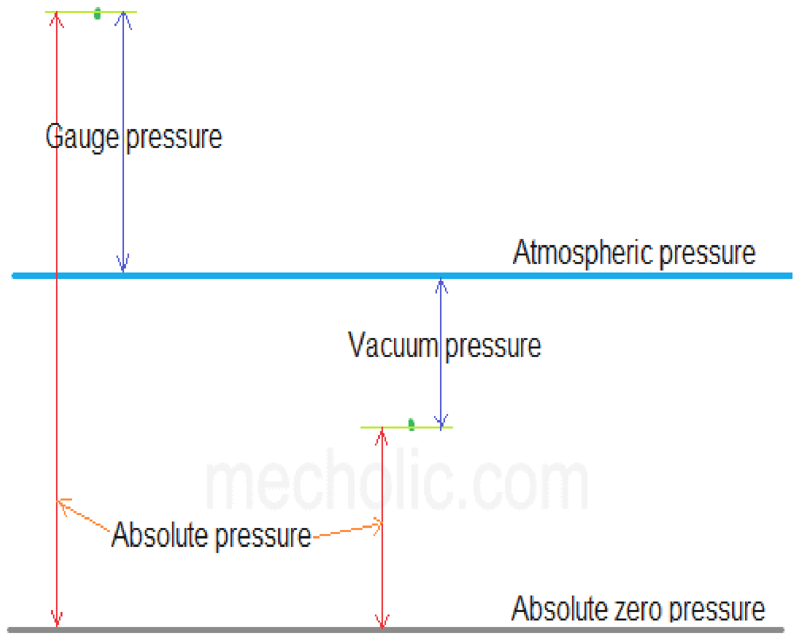
- Pressure Measuring System
- Atmospheric, Gauge & Vaccum pressure
- Measurement of pressure
- Piezometer
- U Tube manometer

LECTURE 4

Pressure Measuring System

PRESSURE MEASURING SYSTEM

- The pressure on a fluid is measure in two different systems.
- In one system, it is measured above the absolute zero or complete vacuum and it is called the Absolute pressure.
- In other system, pressure is measured above the atmospheric pressure and is called Gauge pressure.



DEFINITIONS

- **ABSOLUTE PRESSURE:** It is defined as the pressure which is measured with reference to absolute vacuum pressure.
- **GAUGE PRESSURE:** It is defined as the pressure, which is measured with the help of a pressure measuring instrument, in which the atmospheric pressure is taken as datum. The atmospheric on the scale is marked as zero.
- **VACUUM PRESSURE:** It is defined as the pressure below the atmospheric pressure

i) Absolute pressure = Atmospheric pressure+ gauge pressure

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

Vaccum pressure= atmospheric pressure - Absolute pressure

- The atmospheric pressure at sea level at 15^0C 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.
  - Manometers
  - Mechanical gauges.

- **Manometers:** Manometers are defined as the devices used for measuring the pressure at a point in a fluid by balancing the column of fluid by the same or another column of fluid. They are classified as:
  - Simple Manometers
  - Differential Manometers

MEASUREMENT OF PRESSURE

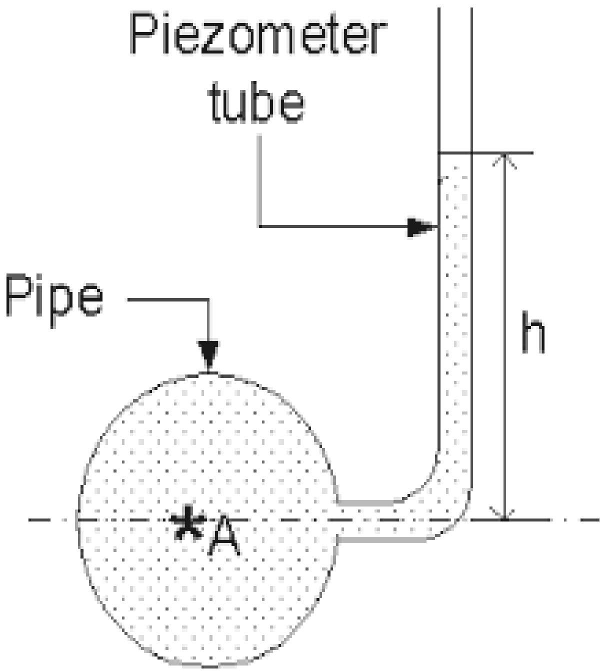
- **Mechanical Gauges:** These are defined as the devices used for measuring the pressure by balancing the fluid column by the spring or dead weight.
- The commonly used Mechanical pressure gauges are:
    - Diaphragm pressure gauge
    - Bourdon tube pressure gauge
    - Dead – Weight pressure gauge
    - Bellows pressure gauge.

SIMPLE MANOMETER

- A simple manometer consists of a glass tube having one of its ends connected to a point where pressure is to be measured and the other end remains open to the atmosphere.
- The common types of simple manometers are:
    - ➢ Piezometer.
    - ➢ U-tube manometer (for gauge & vaccum pressure)
    - ➢ Single column manometer
        - ❑ Vertical Single column manometer
        - ❑ Inclined Single column manometer

PIEZOMETER

- It is a simplest form of manometer used for measuring gauge pressure.
- One end of this manometer is connected to the point where pressure is to be measured and other end is open to the atmosphere.
- The rise of liquid in the Piezometer gives pressure head at that point A.
- The height of liquid say water is ‘h’ in piezometer tube, then



Pressure at A = ρ g h $\frac{N}{m^2}$

U- TUBE MANOMETER

- It consists of a glass tube bent in u-shape, one end of which is connected to a point at which pressure is to be measured and other end remains open to the atmosphere.
- The tube generally contains mercury or any other liquid whose specific gravity is greater than the specific gravity of the liquid whose pressure is to be measured.
- **For Gauge Pressure:** Let B is the point at which pressure is to be measured, whose value is p. The datum line A – A

