# Mechanical Properties of Fluids

1. **Fluid**
Fluids (liquids and gases) that flow under the action of an applied force and do not have a shape of their own. They take the shape of the vessel in which they are placed.

2. **Thrust**
The normal change in momentum transferred to the walls of the container per unit time by the molecules of the fluid is called thrust of the fluid on the container.

3. **Pressure**
The pressure of liquid at a point is the thrust (or normal force) exerted by the liquid at rest per unit area around that point. If a total force $F$ acts normally over a flat area $A$, then the pressure is

$$p = \frac{\text{thrust}}{\text{area}} \quad \text{or} \quad \text{pressure, } p = \frac{F}{A}$$

The unit of pressure is dyne $cm^{-2}$ in CGS system and $Nm^{-2}$ or pascal (Pa) in SI system.

$$1 \text{ Pa (or } 1 \text{ Nm}^{-2}) = 10 \text{ dyne cm}^{-2}$$

or $$1 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$$

4. **Density and Relative Density**
**Density** of a substance is defined as mass per unit volume of the substance. It is denoted by ρ.

$$\text{Density, } \rho = \frac{M}{V}$$

The SI unit of density is kg $m^{-3}$ and dimensional formula is $[ML^{-3}T^0]$.

**Relative density** (or specific gravity) of substance is defined as the ratio of the density of that substance to the density of water at 4° C, i.e.

$$\text{Relative density} = \frac{\text{Density of substance}}{\text{Density of water at } 4°\text{C}}$$

It has no unit and no dimensions. It is a positive scalar quantity. The density of water at 4°C is maximum and equal to 1000 $kgm^{-3}$.

5. **Pascal's Law**
The French scientist *Blaise Pascal* observed that pressure in a fluid at rest is the same at all points, if they are at same height. This is known as Pascal's law.

6. **Variation of Pressure with Depth**

$$\text{Pressure, } p = p_a + h\rho g$$

where, $p_a$ = atmospheric pressure

The pressure $p$ at depth below the surface of a liquid open to the atmosphere is greater than atmospheric pressure by an amount $\rho gh$.
This excess of pressure at depth $h$ in liquid $p - p_a = h\rho g$, i.e. called gauge pressure.

7. **Atmospheric Pressure**
The gaseous envelope surrounding the earth is called earth's atmosphere. The pressure exerted by the atmosphere is called atmospheric pressure. The force exerted by air column of air on a unit area on the earth's surface is equal to the atmospheric pressure. It is denoted by $p_a$ and it is about $1.013 \times 10^5$ $Nm^{-2}$.

8. **Pascal's Law for Transmission of Fluid Pressure**
Pascal's law states that, whenever external pressure is applied on any part of a fluid contained in a vessel, it is transmitted undiminished and equally in all directions.

9. **Buoyancy**
When a body is partially or wholly immersed in a fluid at rest, it displaces the fluid. The displaced fluid exerts a thrust or an upward force on the body.
The upward force acting on the body immersed in a fluid is called upward thrust or buoyant force and the phenomenon is called buoyancy.

10. **Archimedes' Principle**
The Archimedes' principle gives the magnitude of buoyant force on a body. It states that when a body is immersed wholly or partially in a liquid at rest, it experiences an upthrust. The upthrust is equal to the weight of the liquid displaced by the immersed part of the body.

11. **Surface Tension**
Surface tension is the property of liquid at rest by virtue of which a liquid surface tends to occupy a minimum surface area and behaves like stretched membrane. Surface tension, $S = \frac{\text{Force}}{\text{Length}}$
It is a scalar quantity.
SI units of surface tension is $Nm^{-1}$ and CGS unit of surface tension = dyne-$cm^{-1}$.
Dimensions of surface tension are $[ML^0T^{-2}]$.

12. **Surface Energy**
The surface energy may be defined as the amount of work done in increasing the area of the surface film through unity. Thus, surface energy

$$= \frac{\text{work done in increasing the surface area}}{\text{increase in surface area}}$$

The SI unit of surface energy is $Jm^{-2}$.

## 13. Angle of Contact

The angle between tangent to the liquid surface at the point of contact and solid surface inside the liquid is called angle of contact. It is denoted by $\theta$.

*The value of angle of contact depends on the following factors*

(i) Nature of the solid and liquid in contact.
(ii) Cleanliness of the surface in contact.
(iii) Medium above the free surface of the liquid.
(iv) Temperature of the liquid.

**Note** *Due to spherical shape there is an excess pressure inside the drop and soap bubble over that at outside.*

$$(p_{excess})_{drop\ bubble} = \frac{2S}{R}$$

$$(p_{excess})_{soap\ bubble} = \frac{4S}{R}$$

*where, S = surface tension, R = radius of drop or bubble.*

## 14. Capillarity

The term capilla means hair which is a Latin word. A tube of very fine (hair-like) bore is called a capillary tube. If a capillary tube of glass is dipped in liquid like water, the liquid rises in the tube, but when the capillary tube is dipped in a liquid like mercury, the level of liquid falls in the tube.

This phenomenon of rise or fall of a liquid in the capillary is called capillarity.

*Some examples are*

(i) We use towels for drying our skin.
(ii) In trees sap rises due to vessels. It is similar to capillary action.

## 15. Capillary Rise

One application of the pressure difference across a curved surface is, the water rises up in a narrow tube (capillary) inspite of gravity. If the tube was hair thin, the rise would be very large.

Height or rise of liquid or water in capillary,

$$h = \frac{2S\cos\theta}{\rho r g}$$

where, $S$ = surface tension of the liquid,
$\theta$ = angle of contact,
$r$ = radius of capillary tube and
$\rho$ = density of the liquid

This is the formula for the rise of liquid in a capillary.

