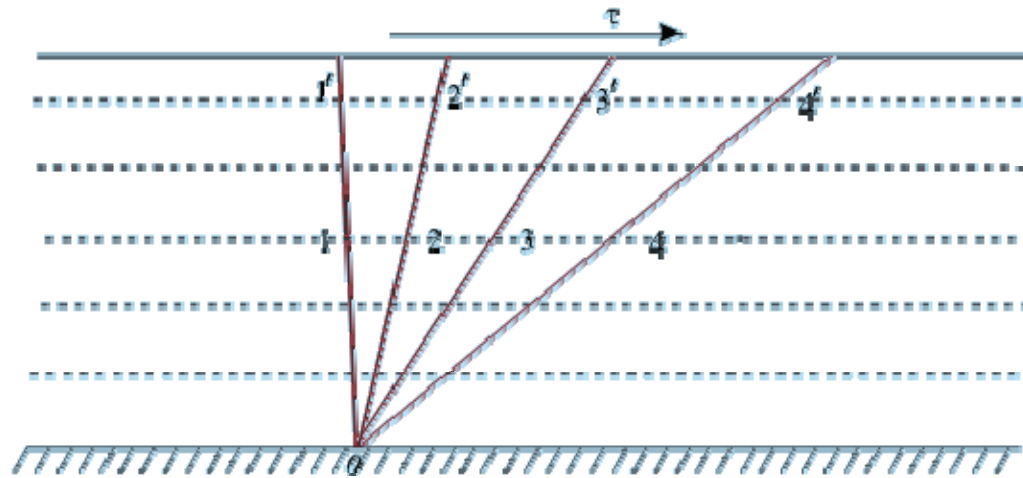


- **FLUID MECHANICS-1**
Unit-1

A fluid is a substance that **deforms continuously** in the face of tangential or shear stress, **irrespective of the magnitude of shear stress**. This continuous deformation under the application of shear stress constitutes a flow.

In this connection fluid can also be defined as the **state of matter that cannot sustain any shear stress**.



If a shear stress τ is applied at any location in a fluid, the element 011' which is initially at rest, will move to 022', then to 033'. Further, it moves to 044' and continues to move in a similar fashion.

In other words, the **tangential stress in a fluid body depends on velocity of deformation and vanishes as this velocity approaches zero**. A good example is [Newton's parallel plate experiment](#) where dependence of shear force on the velocity of deformation was established.

Concept of Continuum

The concept of continuum is a kind of idealization of the continuous description of matter where the properties of the matter are considered as continuous functions of space variables. Although any matter is composed of several molecules, the concept of continuum assumes a continuous distribution of mass within the matter or system with no empty space, instead of the actual conglomeration of separate molecules.

Describing a fluid flow quantitatively makes it necessary to assume that flow variables (pressure , velocity etc.) and fluid properties vary continuously from one point to another. Mathematical description of flow on this basis have proved to be reliable and treatment of fluid medium as a continuum has firmly become established. For example density at a point is normally defined as

$$\rho = \lim_{\Delta V \rightarrow 0} \left(\frac{m}{\Delta V} \right)$$

Properties of Fluids

1. Viscosity (μ) : Resistance to flow

- Viscosity is a fluid property whose effect is understood when the fluid is in motion.
- In a flow of fluid, when the fluid elements move with different velocities, each element will feel some resistance due to fluid friction within the elements.
- Therefore, shear stresses can be identified between the fluid elements with different velocities.
- The relationship between the shear stress and the velocity field was given by Sir Isaac Newton.

Viscosity contd..

- The upper layer, which is moving faster, tries to draw the lower slowly moving layer along with it by means of a force F along the direction of flow on this layer. Similarly, the lower layer tries to retard the upper one, according to Newton's third law, with an equal and opposite force F on it (Figure 1.6).
- Such a fluid flow where x-direction velocities, for example, change with y-coordinate is called **shear flow** of the fluid.
- Thus, the dragging effect of one layer on the other is experienced by a tangential force F on the respective layers. If F acts over an area of contact A , then the shear stress τ is defined as

$$\tau = F/A$$

Viscosity contd..