U- TUBE MANOMETER

- Let

h_1 = height of light liquid above datum line

h_2 =height of heavy liquid above datum line

S_1 = sp. gravity of light liquid

ρ_1= density of light liquid

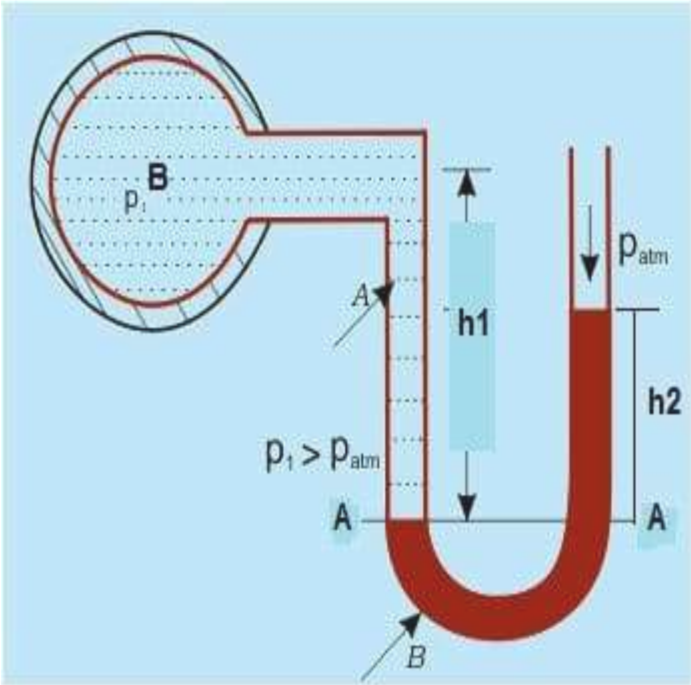
= 1000 S_1

S_2 = sp. gravity of heavy liquid

ρ_2= density of heavy liquid

= 1000 S_2

GAUGE PRESSURE



U- TUBE MANOMETER

- As the pressure is the same for the horizontal surface. Hence the pressure above the horizontal datum line A – A in the left column and the right column of U – tube manometer should be same.
- Pressure above A—A ion the left column = p + ρ_1 gh_1
- Pressure above A – A in the left column = ρ_2 gh_2
- Hence equating the two pressures p + ρ_1 gh_1 = ρ_2 gh_2

$$p = \rho_2 g h_2 - \rho_1 g h_1$$

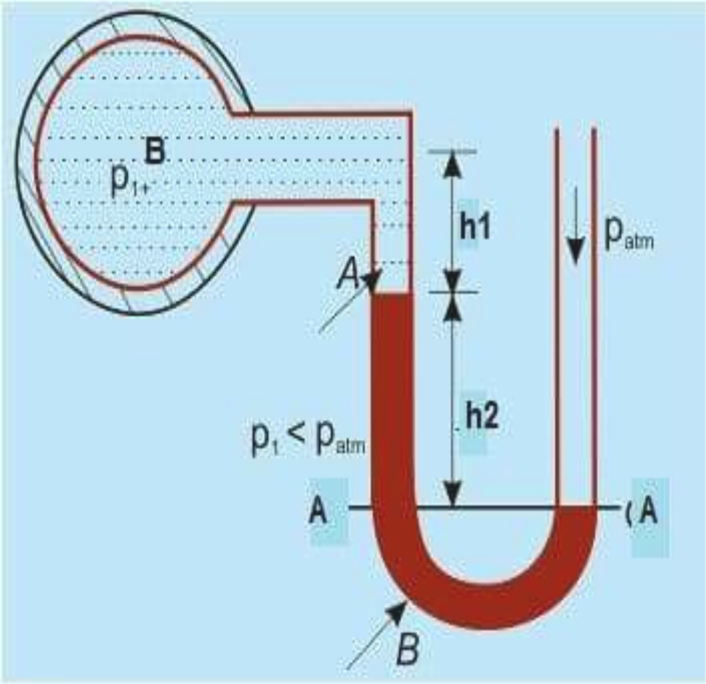
U- TUBE MANOMETER

- For measuring vacuum pressure, the level of heavy fluid in the manometer will be as shown in fig.
- Pressure above AA in the left column = ρ_2 g h_2 + ρ_1g h_1+ P
- Pressure head in the right column above AA = 0
- Therefore, equating two pressures we get,

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

$$\mathbf{p = -(\rho_2 g h_2 + \rho_1 g h_1)}$$

VACCUM PRESSURE



TOPICS TO BE COVERED

- Single column Manometer
- Vertical single column manometer
- Inclined single column manometer
- Differential manometer
- U- Tube differential manometer
- Inverted U- Tube differential manometer

LECTURE 5

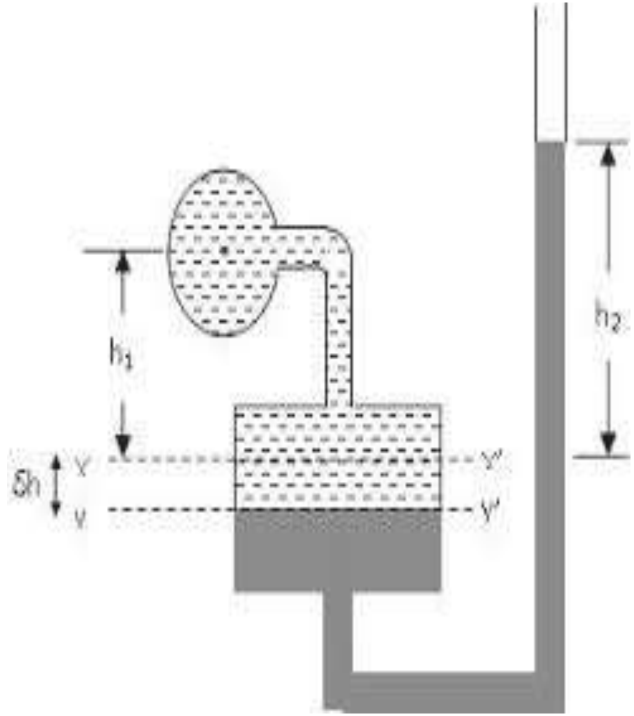
Measurement of pressure- Types of Manometers

