1- Fluid Properties

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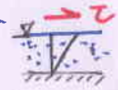
1.1 Introduction :-

→ Fluid :- A Fluid is define as a substance which is capable of flowing and deforms continuosly under the action of shearing stresses. A shear force is the component of the force which is tangential to a fluid surface.



Fluids → Liquid, Grases

→ Fluid Mechanics : Fluid mechanics is that branch of science which deals with the behaviour of the fluids (liquids or gases) at rest as well as in motion. This branch of science deals with the static, kinematics and dynamic aspects of fluid. The study of fluids at rest is called fluid static, The study of fluids in motion where pressure forces are not considered, is called fluid kinematics and if the pressure forces are also considered for the fluid in motion, that branch of science is called fluid dynamics

1.2 Properties of fluids :-

→ Density or Mass density : Density or mass density of a fluid is defined as the ratio of the mass of a fluid to its volume. It is denoted the symbol ρ (rho) The density of liquids may be considered as constant while that of gases changes with the variation of pressure and temperature

$$\text{density } \rho = \frac{\text{Mass of fluid}}{\text{Volume of fluid}}, \quad \frac{kg}{m^3}$$

The value of density of water is $1000 \, kg/m^3$

→ Specific weight or weight density :- It is ratio of weight of a fluid to its volume.

$$\text{Specific weight } (w) = \frac{\text{Weight of fluid}}{\text{Volume of fluid}} = \frac{\text{mass of fluid} \times g}{\text{volume of fluid}} = \rho g$$

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- Specific Volume:- Specific volume of a fluid is define as the volume of fluid occupied by a unit mass or volume per unit mass of a fluid is called specific volume.

$$\text{Specific volume} = \frac{\text{Volume of fluid}}{\text{Mass of fluid}} = \frac{1}{\rho} \quad m^3/kg$$

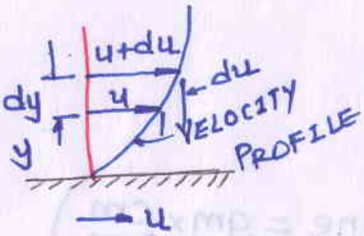
specific volume is the reciprocal of mass density.

- Specific gravity:- Specific gravity is defined as the ratio of the weight density of a fluid to weight density of a standard fluid.
  For Liquids. the standard fluid is taken water
  For gases, the standard fluid is taken air
- specific gravity is also called relative density

$$S_{Liquid} = \frac{\text{Weight density of liquid}}{\text{Weight density of water}}$$

$$S_{gases} = \frac{\text{Weight density of gas}}{\text{Weight density of air}}$$

- Viscosity:- Viscosity is define as the property of a fluid which offers resistance to the movement of one layer of fluid over another adjacent Layer of the fluid. When two Layers of a fluid. a distance 'dy' apart, move one over the other at different velocities, say u and $u+du$, the viscosity together with relative velocity causes a shear stress acting between the fluid layer



The top Layer causes a shear stress on the adjacent Lower Layer while the lower Layer causes a shear stress on the adjacent top layer.

This shear stress is propostional to the rate of change of velocity with respect to 'y'

$$\tau \propto \frac{du}{dy}$$

$$\tau = \mu \frac{du}{dy}$$

where μ (mu) is the constant of proportionality and is known as the co-efficient of dynamic viscosity

— Unit of viscosity:

$$\mu = \frac{\tau}{du/dy} = \frac{\text{shear stress}}{\frac{\text{change of velocity}}{\text{change of distance}}} = \frac{\text{Force/Area}}{\left(\frac{\text{Length}}{\text{time}}\right)\frac{1}{\text{Length}}}$$

$$= \frac{\text{Force}}{\text{Area}}.\text{time} = N/m^2 \cdot \text{Sec}$$

We know N/m^2 is Pascal which is represented by Pa.

$$\text{SI unit of viscosity} = \frac{N \cdot s}{m^2} = Pa \cdot S$$

$$\text{MKS unit of viscosity} = \frac{kgf \cdot sec}{m^2}$$

$$\text{CGS unit of viscosity} = \frac{dyne\text{-}sec}{cm^2}$$

The numerical conversion of the unit of viscosity from MKS unit to CGS unit

$$\frac{kgf\text{-}sec}{m^2} = 9.81\frac{N\text{-}sec}{m^2} \quad (\because 1\,kgf = 9.81\,N)$$