- **Viscosity (μ) :**
- [Newton postulated](#) that τ is proportional to the quantity $\Delta u / \Delta y$ where Δy is the distance of separation of the two layers and Δu is the difference in their velocities.
- In the limiting case of , $\Delta u / \Delta y$ equals du/dy , the velocity gradient at a point in a direction perpendicular to the direction of the motion of the layer.

According to Newton τ and du/dy bears the relation

- $\tau = \mu du/dy$

- where, the constant of proportionality μ is known as the **coefficient of viscosity** or simply viscosity which is a property of the fluid and depends on its state. Sign of τ depends upon the sign of du/dy

Viscosity contd..

- defining the viscosity of a fluid, is known as Newton's law of viscosity. Common fluids, viz. water, air, mercury obey Newton's law of viscosity and are known as *Newtonian fluids*.
- Other classes of fluids, viz. paints, different polymer solution, blood do not obey the typical linear relationship, of τ and du/dy and are known as **non-Newtonian fluids**. In non-newtonian fluids viscosity itself may be a function of deformation rate as you will study in the next lecture.

Ideal Fluid

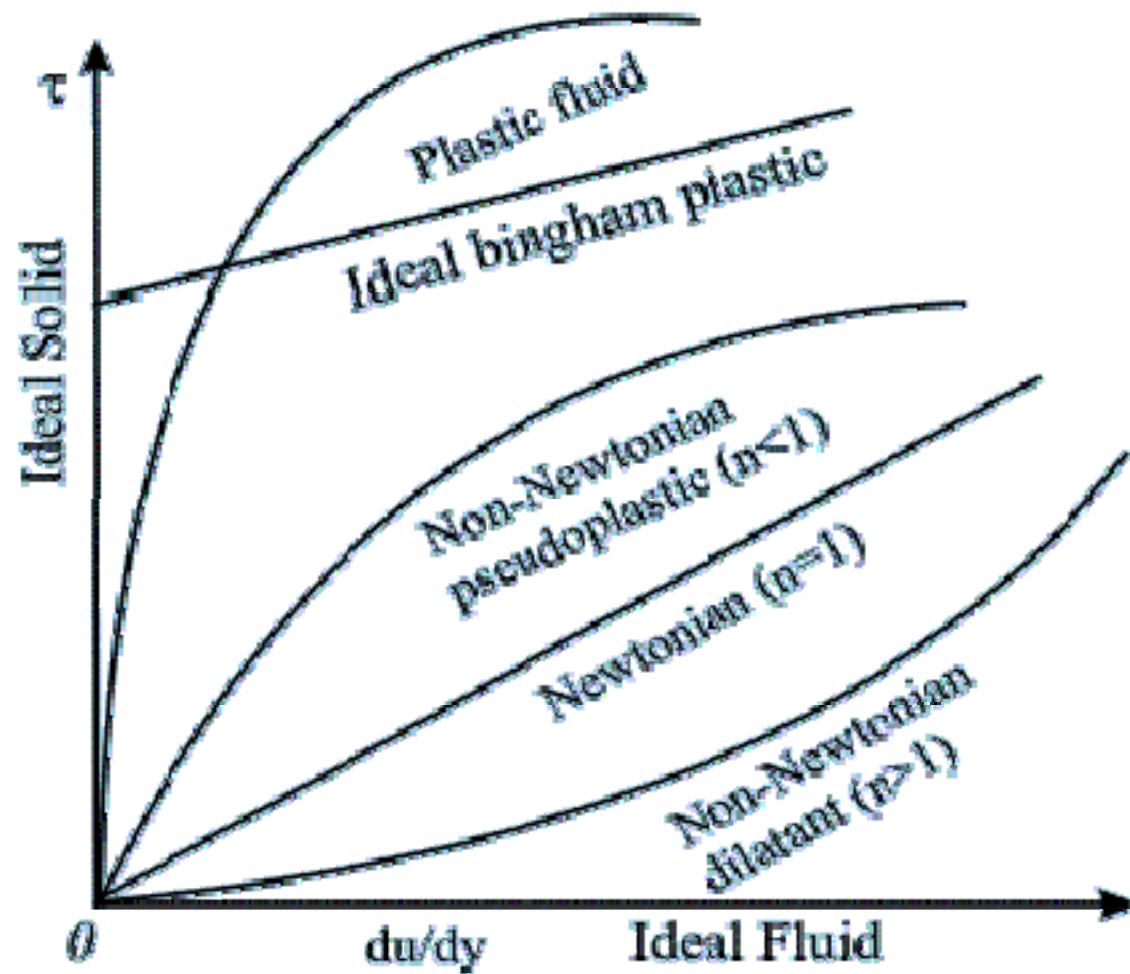
- Consider a hypothetical fluid having a zero viscosity ($\mu = 0$). Such a fluid is called an *ideal fluid* and the resulting motion is called as **ideal or inviscid flow. In an ideal flow, there is no existence of shear force because of vanishing viscosity.**