SINGLE COLUMN MANOMETER

- Single column manometer is a modified form of a U- tube manometer in which a reservoir, having a large cross sectional area (about. 100 times) as compared to the area of tube is connected to one of the limbs (say left limb) of the manometer.
- Due to large cross sectional area of the reservoir for any variation in pressure, the change in the liquid level in the reservoir will be very small which may be neglected and hence the pressure is given by the height of the liquid in the other limb.
- The other limb may be vertical or inclined.
- Thus, there are two types of single column manometer
    - ➢ Vertical Single Column Manometer
    - ➢ Inclined Single Column Manometer

VERTICAL SINGLE COLUMN MANOMETER

- Let X – X be the datum line in the reservoir and in the right limb of the manometer, when it is connected to the pipe, when the Manometer is connected to the pipe, due to high pressure at A.
- The heavy pressure in the reservoir will be pushed downwards and will rise in the right limb.



DERIVATION

- Let, Δh= fall of heavy liquid in the reservoir

  h_2= rise of heavy liquid in the right limb

  h_1= height of the centre of the pipe above X – X

  p_A= Pressure at A, which is to be measured.

  A = Cross- sectional area of the reservoir

  a = cross sectional area of the right limb

  S_1= Specific. Gravity of liquid in pipe

  S_2= sp. Gravity of heavy liquid in the reservoir and right limb

  ρ_1 = density of liquid in pipe

  ρ_2 = density of liquid in reservoir

- Fall of heavy liquid reservoir will cause a rise of heavy liquid level in the right limb

$$A \times \Delta h = a \times h_2$$

$$\Delta h = \frac{a \times h_2}{A} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

- Now consider the datum line Y –Y
- Then the pressure in the right limb above Y – Y = $\rho_2 \times g \times (\Delta h+h_2)$
- Pressure in the left limb above Y—Y = $\rho_1 \times g \times (\Delta h+h_1) + P_A$
- Equating the pressures, we have

$$\rho_2\, g \times (\Delta h+h_2) = \rho_1 \times g \times (\Delta h+h_1) + p_A$$

$$p_A = \rho_2 \times g \times (\Delta h+h_2) - \rho_1 \times g \times (\Delta h+h_1)$$

$$= \Delta h\ (\rho_2 g\ \rho_1 g) + h_2\rho_2 g - h_1\rho_1 g$$

- But, from eq. (1) $\Delta h = \frac{a \times h_2}{A}$
- $P_A = \frac{a \times h_2}{A} (\rho_2 g - \rho_1 g) + h_2 \rho_2 g - h_1 \rho_1 g$
- As the area A is very large as compared to a, hence the ratio $\frac{a}{A}$ becomes very small and can be neglected Then,

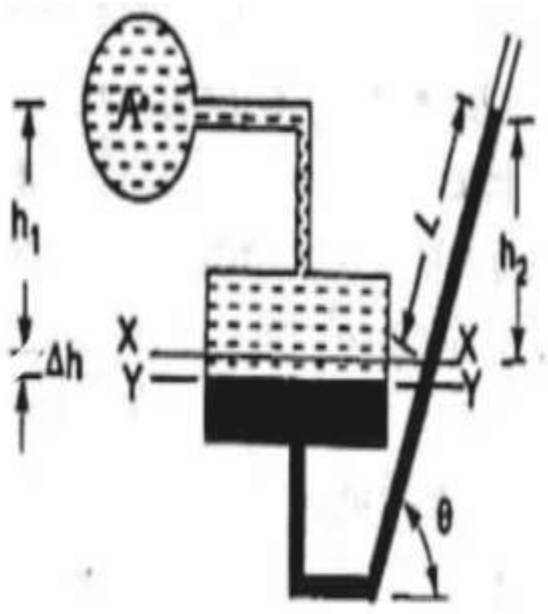
$$\mathbf{p_A = h_2 \rho_2 g - h_1 \rho_1 g} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

INCLINED SINGLE COLUMN MANOMETER

- The manometer is more sensitive.
- Due to inclination the distance moved by heavy liquid in the right limb will be more.
- Let L= length of heavy liquid moved in the rite limb

θ = inclination of right Limb with horizontal.

H_2 = vertical rise of heavy liquid in the right limb above X – X = L sinθ



- From above eq.(2), the pressure at A is

$$p_A = h_2\rho_2 g - h_1\rho_1 g$$

- Substituting the value of h_2

$$\mathbf{p_A = L\sin\theta\,\rho_2 g - h_1\rho_1 g}$$

DIFFERENTIAL MANOMETERS

- Differential manometers are the devices used for measuring the difference of pressure between two points in a pipe or in two different pipes.
- A differential manometer consists of a U-tube, containing heavy liquid, whose two ends are connected to the points, whose difference of pressure is to be measured.
- The common types of U- tube differential manometers are:
    - U- Tube differential manometer
    - Inverted U- tube differential manometer

U-TUBE DIFFERENTIAL MANOMETER

TWO POINTS A AND B ARE AT DIFFERENT LEVELS AND ALSO CONTAINS LIQUIDS OF DIFFERENT SP.GR.

