UNIT -2

SURFACE TENSION AND VISCOSITY

Fluids

Fluids are those substances which can flow when an external force is applied on it.

Liquids and gases are fluids.

Fluids do not have finite shape but takes the shape of the containing vessel,

The total normal force exerted by liquid at rest on a given surface is called thrust of liquid.

The SI unit of thrust is newton.

In fluid mechanics the following properties of fluid would be considered

(i) When the fluid is at rest **– hydrostatics**

(ii) When the fluid is in motion **– hydrodynamics**

Pressure : Force per unit area of the surface acting in a direction perpendicular (or normal) to it is called pressure (P). If F is the force acting perpendicularly on a surface having an area A, then

Pressure = (Force acting normally on the surface)/(Area A of the surface)

$P = F/A$

The S.I. unit of pressure is Newton per metre square (Nm^{-2}). Another name for the S.I. unit of pressure is pascal (Pa). 1 Pa = 1 Nm^{-2}

Pressure Exerted by the Liquid

The normal force exerted by a liquid per unit area of the surface in contact is called **pressure of liquid** or **hydrostatic pressure**.

Pressure exerted by a liquid column

$p = h\rho g$

Where, h = height of liquid column, ρ = density of liquid

and g = acceleration due to gravity

Mean pressure on the walls of a vessel containing liquid upto height h is ($h\rho g$ / 2).

Density,

Mass per unit volume of a material substance is defined as density. The formula for density is *d* = *M*/*V*, where *d* is density, *M* is mass, and *V* is volume. Density is commonly expressed in units of grams per cubic centimetre. For example, the density of water is 1 gram per cubic centimetre,

Pascal's Law

The increase in pressure at a point in the enclosed liquid in equilibrium is transmitted equally in all directions in liquid and to the Walls of the container.

The working of hydraulic lift, hydraulic press and hydraulic brakes are based on Pascal's law.

Atmospheric Pressure

The pressure exerted by the atmosphere on earth is **atmospheric pressure**.

It is about 100000 N/m^2.

It is equivalent to a weight of 10 tones on 1 m^2.

At sea level, atmospheric pressure is equal to 76 cm of mercury column. Then, atmospheric pressure

$= hdg = 76 \times 13.6 \times 980$ $dyne/cm^2$

[The atmospheric pressure does not crush our body because the pressure of the blood flowing through our circulatory system] balanced this pressure.]

Atmospheric pressure is also measured in torr and bar.

1 torr = 1 mm of mercury column

1 bar = $l0^5$ Pa

Aneroid barometer is used to measure atmospheric pressure.

Buoyancy

When a body is partially or fully immersed in a fluid an upward force acts on it, which is called buoyant force or simply buoyancy.

The buoyant force acts at the centre of gravity of the liquid displaced] by the immersed part of the body and this point is called the centre buoyancy.

Archimedes' Principle

When a body is partially or fully immersed in a liquid, it loses some of its weight. and it is equal to the weight of the liquid displaced by the immersed part of the body.

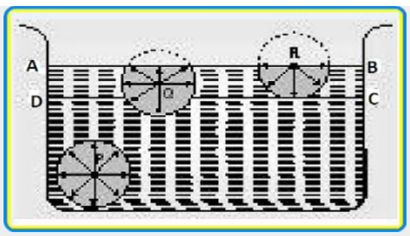
Surface tension

Surface tension is the property of a liquid, by virtue of which its free surface at rest behaves like an elastic skin or a stretched rubber membrane, with a tendency to contract so as to occupy minimum surface area. This property is caused by cohesion of molecules and is responsible for much of the behaviors of liquids.

The property of surface tension is revealed, for example, by the ability of some objects to float on the surface of water, even though they are denser than water. Surface tension is also seen in the ability of some insects, such as water striders, and even reptiles like basilisk, to run on the water's surface.

The Theory Behind Surface Tension

Surface tension has been well- explained by the molecular theory of matter. According to this theory, cohesive forces among liquid molecules are responsible for the phenomenon of surface tension. The molecules well inside the liquid are attracted equally in all directions by the other molecules. The molecules on the surface experience an inward pull.



MOLECULAR THEORY OF SURFACE TENSION

In Fig. ABCD represents the surface

So, a network is formed against the inward pull, in order to move a molecule to the liquid surface. It results in a greater potential energy on surface molecules. In order to attain minimum potential energy and hence stable equilibrium, the free surface of the liquid tends to have the minimum surface area and thereby it behaves like a stretched membrane.

Surface tension is measured as the force acting normally per unit length on an imaginary line drawn on the free liquid surface at rest. It is represented by the symbol T (or S). It's S.I. The unit is Nm^{-1} and dimensional formula is $M^1L^0T^{-2}$.

Capillarity in Liquids

When a capillary tube is dipped in a liquid, the liquid level either rises or falls in the capillary tube. The phenomena of rise or fall of a liquid level in a capillary tube is called capillarity or capillary action.

How do we define the surface tension of a liquid through the capillary rise method?

When a liquid rises in a capillary tube, the weight of the column of the liquid of density ρ inside the tube is supported by the upward force of surface tension acting around the circumference of the points of contact.