$$\tau = \mu \, du/dy = 0$$

- All the **fluids in reality have viscosity** ($\mu > 0$) and hence they are termed as real fluid and their motion is known as viscous flow.
- Under certain situations of very high velocity flow of viscous fluids, an accurate analysis of flow field away from a solid surface can be made from the ideal flow theory.

Ideal Fluid contd..

- There are certain fluids where the linear relationship between the shear stress and the deformation rate (velocity gradient in parallel flow) as expressed by the $\tau = \mu \, du/dy$ is not valid.
- For these fluids the viscosity varies with rate of deformation



Compressibility

Compressibility of any substance is the measure of its change in volume under the action of external forces.

The normal compressive stress on any fluid element at rest is known as hydrostatic pressure p and arises as a result of innumerable molecular collisions in the entire fluid.

The degree of compressibility of a substance is characterized by the bulk modulus of elasticity E defined as

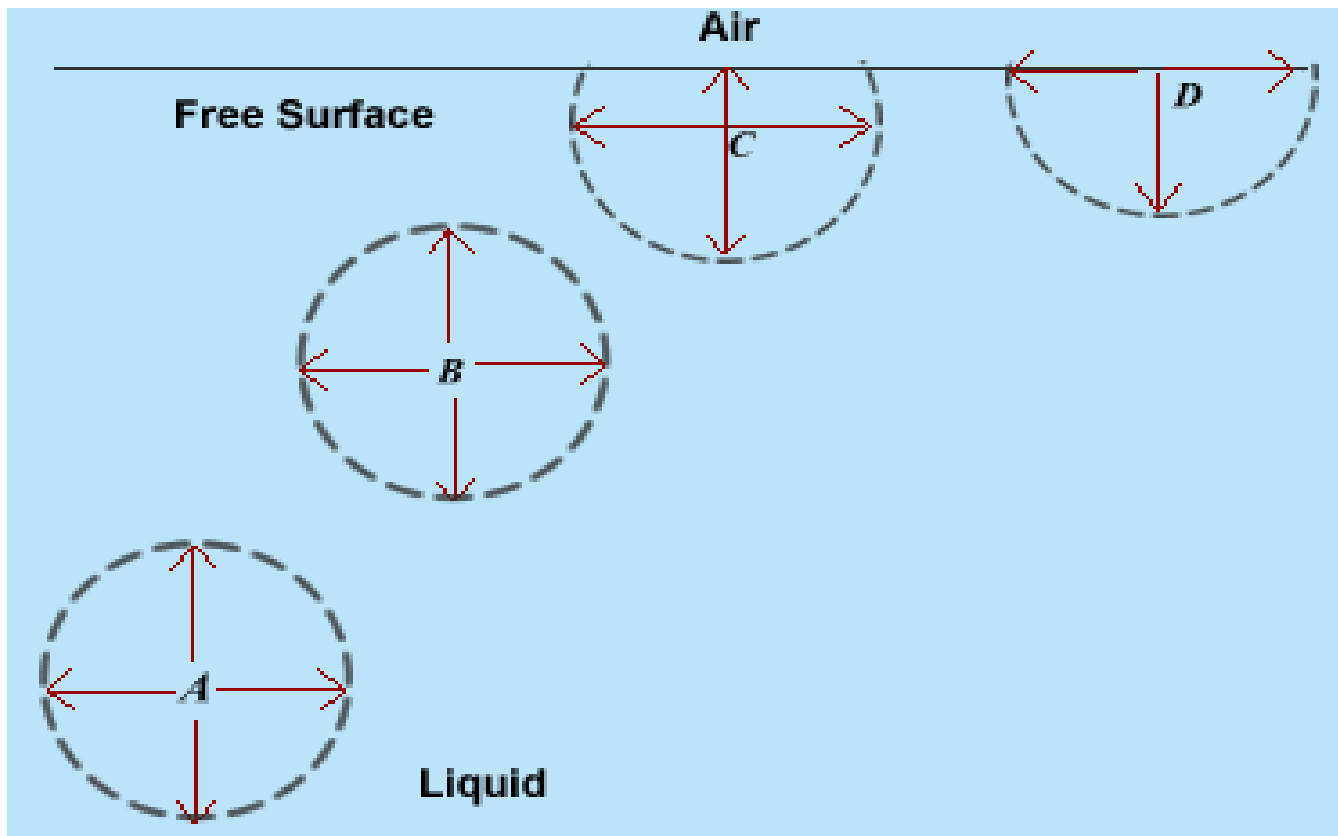
$$E = \lim_{\Delta V \rightarrow 0} \left(\frac{-\Delta p}{\Delta V / V} \right)$$