- These points are connected to the U – Tube differential manometer.
- Let the pressure at A and B are p_A and p_B
- Let h = Difference of mercury levels in the u – tube

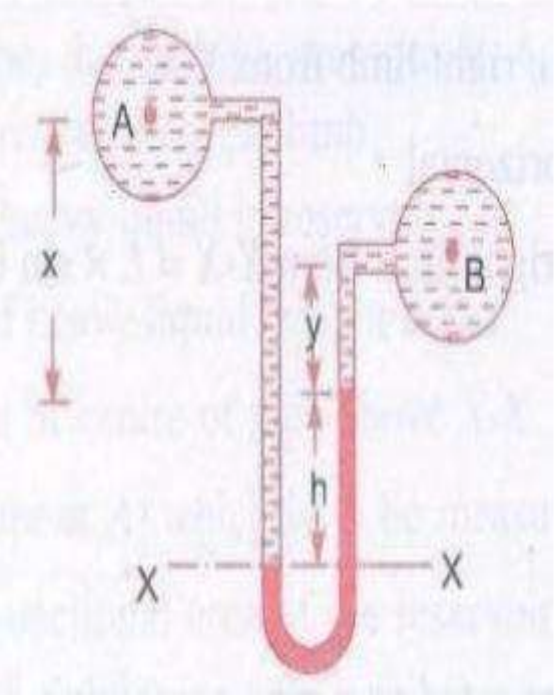
y = Distance of centre of B from the mercury level in the right limb

x = Distance of centre of A from the mercury level in the left limb

ρ_1 = Density of liquid A

ρ_2 = Density of liquid B

ρ_g= Density of heavy liquid or mercury



- Taking datum line at X – X
- Pressure above X – X in the left limb $=\rho_1 g(h + x) + p_A$

  (where p_A = Pressure at A)
- Pressure above X – X in the right limb = $\rho_g\ g\ h + \rho_2 g\ y + P_B$

  (where p_B = Pressure at B)
- Equating the above two pressures, we have

$$\rho_1 g(h + x) + p_A = \rho_g\ g\ h + \rho_2\ g\ y + p_B$$

$$p_A - p_B = \rho_g\ g\ h + \rho_2 g\ y - \rho_1 g\ (h + x)$$

$$= h\ g\ (\rho_g - \rho_1) + \rho_2 g\ y - \rho_1 g\ x$$

- Therefore, Difference of Pressures at A and B is

$$h\ g\ (\rho_g - \ell_1) + \rho_2\ g\ y - \rho_1 g\ x$$

U-TUBE DIFFERENTIAL MANOMETER

TWO POINTS A AND B ARE AT SAME LEVELS AND ALSO CONTAINS SAME LIQUIDS OF SP.GR.

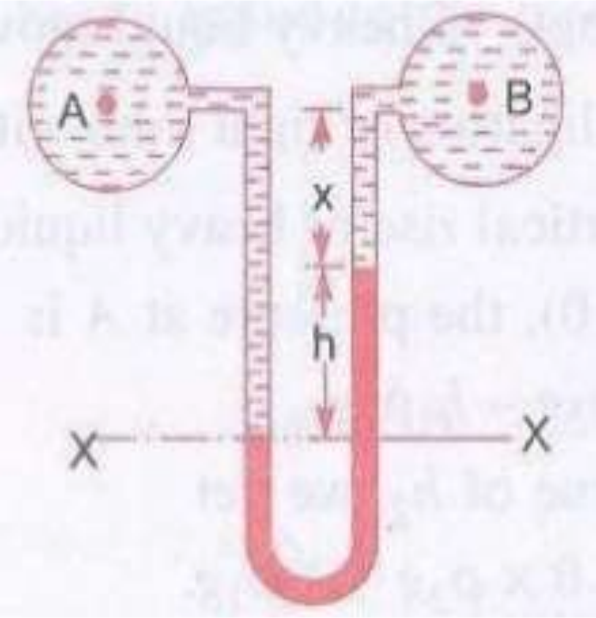
- Then pressure above X – X in the right limb = ρ_g g h + ρ_1g x + P_B
- Pressure above X—X in the left limb = ρ_1g (h + x) + P_A
- Equating the two pressures

$$\rho_g \, g \, h + \rho_1 g \, x + p_B = \rho_1 g \, (h + x) + p_A$$

$$P_A - P_B = \rho_g \, g \, h + \rho_1 g \, x - \rho_1 g(h + x)$$

$$= g \, h \, (\rho_g - \rho_1)$$

- Therefore, Difference of pressure at A and B = $g \, h \, (\rho_g - \rho_1)$



TOPICS TO BE COVERED

- Applications
- Problems on Viscosity
- Problems on manometers

LECTURE 6

Applications & Problems

APPLICATIONS

- Specific pressure monitoring applications
- Visual monitoring of air and gas pressure for compressors.
- Vacuum equipment and specialty tank applications such as medical gas cylinders, fire extinguishers.
- In power plants, mercury absolute manometer have been used to check condenser efficiency by monitoring vacuum at several points of the condenser
- Used for the research of atmosphere of other planets.
- And many more applications such as in whether studies, research labs, gas analysis and in medical equipment's.
- Never operate damage equipment.
- Meter and its tubing should be free from any breaking and blockage.

- In addition, since the tubes in many manometers are made of glass and can be easily broken, it is important to use care in handling these manometers.
- Electronic manometers do not measure water pressures; under these conditions they will fail. Do not exceed 10 PSI input pressure.
- Some types of liquids used in manometers are toxic and can be damaging to the environment. Therefore, when using manometers to measure or indicate pressure, do not connect any manometer to a pressure that has the potential to exceed the range of the manometer. This could cause the liquid to be forced out of the tube

PROBLEM-1

- Two horizontal plates are placed 1.25 cm apart, the space between them being filled with oil of viscosity 14 poises. Calculate shear stress in oil, if the upper plate is moved velocity of 2.5 m/sec.

