ATME College of Engineering

FLUID MECHANICS BME403

Module-1

Basics, Fluid Statics

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MODULE-1

Fluids & Their Properties

Fluid Pressure and Its Measurements

1.1 DEFINITION OF FLUID: A fluid is a substance which deforms continuously under the action of shearing forces, however small they may be. Conversely, it follows that: If a fluid is at rest, there can be no shearing forces acting and, therefore, all forces in the fluid must be perpendicular to the planes upon which they act.

Learning Structure

- **Concept of fluid, Systems of units.**
- **Properties of fluid; Mass density, Specific weight, Specific gravity, Specific volume,**
- **Viscosity, Cohesion, Adhesion, Surface tension& Capillarity.**
- **Fluid as a continuum, Newton's law of viscosity (theory &problems).Capillary rise in a vertical tube and between two plane surfaces (theory & problems).**
- **Vapor pressure of liquid, compressibility and bulk modulus,**
- **capillarity, surface tension, pressure inside a water droplet, pressure inside a soap bubble and liquid jet.**
- **Numerical problems**

Differences between solids and fluids:

The differences between the behavior of solids and fluids under an applied force are as follows:

i. For a solid, the strain is a function of the applied stress, providing that the elastic limit is not exceeded. For a fluid, the rate of strain is proportional to the applied stress.

ii. ii. The strain in a solid is independent of the time over which the force is applied and, if the elastic limit is not exceeded, the deformation disappears when the force is removed. A fluid continues to flow as long as the force is applied and will not recover its original form when the force is removed.

Differences between liquids and gases:

Although liquids and gases both share the common characteristics of fluids, they have many distinctive characteristics of their own. A liquid is difficult to compress and, for many purposes, may be regarded as incompressible. A given mass of liquid occupies a fixed volume, irrespective of the size or shape of its container, and a free surface is formed if the volume of the container is greater than that of the liquid.

Differences between liquids and gases:

A gas is comparatively easy to compress (Fig.1). Changes of volume with pressure are large, cannot normally be neglected and are related to changes of temperature. A given mass of gas has no fixed volume and will expand continuously unless restrained by a containing vessel. It will completely fill any vessel in which it is placed and, therefore, does not form a free surface.

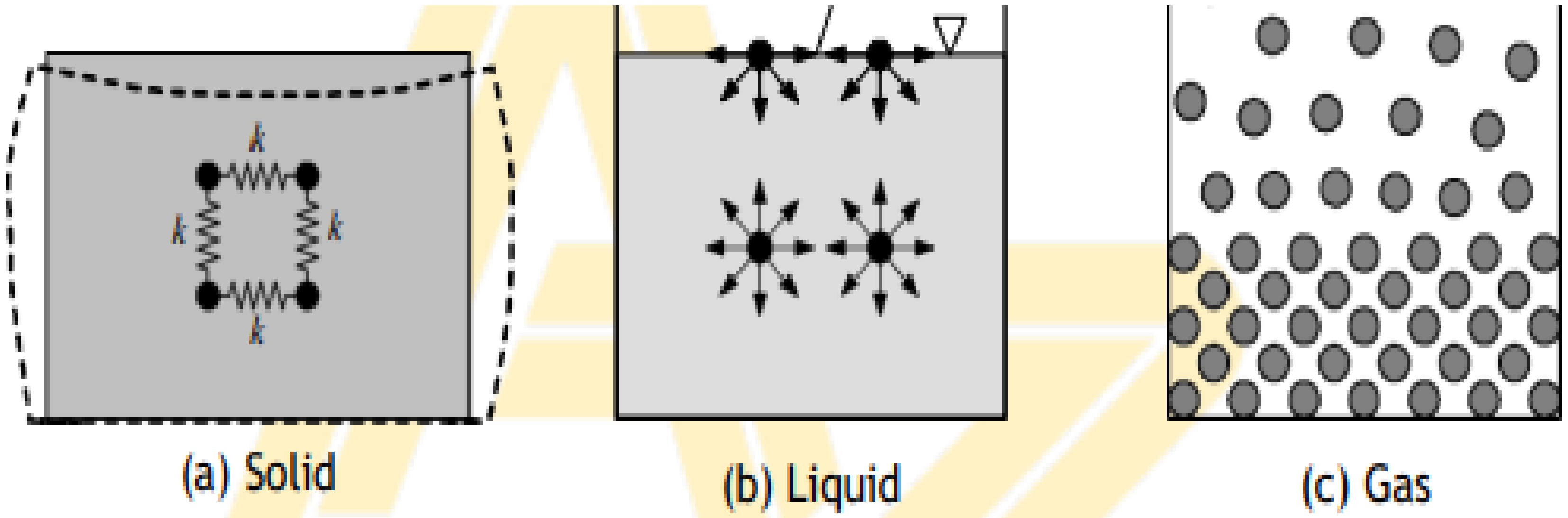


Fig.1

1.2 Systems of Units:

SI system:

Primary quantities:

Quantity	*Unit*
Mass in Kilogram	kg
Length in Meter	m
Time in Second	s or as sec
Temperature in Kelvin	K
Mole	mol

Derived quantities:

Quantity	*Unit*
Force in Newton (1 N = 1 kg.m/s^2)	N
Pressure in Pascal (1 Pa = 1 N/m^2)	N/m^2
Work, energy in Joule (1 J = 1 N.m)	J
Power in Watt (1 W = 1 J/s)	W

1.3 Properties of fluids

- **1.3.1 Mass density or Specific mass (ρ):** Mass density or specific mass is the mass per unit volume of the fluid.

$$\therefore \rho = \frac{Mass}{Volume}$$

$$\rho = \frac{M}{V} \text{ or } \frac{dM}{dV}$$

Unit: kg/m3 M or dM V dV

With the increase in temperature volume of fluid increases and hence mass density decreases in case of fluids as the pressure increases volume decreases and hence mass density increases.

- **1.3.2 Weight density or Specific weight (ɤ)**: Weight density or Specific weight of a fluid is the weight per unit volume.

$$\therefore \gamma = \frac{Weight}{Volume} = \frac{W}{V} \text{ or } \frac{dW}{dV}$$

Unit: N/m^3 or Nm^{-3}.

1.3 Properties of fluids

With increase in temperature volume increases and hence specific weight decreases. With increases in pressure volume decreases and hence specific weight increases.

Note: Relationship between mass density and weight density:

$$\text{We have } \gamma = \frac{Weight}{Volume}$$

$$\gamma = \frac{mass \ x \ g}{Volume}$$

$$\gamma = \rho \ x \ g$$

1.3.3 Specific gravity or Relative density (S): It is the ratio of density of the fluid to the density of a standard fluid.

$$S = \frac{\rho_{fluid}}{\rho_{standard\ fluid}}$$

1.3 Properties of fluids

1.3.4 Specific volume (∀): It is the volume per unit mass of the fluid.

$$\therefore \quad \forall = \frac{Volume}{mass} = \frac{V}{M} \; or \; \frac{dV}{dM}$$

Unit: m3 /kg

As the temperature increases volume increases and hence specific volume increases. As the pressure increases volume decreases and hence specific volume decreases.

Viscosity of the fluid.