Surface Tension of Liquids

The phenomenon of surface tension arises due to the two kinds of intermolecular forces

(i) **Cohesion** : The force of attraction between the molecules of a liquid by virtue of which they are bound to each other to remain as one assemblage of particles is known as the force of cohesion. This property enables the liquid to resist tensile stress.

(ii) **Adhesion** : The force of attraction between unlike molecules, i.e. between the molecules of different liquids or between the molecules of a liquid and those of a solid body when they are in contact with each other, is known as the force of adhesion. This force enables two different liquids to adhere to each other or a liquid to adhere to a solid body or surface.



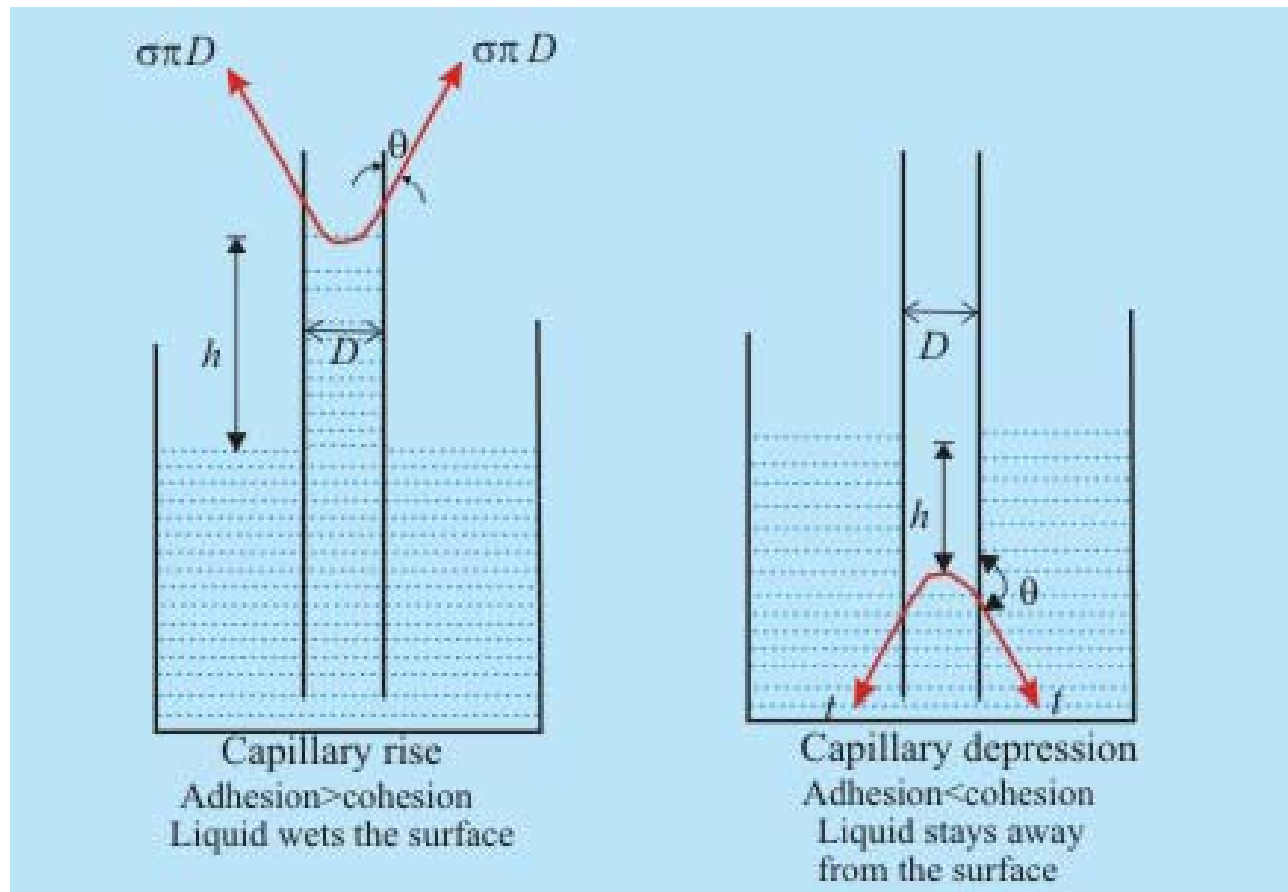
The dimensional formula is F/L or MT^{-2} . It is usually expressed in N/m in SI units