Sol: Given Data

Distance between the plates, dy= 1.25 cm = 0.0125m

Viscosity, μ = 14 poise = $\frac{14}{10}$ N s/m^2

Velocity of upper plate, u = 2.5 m/sec

Shear stress, $\tau = \mu \frac{du}{dy}$

Where du = change of velocity between plates = u – 0

= u = 2.5 m/sec

$\tau = \frac{14}{10} \times \frac{2.5}{0.0125} =$ **280 N/m²**

PROBLEM-2

- The dynamic viscosity of oil used for lubrication between a shaft and sleeve is 6 poise. The shaft dia. is 0.4m and rotates at 190 rpm. Calculate the power lost in the bearing for a sleeve length of 90mm. The thickness foil film is 1.5mm

<u>Sol: </u>Given Data,

Viscosity, μ = 6 poise = $\frac{6}{10}\frac{\text{N s}}{\text{m}^2}$ = 0.6 $\frac{\text{N s}}{\text{m}^2}$

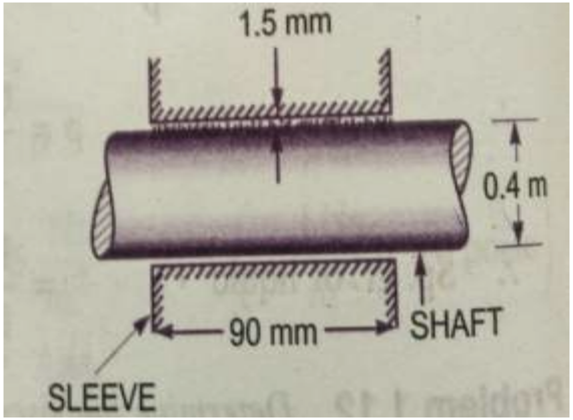
Dia. of shaft, D = 0.4M

Speed of shaft, N = 190 rpm

Sleeve length, L = 90mm = 90

Thickness of a film, t = 1.5mm

= 1.5×10^{-3} m



Tangential velocity of shaft = u = $\frac{\pi DN}{60} = \frac{\pi \times 0.4 \times 190}{60}$ = 3.98 m/sec

Using the relation $\tau = \mu \frac{du}{dy}$

Where du = change of velocity = u – 0 = u = 3.98 m/sec

dy = change of distance = t = 1.5

Then, Shear stress on the shaft

$$\tau = 0.6 \times \frac{3.98}{1.5 \times 10^{-3}} = 1592 \text{ N/m}^2$$

We know that, Shear force on the shaft, F = shear stress × Area

=1592 × πDL= 180.05 N

Torque on the shaft, T = Force × $\frac{D}{2}$ = 36.01 Nm

Therefore, Power lost, P = $\frac{2\pi NT}{60}$ = **716.48 W**

PROBLEM 3

Example 1.5. *The space between two square flat parallel plates is filled with oil. Each side of the plate is 720 mm. The thickness of the oil film is 15 mm. The upper plate, which moves at 3 m/s requires a force of 120 N to maintain the speed. Determine:*

(i) *The dynamic viscosity of the oil;*

(ii) *The kinematic viscosity of oil if the specific gravity of oil is 0.95.*

Solution. Each side of a square plate = 720 mm = 0.72 m

The thickness of the oil, dy = 15 mm = 0.015 m

Velocity of the upper plate = 3 m/s

$\therefore$ Change of velocity between plates, du = 3 – 0 = 3 m/s

Force required on upper plate, F = 120 N

$$\therefore \quad \text{Shear stress, } \tau = \frac{\text{force}}{\text{area}} = \frac{120}{0.72 \times 0.72} = 231.5 \text{ N/m}^2$$

(i) Dynamic viscosity, μ:

We know that,

$$\tau = \mu \cdot \frac{du}{dy}$$

$$231.5 = \mu \cdot \frac{3}{0.015}$$

$$\therefore \quad \mu = \frac{231.5 \times 0.015}{3} = \mathbf{1.16\ N.s/m^2}$$ **(Ans.)**

(ii) Kinematic viscosity, ν:

Weight density of oil, $w = 0.95 \times 9.81 \text{ kN/m}^2 = 9.32 \text{ kN/m}^2 = \text{or } 9320 \text{ N/m}^3$

$$\text{Mass density of oil, } \rho = \frac{w}{g} = \frac{9320}{9.81} = 950$$

$$\text{Using the relation:} \quad \nu = \frac{\mu}{\rho} = \frac{1.16}{950} = 0.00122 \text{ m}^2/\text{s}$$

Hence $\nu = 0.00122 \text{ m}^2/\text{s}$ (Ans.)

PROBLEM 4

Example 1.17. *In the Fig. 1.14 is shown a central plate of area 6 m^2 being pulled with a force of 160 N. If the dynamic viscosities of the two oils are in the ratio of 1:3 and the viscosity of top oil is 0.12 N.s/m^2 determine the velocity at which the central plate will move.*

Solution: Area of the plate, $A = 6\ m^2$

Force applied to the plate, $F = 160$ N

Viscosity of top oil, $\mu = 0.12$ N.s/m^2

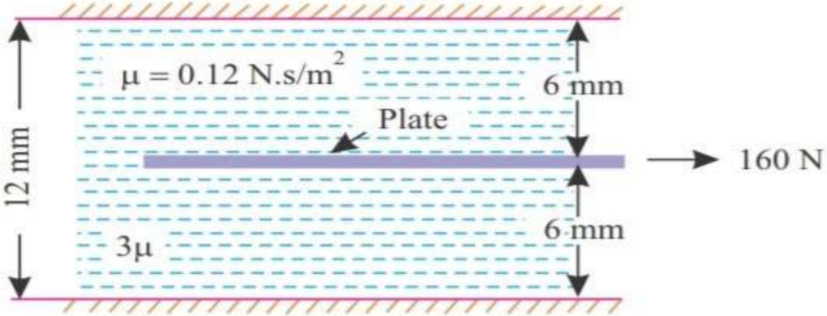


Fig. 1.14

Velocity of the plate, *u*:

Let F_1 = Shear force in the upper side of *thin* (assumed) plate,

F_2 = Shear force on the lower side of the thin plate, and

F = Total force required to drag the plate $(= F_1 + F_2)$

Then, $F = F_1 + F_2 = \tau_1 \times A + \tau_2 \times A$

$$= \mu\left(\frac{\partial u}{\partial y}\right)_1 \times A + 3\mu\left(\frac{du}{dy}\right)_2 \times A$$

(where τ_1 and τ_2 are the shear stresses on the two sides of the plate)

$$160 = 0.12 \times \frac{u}{6 \times 10^{-3}} \times 6 + 3 \times 0.12 \times \frac{u}{6 \times 10^{-3}} \times 6$$

or $160 = 120u + 360u = 480u$ or $u = \frac{160}{480}$ = **0.333 m/s (Ans.)**

PROBLEMS ON SURFACE TENSION

Example 1.24. *In order to form a stream of bubbles, air is introduced through a nozzle into a tank of water at 20°C. If the process requires 3.0 mm diameter bubbles to be formed, by how much the air pressure at the nozzle must exceed that of the surrounding water?*

What would be the absolute pressure inside the bubble if the surrounding water is at 100.3 kN/m²?