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$$= \text{mass} \times \text{acceleration}$$

$$1 \text{ Newton} = 1\,kg \cdot 1\left(\frac{m}{s^2}\right)$$

$$= \frac{1000\,gm \times 100\,cm}{sec^2} = 10^5 \frac{gm \times cm}{sec^2}$$

$$= 10^5 \text{ dyne} \qquad \left(\because \text{dyne} = gm \times \frac{cm}{sec^2}\right)$$

$$\frac{kgf\text{-}sec}{m^2} = 9.81 \times 10^5 \frac{dyne\text{-}sec}{(m^2)} = 9.81 \times 10^5 \frac{dyne\text{-}sec}{10^4\,cm^2}$$

$$= 98.1 \frac{dyne\text{-}sec}{cm^2} = 98.1 \text{ Poise}$$

$$1 \frac{kgf\text{-}sec}{m^2} = 9.81 \frac{N \cdot sec}{m^2} = 98.1 \text{ Poise}$$

$$1 \text{ Poise} = 0.1 \frac{N.S}{m^2} = 0.1 \text{ Pa.s}$$

$$1 \text{ centipoise} = \frac{1}{100} \text{ Poise} = \frac{0.1}{100} \frac{N.sec}{m^2}$$

→ Kinematic Viscosity:- It is defined as the ratio between the dynamic viscosity and density of fluid. It is denoted by the greek symbol ν (nu)

$$\nu = \frac{\text{Dynamic viscosity}}{\text{Density}}$$

Unit of kinematic viscosity

$$\nu = \frac{\mu}{\rho} = \frac{\frac{\text{Force.sec}}{m^2}}{kg/m^3} = \frac{\frac{\text{Mass.length}}{sec^2}.\,sec}{\text{mass}/\text{Length}^3}$$

$$= \frac{(\text{Length})^2}{sec} = \frac{m^2}{s}$$

$$1 \text{ stoke} = cm^2/sec = \left(\frac{1}{100}\right)^2 \frac{m^2}{s} = 10^{-4}\,m^2/sec$$

— Variation of Viscosity with temperature

Temperature affects the viscosity. The viscosity of liquid decrease with the increase of temperature while the viscosity of gases increases with the increase of temperature.

This is due to reason that the viscous forces in a fluid are due to cohesive forces and molecular momentum transfer (molecular interchange).

In liquid the cohesive forces predominates the molecular momentum transfer due to closely packed molecules and with the increase in temperature, the cohesive forces decreases with the result of decreasing viscosity

For liquids $\mu = \mu_0 \left[\frac{1}{1+\alpha t+\beta t^2}\right]$

where μ = Viscosity of liquid at $t^\circ C$, in poise

μ_0 = Viscosity of liquid at $0^\circ C$ in poise

α, β = are constants for the liquid

For water $\mu_0 = 1.79\times10^{-3}$ poise, $\alpha = 0.03368$ & $\beta = 0.000221$

In case of gases the cohesive force are small and molecular momentum transfer predominates with the increase in temperature, molecular momentum transfer increase and hence viscosity increase

For a gas $\mu = \mu_0 + \alpha t - \beta t^2$

$\mu_0 = 0.000017$, $\alpha = 0.000000056$, $\beta = 0.1189\times10^{-9}$

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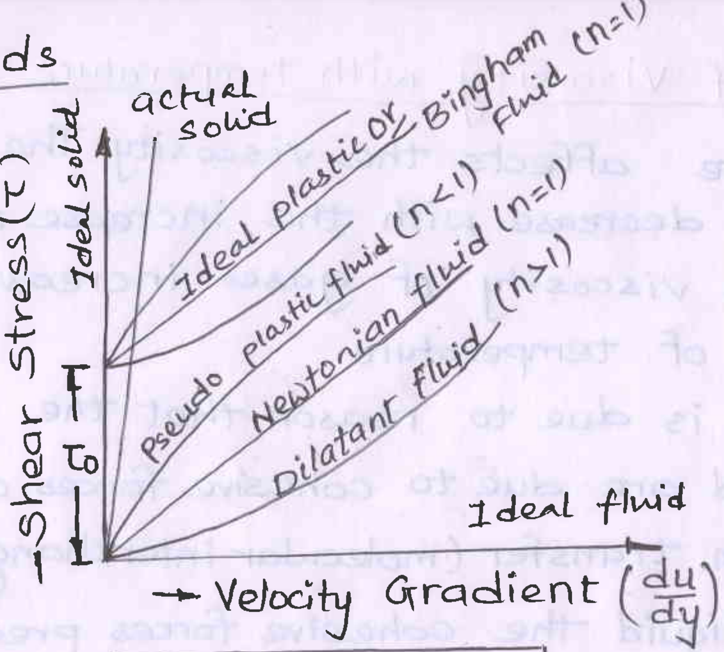
1.3 Type of Fluids