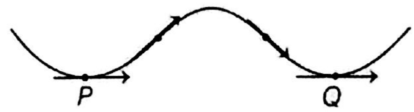
*Some common examples of capillarity are*

(i) Blotting paper absorbs ink due to capillarity.
(ii) A towel soaks water on account of capillarity motion.
(iii) Oil rises through the wicks due to capillarity.

## 16. Streamline Flow

Streamline flow of a liquid is that flow in which each particle of the liquid passing through a point travels along the same path and with the same velocity as the preceeding particle passing through the same point.

It is also defined as a curve whose tangent at any point is in the direction of the fluid velocity at that point.



Trajectory of a fluid particle

## 17. Equation of Continuity

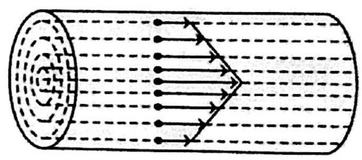
It states that, during the streamline flow of the non-viscous and incompressible fluid through a pipe of varying cross-section, the product of area of cross-section and the normal fluid velocity ($av$) remains constant throughout the flow.

$$av = \text{constant}$$

This is known as equation of continuity.

## 18. Laminar Flow

If the liquid flows over a horizontal surface in the form of layers of different velocities, then the flow of liquid is called laminar flow. In laminar flow, the particles of one layer do not enter into another layer. In general, laminar flow is a streamline flow as shown in figure.

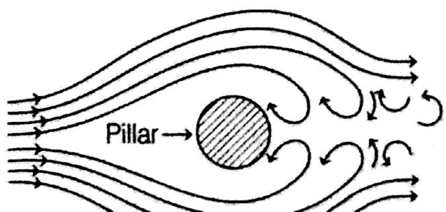


Laminar flow of liquid

## 19. Turbulent Flow

If the liquid flows irregularly like, in rivers and canals, i.e. where speed of water is quite high or the boundary surfaces cause abrupt changes in velocity of the flow, then the flow of liquid is called turbulent flow

Thus, the flow of fluid in which velocity of all particles crossing a given point is not same and the motion of the fluid becomes irregular or disordered is called turbulent flow as shown in figure.




Turbulent flow of liquid

## 20. Bernoulli's Theorem

It states that, the sum of pressure energy, kinetic energy and potential energy per unit volume of an incompressible, non-viscous fluid in a streamlined irrotational flow remains constant at every cross-section throughout the liquid flow.

Mathematically, it can be expressed as

$$p + \frac{1}{2}\rho v^2 + \rho gh = \text{constant} \quad \ldots\text{(i)}$$

where, $p$ represents pressure energy, $\frac{1}{2}\rho v^2$ for kinetic energy and $\rho gh$ for potential energy per unit volume.

Dividing both sides of Eq. (i) by $\rho g$, we get

$$\frac{p}{\rho g} + h + \frac{v^2}{2g} = \frac{\text{constant}}{\rho g} = \text{new constant}$$

Here, $\frac{p}{\rho g}$ is called pressure head, $h$ is called gravitational head and $\frac{v^2}{2g}$ is called velocity head.

## 21. Viscosity

When a layer of liquid slides over another layer of the liquid, a force of friction that opposes the relative motion is called viscous force or internal force. So, the tendency of fluids to oppose the relative motion of its layers is called viscosity of fluid. The backward dragging force is called viscous drag or viscous force.

### Coefficient of Viscosity

$$\eta = \frac{Fl}{vA}$$

The SI unit of $\eta$ is N-s $m^{-2}$ or kg $m^{-1}s^{-1}$ and it is called decapoise or poiseuille. 1 poiseuille = 1 N-s $m^{-2}$

In CGS system, the unit of $\eta$ is dyne-s $cm^{-2}$ and it is called poise. 1 poise = 1 dyne s-$cm^{-2}$

Dimensions of coefficient of viscosity are $[ML^{-1}T^{-1}]$.

### Relative Viscosity

Relative viscosity of liquid $= \frac{\eta_{liquid}}{\eta_{water}}$

Relative viscosity of blood remains constant between 0°C and 37°C.

## 22. Critical Velocity

The critical velocity of a liquid is that limiting value of its velocity of flow upto which the flow is streamlined and above which the flow becomes turbulent.

Critical velocity, $v_c = \frac{k\eta}{\rho r}$

where, $v_c$ = critical velocity,
$\eta$ = viscosity of the liquid,
$k$ = dimensionless constant,
$\rho$ = density of the liquid and
$r$ = radius of the tube through which the liquid is flowing.

## 23. Stokes' Law

When a small spherical body (of radius $r$) falls (with speed $v$) through a viscous fluid (of viscosity $\eta$) at rest, the layers of fluid in contact with the body are dragged alongwith it. This produces a relative motion between different layers of the fluid.

Dragging force, $F = 6\pi\eta rv$

This is called Stokes' law of viscosity.

## 24. Terminal Velocity

The maximum constant velocity acquired by a body while falling through a viscous fluid is called its terminal velocity.

$\therefore$ Terminal velocity, $v = \frac{2}{9} \cdot \frac{r^2(\rho - \sigma)g}{\eta}$

where, $r$ = radius of the spherical body,
$v$ = terminal velocity,
$\eta$ = coefficient of viscosity of fluid,
$\rho$ = density of the spherical body and
$\sigma$ = density of fluid.

## 25. Reynold's Number

A dimensionless parameter whose value decides the nature of flow of a liquid through a pipe, i.e. whether a flow will be steady or turbulent, it is given by

Reynold's number, $R_e = \frac{\rho v D}{\eta}$

where, $\rho$ = density of the liquid,
$v$ = velocity of the liquid,
$\eta$ = coefficient of viscosity of the liquid and
$D$ = diameter of the pipe.