- **Effect of Pressure on Viscosity of fluids:**

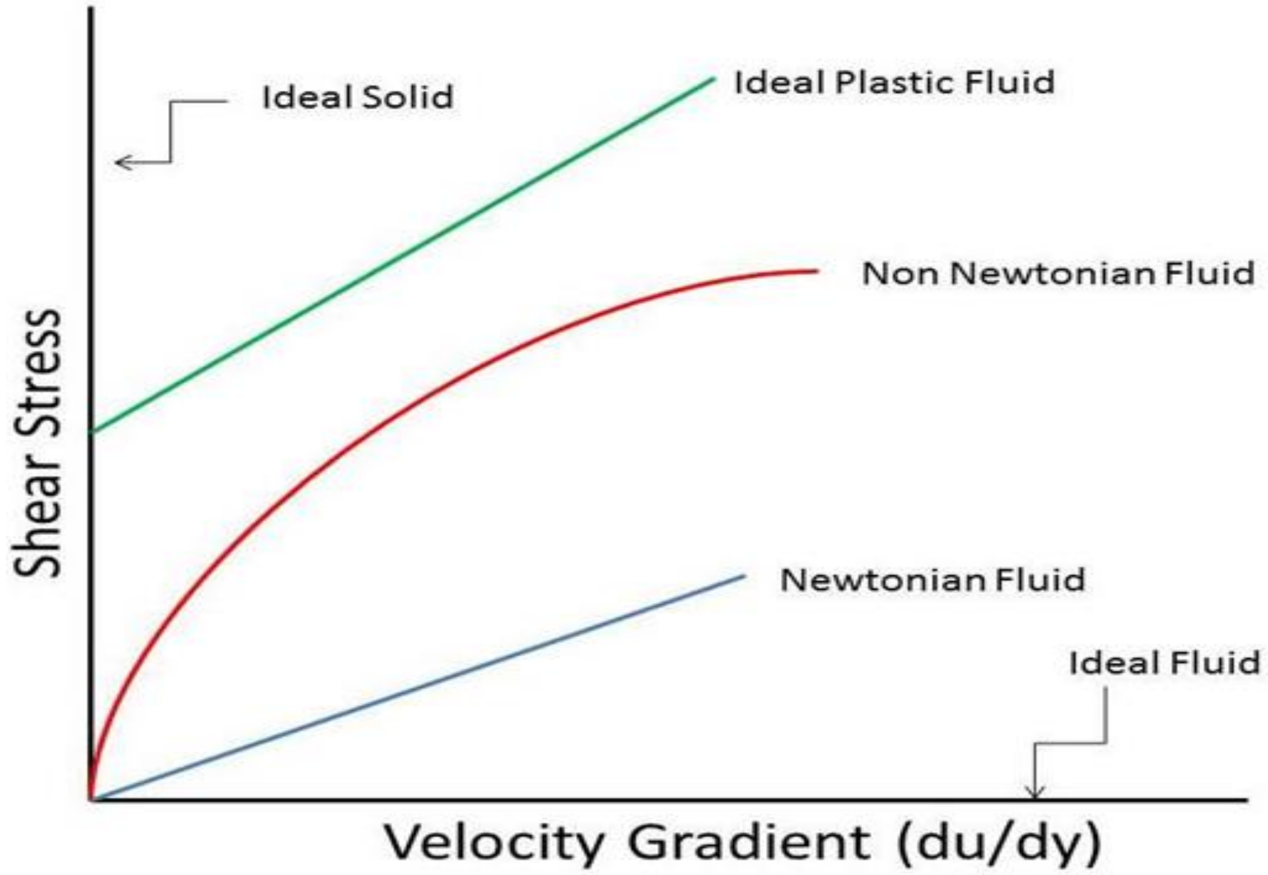
  Pressure has very little or no effect on the viscosity of fluids.

- **Effect of Temperature on Viscosity of fluids:**

  1. *Effect of temperature on viscosity of liquids*: Viscosity of liquids is due to cohesive force between the molecules of adjacent layers. As the temperature increases cohesive force decreases and hence viscosity decreases.

  2. *Effect of temperature on viscosity of gases*: Viscosity of gases is due to molecular activity between adjacent layers. As the temperature increases molecular activity increases and hence viscosity increases.

Classification of Fluids



Types of fluids

1) **Ideal Fluid:** A fluid, which is incompressible and is having no viscosity, is known as an ideal fluid. Ideal fluid is only an imaginary fluid as all the fluids, which exist, have some viscosity.

2) **Real Fluid:** A fluid, which possesses viscosity, is known as real fluid. All the fluids, in practice, are real fluids.

3) **Newtonian Fluid:** A real fluid, in which the shear stress is directly proportional to the rate of shear strain (or velocity gradient), is known as Newtonian fluid.

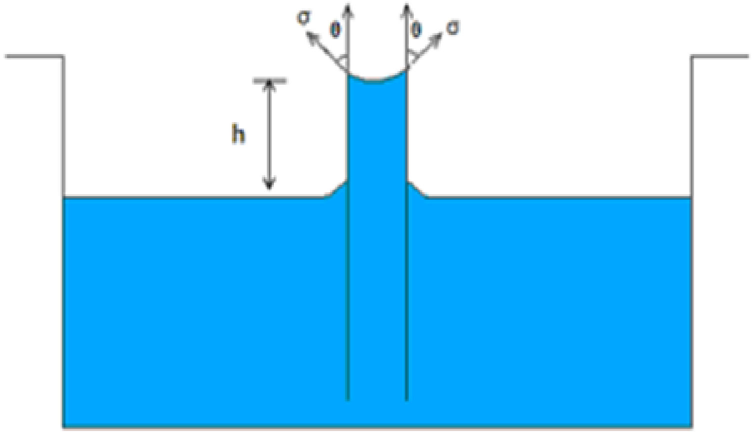
4) **Non-newtonian fluid**: A real fluid, in which the shear stress is not proportional to the rate of shear strain (or velocity gradient), known as a Non-newtonian fluid.

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 (or velocity gradient), is known as ideal plastic fluid.

