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## MECHANICAL PROPERTIES OF FLUIDS

1 OMQ + 1 VSAQ + 1 SAQ [1 M + 2M + 4M = 7 M]

## CONCEPTS &amp; DEFINITIONS

1. Any **substance that can flow** is called a **Fluid**.

**Ex:** Liquids & Gases are Fluids, while Solid is not a Fluid.

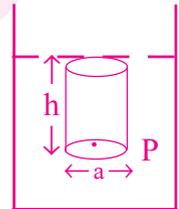
- 2.1. **Average pressure:** if  $F$  is the magnitude of the normal force on the piston of area  $A$  then average pressure is defined as the normal force acting per unit area.

$$P_{\text{avg}} = \frac{F}{A}$$

- 2.2. **Expression for pressure at a point inside the fluid:**  $P = \rho hg$

where  $\rho$  = density of the fluid,  $g$  = gravitational constant,

$h$  = depth of the point below the surface of the fluid at rest.



- 2.3. **Atmospheric pressure:** The pressure of the atmosphere at any point is equal to the weight of a column of air of unit cross sectional area extending from that point to the top of the atmosphere. The atmospheric pressure at the sea level =  $1 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$

3. **Hydraulic Machines:** Hydraulic Machines such as hydraulic lift and hydraulic brakes are based on the Pascal's Law.

**Pascal's Law:** Whenever external pressure is applied on any part of a fluid contained in a vessel, it is transmitted undiminished and equally in all directions. This is the Pascal's law for transmission of fluid pressure and has many applications in daily life.

4. Flow of fluids is of two types (i) Streamline flow (ii) Turbulent flow.

- 4.1. A line in a fluid on which, a tangent drawn at every point represents the direction of velocity of the fluid is called a Streamline. And Flow of such fluids is called **Streamline flow**. Bundle of stream lines is known as a **Tube of flow**.

- 4.2. If the velocity of the fluid at a point varies with time, that flow is called a **Turbulent flow**.

- 4.3. **Laminar Flow:** The flow in which the velocities at different points in the fluid may have different magnitudes that made directions are parallel is called Laminar Flow.

- 4.4. **Equation of continuity:**  $A_P v_P = A_R v_R = A_Q v_Q$ , where  $A_P, A_R, A_Q$  are the areas of cross sections at the points P, Q, R and  $v_P, v_R, v_Q$  are speeds of fluid particles.

- 4.5. **Critical speed:** Steady flow is achieved at low flow speeds. Beyond a limiting value, called critical speed, this flow loses steadiness and becomes turbulent.

5. **Bernoulli's theorem :** For an ideal fluid flow (steady flow of a non-viscous, incompressible fluid) the sum of the pressure energy, kinetic energy and the potential energy per unit volume of the fluid, remains constant, at all points in the path of the flow.

The equation is given by  $P + \frac{1}{2} \rho v^2 + \rho gh = \text{constant}$ .

**5.1. Torricelli's Law :** The speed of efflux (fluid out flow) from the side of an open container at the top is given by  $v = \sqrt{2gh}$

**5.2. Venturi-meter:** The Venturi-meter is a device to measure the flow speed of incompressible fluid. It consists of a tube with a broad diameter and a small constriction at the middle.

**5.3. Dynamic Lift:** Dynamic lift is the force that acts on a body, such as aeroplane wing, a hydrofoil or a spinning ball, by virtue of its motion through a fluid. In many games such as cricket, tennis, baseball or golf, we notice that a spinning ball deviates from its parabolic trajectory as it moves through air.

**6. Viscosity:** The property of a fluid which resists the relative motion between different layers is called viscosity.

The SI unit of viscosity is poiseuille (P)

The dimensions of viscosity are  $[ML^{-1}T^{-1}]$ .

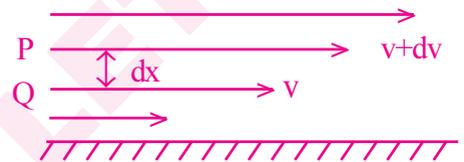
**6.1.** The frictional force between the successive layers of a flowing fluid is called viscous force. This frictional force hampers (opposes) the flow of the fluid.