Take surface tension of water at 20°C = 0.0735 N/m.

Solution. Diameter of a bubble, $d = 3.0 \text{ mm} = 3 \times 10^{-3}$ m

Surface tension of water at 20°C, $\sigma = 0.0735$ N/m

The excess pressure intensity of air over that of surrounding water, $\Delta p = p$.

We know,
$$p = \frac{4\sigma}{d} = \frac{4 \times 0.0735}{3 \times 10^{-3}} = \mathbf{98\ N/m^2}\ \textbf{(Ans.)}$$

Absolute pressure inside the bubble, p_{abs}:

$$p_{abs} = p + p_{atm}$$
$$= 98 \times 10^{-3} + 100.3$$
$$= 0.098 + 100.3 = \mathbf{100.398\ kN/m^2}\ \textbf{(Ans.)}$$

Example 1.25. *A soap bubble 62.5 mm diameter has an internal pressure in excess of the outside pressure of 20 N/m². What is tension in the soap film?*

Solution. *Given*: Diameter of the bubble, $d = 62.5 \text{ mm} = 62.5 \times 10^{-3}$ m;

Internal pressure in excess of the outside pressure, $p = 20$ N/m².

Surface tension, σ:

Using the relation,
$$p = \frac{8\sigma}{d}$$

i.e.,
$$20 = \frac{8\sigma}{62.5 \times 10^{-3}} \quad \therefore \quad \sigma = 20 \times \frac{62.5 \times 10^{-3}}{8} = \mathbf{0.156\ N/m}\ \textbf{(Ans.)}$$

Example 1.26. *What do you mean by surface tension? If the pressure difference between the inside and outside of the air bubble of diameter 0.01 mm is 29.2 kPa, what will be the surface tension at air-water interface?* **(N.U.)**

Solution. Surface tension is defined *as the tensile force acting on the surface of a liquid in contact with a gas or on the surface between two immiscible liquids such that the contact surface behaves like a membrane under tension.* The magnitude of this force per unit length of the free surface will have the same value as the surface energy per unit area. It is denoted by the letter σ and is expressed as N/m.

$$p \times \frac{\pi}{4} d^2 = \sigma (\pi d)$$

or
$$\sigma = p \times \frac{d}{4}$$

Substituting the values; $d = 0.01 \times 10^{-3}$ m; $p = 29.2 \times 10^3$ Pa (or N/m²), we get

PROBLEM-6

Example 1.30. *Determine the minimum size of glass tubing that can be used to measure water level, if the capillary rise in the tube is not to exceed 0.3 mm. Take surface tension of water in contact with air as 0.0735 N/m.*

Solution. *Given* :Capillary rise, $h = 0.3 \text{ mm} = 0.3 \times 10^{-3}$ m

Surface tension, $\sigma = 0.0735$ N/m

Specific weight of water, $w = 9810 \text{ N/m}^3$.

Size of glass tubing, *d*:

$$\text{Capillary rise, } h = \frac{4\sigma\cos\theta}{wd} = \frac{4\sigma}{wd}$$

(Assuming $\theta = 0$ for water)

$$0.3 \times 10^{-3} = \frac{4 \times 0.0735}{9810 \times d}$$

$$\therefore \quad d = \frac{4 \times 0.0735}{0.3 \times 10^{-3} \times 9810} = 0.1 \text{ m} = \mathbf{100\ mm}$$ **(Ans.)**

PROBLEM 7

Example 1.31. *A U-tube is made up of two capillaries of bores 1.2 m and 2.4 mm respectively. The tube is held vertical and partially filled with liquid of surface tension 0.06 N/m and zero contact angle. If the estimated difference in the level of two menisci is 15 mm, determine the mass density of the liquid.*

Solution. *Given*: Bores of the capillaries:

$$d_1 = 1.2 \text{ mm} = 0.0012 \text{ m}$$

$$d_2 = 2.4 \text{ mm} = 0.0024 \text{ m}$$

Difference of level, $h_1 - h_2 = 15 \text{ mm} = 0.015 \text{ m}$; Angle of contact, $\theta = 0$

Mass density of the liquid, ρ:

$$h_1 = \frac{4\sigma\cos\theta}{wd_1}, \quad \text{and} \quad h_2 = \frac{4\sigma\cos\theta}{wd_2}$$

[where w (= ρg) = weight density of the liquid)]

$$\therefore \quad h_1 - h_2 = \frac{4\sigma}{w}\left[\frac{1}{d_1} - \frac{1}{d_2}\right] \qquad (\because \theta = 0)$$

$$0.015 = \frac{4 \times 0.06}{\rho \times 9.81}\left[\frac{1}{0.0012} - \frac{1}{0.0024}\right] = \frac{0.02446}{\rho} \times 416.67$$

$$\therefore \quad \rho = \frac{0.02446 \times 416.67}{0.015} = \mathbf{679.45\ kg/m^3}\ \textbf{(Ans.)}$$

PROBLEM-8

- 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.