Capillarity

Capillarity is the phenomena by which liquids will rise or fall in a tube of small diameter dipped in them. Capillarity is due to cohesion adhesion and surface tension of liquids. If adhesion is more than cohesion then there will be capillary rise. If cohesion is greater than adhesion then will be capillary fall or depression. The surface tensile force supports capillary rise or depression

Expression of Capillary Rise



The weight of liquid of height h in the tube $= (\text{Area of the tube} \times h) \times \rho \times g$

$$= \frac{\pi}{4} d^2 \times h \times \rho \times g$$

Vertical component of the surface tensile force $= (\sigma \times \text{Circumference}) \times \cos\theta$

$$= \sigma \times \pi d \times \cos\theta$$

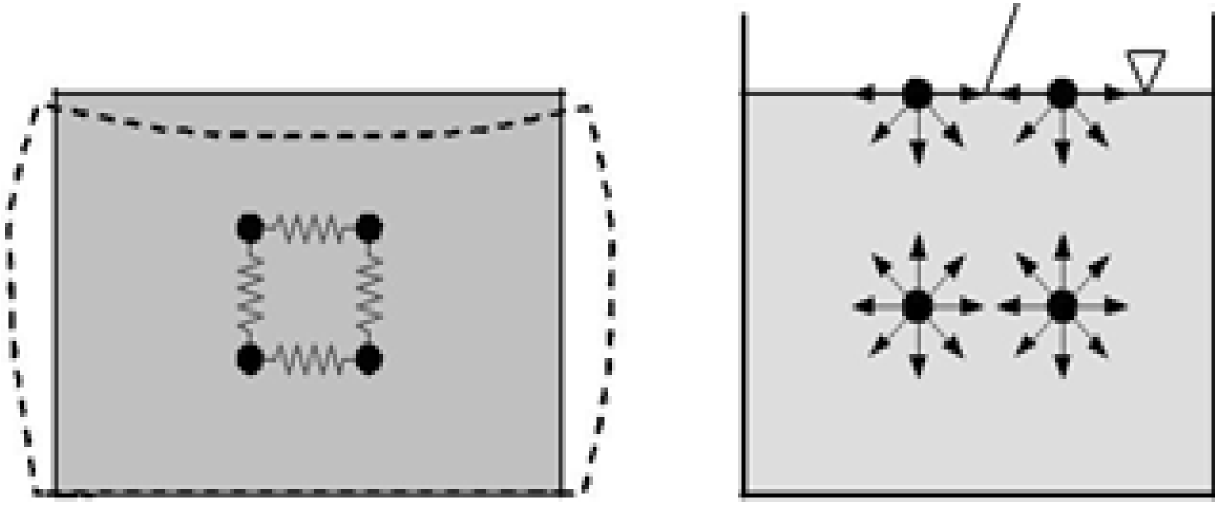
At equilibrium, we get

$$\frac{\pi}{4} d^2 \times h \times \rho \times g = \sigma \times \pi d \times \cos\theta$$

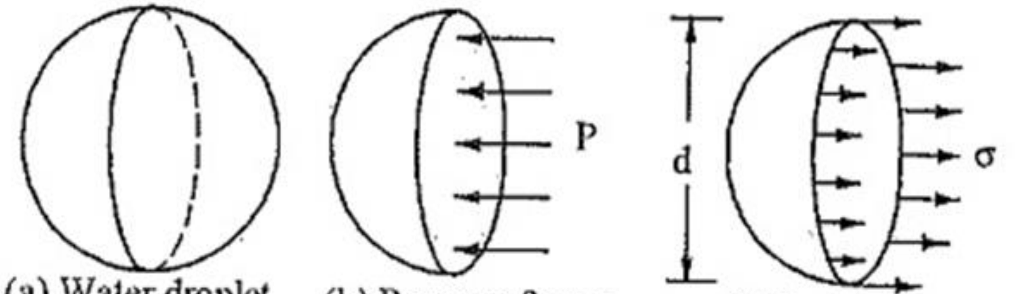
$$h = \frac{4\sigma\cos\theta}{\rho g d}$$

Surface Tension

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



Surface Tension on Liquid Droplet



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

Tensile force due to surface tension = $\sigma \times$ Circumference

$$= \sigma \times \pi d$$

Pressure force on the area = $p \times \frac{\pi d^2}{4}$

These two forces will be equal and opposite under equilibrium conditions

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

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

Vapour Pressure

- Vapour pressure is defined as the pressure at which a liquid will boil(vaporize) and is in equilibrium with its own vapour. Vapour pressure rises as temperature rises. For example, suppose you are camping