**6.2.** Viscous force  $F$  is directly proportional to

i) The area of the layer

ii) Velocity gradient  $\frac{dv}{dx}$

$F \propto -A \left( \frac{dv}{dx} \right) \Rightarrow F = -\eta A \left( \frac{dv}{dx} \right)$ . Here,  $\eta$  is a constant called coefficient of viscosity.



**6.3. Coefficient of viscosity( $\eta$ )** for a fluid is defined as the ratio of shearing stress to the strain rate.

Coefficient of viscosity  $\eta = \frac{(F/A)}{(dv/dx)}$

**6.4. Variation of viscosity of fluids with temperature:** The viscosity of liquids decreases with temperature while it increases in the case of gases.

**6.5. Stokes law:** Viscous force acting on a smooth spherical body moving in a fluid is directly proportional to (i) coefficient of viscosity of fluid ( $\eta$ ) (ii) radius of the spherical body ( $r$ ) (iii) velocity of body ( $v$ )

Thus,  $F_v \propto \eta r v \Rightarrow F_v = k \eta r v$

Experimentally the value of 'k' is found to be  $6\pi$

$\therefore F_v = 6\pi \eta r v$

**6.6. Reynolds Number ( $R_e$ ):** Reynolds defined a dimensionless number called Reynolds number, whose value gives an approximate idea whether the flow would be streamline flow or turbulent

flow.  $R_e = \frac{v\rho d}{\eta}$

where  $\rho$  is the density of the fluid flowing with a speed  $v$ ,  $d$  stands for the dimension (length or diameter) of the pipe and  $\eta$  is the viscosity of the fluid.

**Note: Critical Velocity:** The maximum velocity of a fluid in a tube for which the flow remains streamlined is called the critical velocity.

7. **Surface Tension:** Surface tension is a force per unit length acting in the plane of the interface between the plane of the liquid and any other substance.
8. **Surface energy :** The free surface of a liquid always has a tendency to contract and possess minimum surface area. In order to increase the surface area of the liquid ,some work has to be done. This work done is stored as its Potential energy.

The work done in increasing the area of a surface is stored in it in the form of Potential energy is known as surface energy.

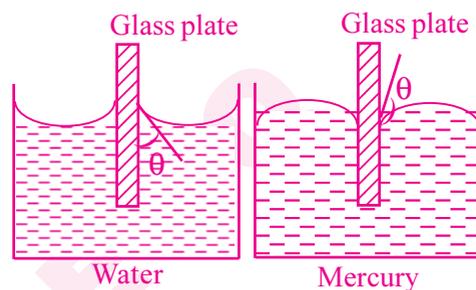
9. **Angle of contact :** “Angle of contact is the angle between solid surface and the tangent drawn to the liquid surface at the point of contact inside the liquid”.

**Remarks :**

1.The angle of contact depends only on the nature of the solid and liquid and is independent of inclination of the solid.

2. Angle of contact for pure water and glass is  $0^\circ$ .

3. Angle of contact for glass and mercury is  $140^\circ$ .



10. **Capillarity:**The phenomenon of rise or fall of liquid level in a capillary tube is called capillarity.

**Examples of capillarity in our daily life :**

1. The Ink in a Pen reaches the Tip of the Nib ,due to Capillary action.
2. Due to Capillary action, water rises to the surface of the field and gets evaporated. To avoid this loss of water, the fields are ploughed. Then water is preserved inside the soil. This destroys the Capillary system of the Soil.

**Imp.Formulae**

1.  $P_{\text{avg}} = \frac{F}{A}$
2.  $P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$
3.  $v = \sqrt{2gh}$
4.  $P_i - P_0 = \frac{2T}{r}$  (liquid drop)
5.  $P_i - P_0 = \frac{4T}{r}$  (Soap bubble)
6.  $W = 8\pi T(r_2^2 - r_1^2)$