Capillarity

The interplay of the forces of cohesion and adhesion explains the phenomenon of capillarity. When a liquid is in contact with a solid, if the forces of adhesion between the molecules of the liquid and the solid are greater than the forces of cohesion among the liquid molecules themselves, the liquid molecules crowd towards the solid surface. The area of contact between the liquid and solid increases and the liquid thus wets the solid surface.

The reverse phenomenon takes place when the force of cohesion is greater than the force of adhesion. These adhesion and cohesion properties result in the phenomenon of capillarity by which a liquid either rises or falls in a tube dipped into the liquid depending upon whether the force of adhesion is more than that of cohesion or not.

Capillarity contd..



For pure water in contact with air in a clean glass tube, the capillary rise takes place with $\theta = 0$. Mercury causes capillary depression with an angle of contact of about 130° in a clean glass in contact with air. Since h varies inversely with D as found from Eq., an appreciable capillary rise or depression is observed in tubes of small diameter only.

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

Vapour pressure

All liquids have a tendency to evaporate when exposed to a gaseous atmosphere. The rate of evaporation depends upon the molecular energy of the liquid which in turn depends upon the type of liquid and its temperature. The vapour molecules exert a partial pressure in the space above the liquid, known as vapour pressure. If the space above the liquid is confined (Fig. 2.5) and the liquid is maintained at constant temperature, after sufficient time, the confined space above the liquid will contain vapour molecules to the extent that some of them will be forced to enter the liquid. Eventually an equilibrium condition will evolve when the rate at which the number of vapour molecules striking back the liquid surface and condensing is just equal to the rate at which they leave from the surface. The space above the liquid then becomes saturated with vapour. The vapour pressure of a given liquid is a function of temperature only and is equal to the saturation pressure for boiling corresponding to that temperature. Hence, the vapour pressure increases with the increase in temperature. Therefore the phenomenon of boiling of a liquid is closely related to the vapour pressure. In fact, when the vapour pressure of a liquid becomes equal to the total pressure impressed on its surface, the liquid starts boiling. This concludes that boiling can be achieved either by raising the temperature of the liquid, so that its vapour pressure is elevated to the ambient pressure, or by lowering the pressure of the ambience (surrounding gas) to the liquid's vapour pressure at the existing temperature.