Sol: Given data,

Sp.gr. of liquid, $S_1 = 0.9$

Density of fluid, $\rho_1 = S_1 \times 1000 = 0.9 \times 1000 = 900$ kg/ m^3

Sp.gr. of mercury, $S_2 = 13.6$

Density of mercury, $\rho_2 = 13.6 \times 1000 = 13600$ kg/m^3

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

$p + \rho_1 g h_1 = \rho_2 g h_2$

$p + 900 \times 9.81 \times 0.08 = 13.6 \times 1000 \times 9.81 \times 0.2$

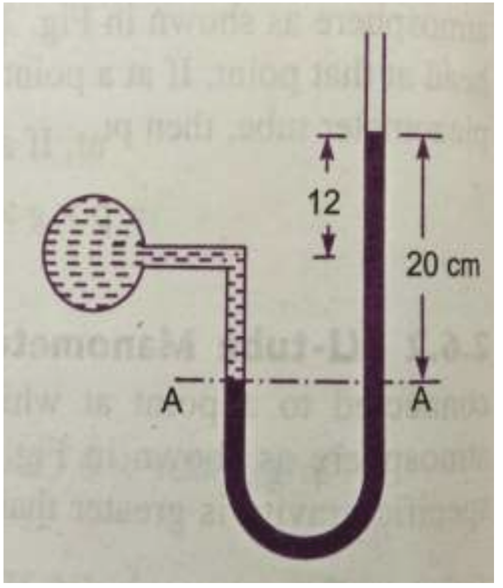
$p = 13.6 \times 1000 \times 9.81 \times 0.2 - 900 \times 9.81 \times 0.08$

$p \ = 26683 - 706$

$p \ = 25977 \text{ N/m}^2$

$p \ = 2.597 \text{ N/cm}^2$

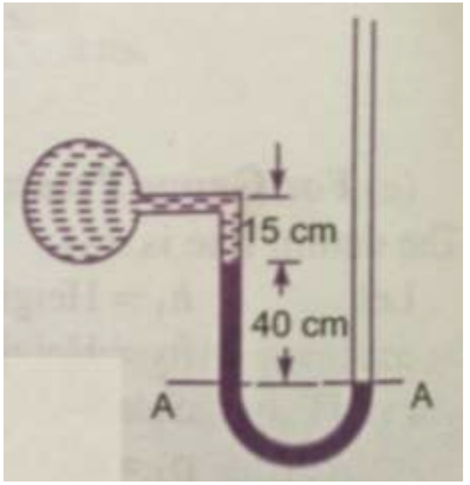
Therefore, Pressure of fluid P= **2.597 N/ cm²**



PROBLEM-9

- 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.

<u>Sol:</u> Given data,



Sp.gr of fluid, $S_1 = 0.8$

Sp.gr. of mercury, $S_2 = 13.6$

Density of the fluid $\rho_1 = S_1 \times 1000 = 0.8 \times 1000$

$= 800\ kg/m^3$

Density of mercury $\rho_2 = 13.6 \times 1000$

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

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

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

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

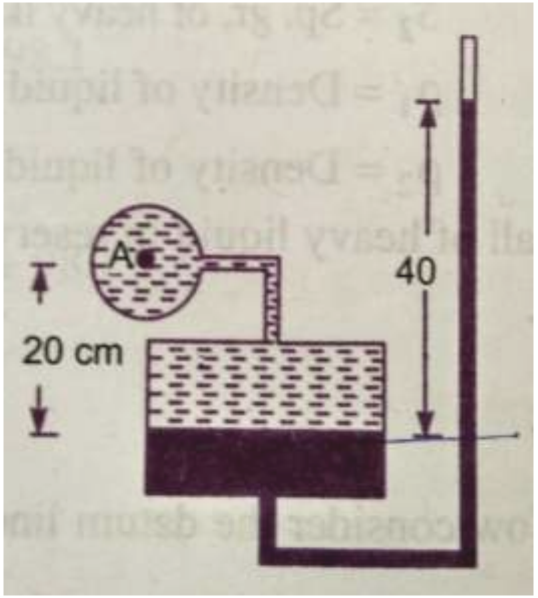
$$= 53366.4 + 1177.2$$

$$= -54543.6 \text{ N/m}^2$$

Therefore, the vacuum pressure in pipe, **$P = - 5.454 \text{ N/cm}^2$**

PROBLEM-10

- A single column manometer is connected to the pipe containing liquid of sp.gr.0.9. Find the pressure in the pipe if the area of the reservoir is 100 times the area of the tube of manometer. sp.gr. of mercury is 13.6. Height of the liquid from the centre of pipe is 20cm and difference in level of mercury is 40cm.



Sol: Given data,

Sp.gr. of liquid in pipe, $S_1 = 0.9$

Density, $\rho_1 = 900\ kg/m^3$

Sp.gr. of heavy liquid, $S_2 = 13.6$

Density, $\rho_2 = 13600$

$$\frac{\text{Area of reservoir}}{\text{Area of right limb}} = \frac{A}{a} = 100$$

Height of the liquid, $h_1 = 20cm = 0.2m$

Rise of mercury in the right limb, $h_2 = 40cm = 0.4m$

Pressure in pipe A

$$p_A = \frac{A}{a} \times \; h_2[\rho_2 g - \rho_1 g] + h_2 \rho_2 g - h_1 \rho_1 g$$

$$= \frac{1}{100} \times 0.4\,[13600 \times 9.81 - 900 \text{ x } 9.81] + 0.4 \times 13600 \times 9.81 - 0.2 \times 900 \times 9.81$$

$$= \frac{0.4}{100}\,[133416 - 8829] + 53366.4 - 1765.8$$

$$= 533.664 + 53366.4 - 1765.8$$

$$= 52134 \text{ N/m}$$

Therefore, Pressure in pipe A= **5.21 N/ cm^2**

PROBLEM-11

- A pipe contains an oil of sp.gr.0.9. A differential manometer is connected at the two points A and B shows a difference in mercury level at 15cm. find the difference of pressure at the two points.