Thus, surface tension;

$$T = \frac{r(h + \frac{r}{3})\rho g}{2cos\theta}$$

Where, h - height of the liquid column above the liquid meniscus
ρ - Density of the liquid
r - Inner radius of the capillary tube
θ - Angle of contact

Viscosity

The property of a fluid by virtue of which an internal frictional force acts between its different layers which opposes their relative motion is called viscosity.

These internal frictional force is called viscous force.

Viscous forces are intermolecular forces acting between the molecules of different layers of liquid moving with different velocities.

$$\text{Viscous force } (F) = -\eta A \frac{dv}{dx}$$

$$\eta = -\frac{F}{A\left(\frac{dv}{dx}\right)}$$

where, (dv/dx) = rate of change of velocity with distance called velocity gradient, A = area of cross-section and = coefficient of viscosity.

SI unit of η is Nsm^{-2} or pascal-second or decapoise. Its dimensional formula is $[ML^{-1}T^{-1}]$.

The knowledge of the coefficient of viscosity of different oils and its variation with temperature helps us to select a suitable lubricant for a given machine.

Viscosity is due to transport of momentum. The value of viscosity (and compressibility) for ideal liquid is zero.

The viscosity of air and of some liquids is utilised for damping the n.ving parts of some instruments.

The knowledge of viscosity of some organic liquids is used in determining the molecular weight and shape of large organic moleculars like proteins and cellulose.

Variation of Viscosity

The viscosity of liquids decreases with increase in temperature

The viscosity of gases increases with increase in temperatures as

$\eta \propto \sqrt{T}$

The viscosity of liquids increases with increase in pressure but the viscosity of water decreases with increase in pressure.

The viscosity of gases do not changes with pressure.

Flow of Liquid

1. **Streamline Flow** The flow of liquid in which each of its particle follows the same path as followed by the proceeding particles, is called streamline flow.
2. **Laminar Flow** The steady flow of liquid over a horizontal surface in the form of layers of different velocities, is called laminar flow.
3. **Turbulent Flow** The flow of liquid with a velocity greater than its critical velocity is disordered and called turbulent flow.

Laminar flow (smooth flow) tends to occur at lower flow rates through smaller pipes. In essence, the fluid particles flow in cylinders. The outermost cylinder, touching the pipe wall, does not move due to viscosity. The next cylinder flows against the unmoving fluid cylinder, which exhibits less frictional “pull” than the pipe wall. This cylinder will move the slowest. This continues, with the centermost cylinder having the greatest velocity

Reynolds Number

How do you know if a flow is turbulent, transitional or laminar? In the late 1800’s, Osbourne Reynolds discovered that the type of fluid flow is related to the fluid’s density, mean velocity and absolute viscosity, plus the diameter of the pipe through which the fluid is flowing. The Reynolds Number (Re) is a dimensionless number (having no units) that helps us predict the flow type under a certain set of conditions.

In simple terms, the Reynolds Number (Re) can be written as:

$Re = \rho VD/\eta$

Where:

ρ = Fluid density

V = Mean velocity

D = Pipe diameter

η = Absolute viscosity of the fluid

It is generally accepted that flow is laminar if the Reynolds Number is less than 2000. Transitional flows have a Reynolds Number between 2000 and 4000. Flows are considered turbulent when the Reynolds Number is greater than 4000.

Types of viscosity

There are two different measurements of viscosity used to describe fluids, dynamic and kinematic viscosities. These describe the flow of the fluid in different ways related to the way they are measured, however they are interchangeable if the fluid density is known.

Dynamic Viscosity

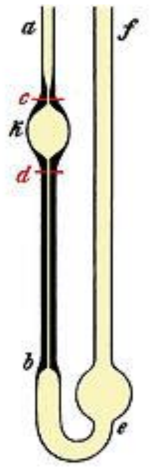
Dynamic viscosity measures the ratio of the shear stress to the shear rate for a fluid.

Kinematic Viscosity

Kinematic viscosity measures the ratio of the viscous force to the inertial force on the fluid. This is shown in the equation below, which may also be used to convert between dynamic and kinematic viscosity provided the density of the fluid is known. Kinematic viscosity is analogous to diffusivity of mass and heat, being the diffusivity of momentum.

Viscometer

A viscometer is an instrument used to measure the viscosity of a fluid. For liquids with viscosities which vary with flow conditions, an instrument called a rheometer is used. Thus, a rheometer can be considered as a special type of viscometer.[1]Viscometers only measure under one flow condition.



Ostwald viscometers measure the viscosity of a fluid with a known density.

U-tube viscometers

These devices are also known as glass capillary viscometers or Ostwald viscometers, named after Wilhelm Ostwald. Another version is the Ubbelohde viscometer, which consists of a U-shaped glass tube held vertically in a controlled temperature bath. In one arm of the U is a vertical section of precise narrow bore (the capillary). Above there is a bulb, with it is another bulb lower down on the other arm. In use, liquid is drawn into the upper bulb by suction, then allowed to flow down through the capillary into the lower bulb. Two marks (one above and one below the upper bulb) indicate a known volume. The time taken for the level of the liquid to pass between these marks is proportional to the kinematic viscosity. Most commercial units are provided with a conversion factor, or can be calibrated by a fluid of known properties.

The time required for the test liquid to flow through a capillary of a known diameter of a certain factor between two marked points is measured. By multiplying the time taken by the factor of the viscometer, the kinematic viscosity is obtained.