Sol: Given data,

Sp.gr. of oil S_1 = 0.9: density ρ_1 = 0.9 x 1000 = 900 kg/m^3

Difference of level in the mercury h = 15cm = 0.15 m

Sp.gr. of mercury = 13.6, Density = 13.6 × 1000 = 13600 kg/m^3

The difference of pressure $p_A - p_B = g \times h \times (\rho_g - \rho_1)$

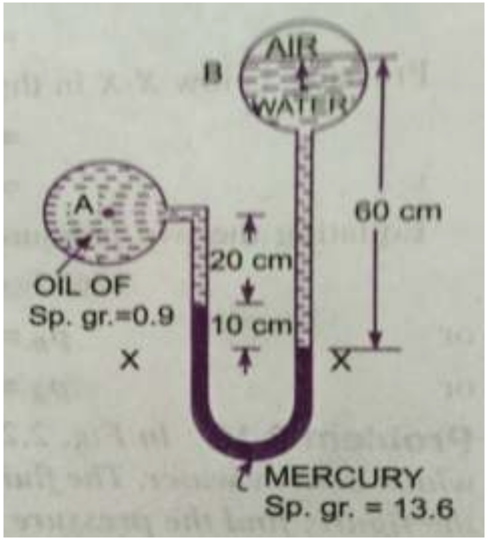
$= 9.81 \times 0.15\ (13600 - 900)$

= 18688 N/m^2

Therefore, $\boldsymbol{p_A - p_B = 18688\ N/\ m^2}$

PROBLEM-12

- A differential manometer is connected at two points A and B .At B air pressure is 9.81 N/cm^2. Find absolute pressure at A.



Sol: Given data,

Density of air = $0.9 \times 1000 = 900\ kg/m^3$

Density of mercury = $13.6 \times 10^3\ kg/\ m^3$

Pressure at B= $9.81\ N/cm^2 = 98100\ N/m^2$

Let pressure at A is p_A

Taking datum as X – X

Pressure above X – X in the right limb

$= 1000 \times 9.81 \times 0.6 + p_B = 5886 + 98100 = 103986$

Pressure above X – X in the left limb

$= 13.6 \times 10^3 \times 9.81 \times 0.1 + 0900 \times 9.81 \times 0.2 + p_A$

$= 13341.6 + 1765.8 + p_A$

Equating the two pressures heads, we get

$$103986 = 13341.6 + 1765.8 + p_A$$

$$103986 = 15107.4 + p_A$$

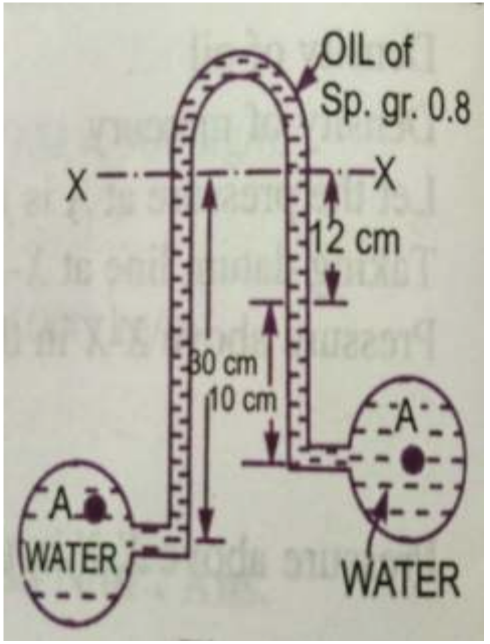
$$p_A = 103986 - 15107.4$$

$$= 88878.6 \text{ N/m}^2$$

Therefore, Pressure at A, $\mathbf{p_A = 8.887 \text{ N/cm}^2}$

PROBLEM-8

- Water is flowing through two different pipes to which an inverted differential manometer having an oil of sp.gr. 0.8 is connected. The pressure head in the pipe A is 2m of water. Find the pressure in the pipe B for the manometer readings shown in fig.



Sol: Given data,

Pressure head at A $= \frac{p_A}{\rho g} = 2$m of water

$p_A = \rho \times g \times 2 = 1000 \times 9.81 \times 2 = 19620\ N/m^2$

Pressure below X – X in the left limb

$= p_A - \rho_1 g h_1$

$= 19620 - 1000 \times 9.81 \times 0.3 = 16677\ N/m^2$

Pressure below X – X in the right limb

$$= p_B - 1000 \times 9.81 \times 0.1 - 800 \times 9.81 \times 0.12$$

$$= p_B - 981 - 941.76 = p_B - 1922.76$$

Equating the two pressures, we get,

$$16677 = p_B - 1922.76$$

$$p_B = 16677 + 1922.76$$

$$p_B = 18599.76 \text{ N/m}^2$$

Therefore, Pressure at B, $\mathbf{p_B = 1.859 \text{ N/cm}^2}$

ASSIGNMENT QUESTIONS

- Two large planes are parallel to each other and are inclined at 30° to the horizontal with the space between them filled with a fluid of viscosity 20 cp. A small thin plate of 0.125 m square slides parallel and midway between the planes and reaches a constant velocity of 2 m/s. The weight of the plate is 1 N. Determine the distance between the plates.
- A U- tube mercury manometer is used to measure the pressure of oil flowing through a pipe whose specific gravity is 0.85. The center of the pipe is 15 cm below the level of mercury. The mercury level difference in the manometer is 25 cm, determine the absolute pressure of the oil flowing through the pipe. Atmospheric pressure is 750 mm of Hg.
- A single column vertical manometer is connected to a pipe containing oil of specific gravity 0.9. The area of the reservoir is 80 times the area of the manometer tube. The reservoir contains mercury of sp. gr. 13.6. The level of mercury in the reservoir is at a height of 30 cm below the center of the pipe and difference of mercury levels in the reservoir in the right limb is 50 cm. find the pressure in the pipe.

- Find the height through which water rises by capillary action in a glass tube of 2mm bore if the surface tension ate the prevailing temperature is 0.075 N/m.
- The space between two parallel square plates each of side 0.8m is filled with an oil of specific gravity 0.8. If the space between the plates is 12.5mm and the upper plate which moves with velocity of 1.25m/s requires a force of 51.2 N. Determine (i) Dynamic viscosity of oil in poise (ii) Kinematic viscosity in stokes.
- List all the properties of fluid and derive Newton’s law of viscosity.
- Explain atmospheric, gauge and vaccum pressure with the help of a neat sketch.