$$\boxed{\tau = A\left(\frac{du}{dy}\right)^n + \tau_0}$$

where A = flow consistency index
n = flow behaviour index
τ_0 = Yield stress

- **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
  $\tau = 0$, $A = \mu = 0$, $\tau_0 = 0$
- **Real Fluid:** A Fluid which possesses viscosity is known as real fluid. All the fluids, in actual practice are real fluids.
- **Newtonian fluid:-** A real fluid, in which the shear stress is directly proportional to rate of shear strain (velocity gradient) is known as a Newtonian fluid.
  $A = \mu$, $n = 1$ & $\tau_0 = 0$
- **Pseudo plastic:-** Fluids for which the flow behaviour index n is less than unity are called pseudo plastic [(eg.) Colloidal solution, milk, cement, blood] $n < 1$, $\tau_0 = 0$
- **Dilatant fluid:-** Fluids for which the flow behaviour index n is greater than unity are called Dilatant fluid [e.g concentrated solution of sugar] $n > 1$, $\tau_0 = 0$
- **Ideal plastic or Bingham fluid:-** This substance indicates no deformation when stressed upto a certain point (yield stress) and beyond that it behaves like a Newtonian fluid.
  $A = \mu$, $n = 1$
- **Thixotropic substances:-** Fluids which show an apparent decrease in viscosity with time. (Jelly paints)
- **Rheopectic substances:-** Fluid which show an apparent increase in viscosity with time [Gypsum pastes, paint ink]

1.4 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 function 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

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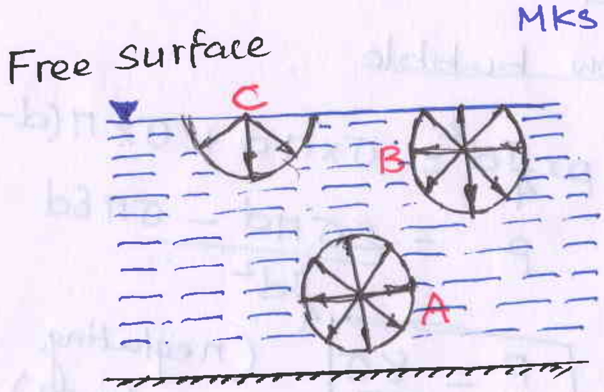
1.5 Surface tension:-

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. The magnitude of this force per unit length of the free surface will have the same value as the surface energy per unit area. It is denoted by Greek letter σ (sigma) SI unit as N/m

MKS unit as kgf/m



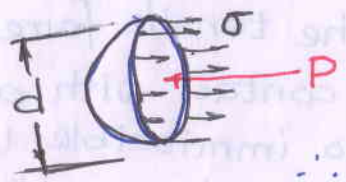
Consider three molecules A, B, C of a liquid in a mass of liquid. The molecule A is attracted in all directions equly by surrounding molecules of the liquid. Thus the resultant force acting on the molecules A is zero. But the molecule B, which is situated near the free surface is acted upon by upward and downward forces which are unbalanced. Thus a net resultant force on molecule B is acting in the downward direction. The molecule C, situated on the free surface of liquid does experience a resultant downward force. All the molecules on the free surface experience downward force.

Thus the free surface of the Liquid act like a very thin film under tension of the surface of the liquid act as through it is an elastic membrance under tension.

– Surface tension on liquid Droplet.

Consider a small spherical droplet of a Liquid of radius 'r'

Let the droplet is cut into two halves.



1) Tensile force due to surface tension acts around the circumference

∴ Tensile force $= \sigma \times \text{circumference}$

$= \sigma \times \pi d$

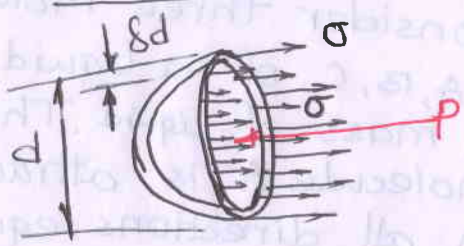
2) Pressure force $= p \times \frac{\pi}{4} d^2$

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

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

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

– Surface tension on Hollow bubble

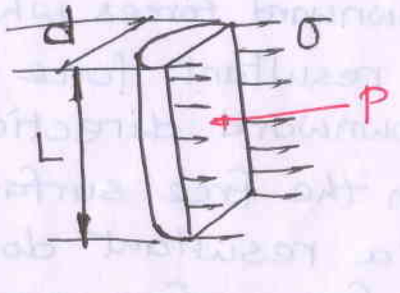


$$p \times \frac{\pi}{4} d^2 = \sigma \times \pi d + \sigma \times \pi (d - \delta d)$$

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

$$\boxed{p = \frac{8\sigma}{d}}$$ (neglating $\frac{4\sigma \delta d}{d^2}$)

– Surface tension on a liquid jet



Force due to pressure

$= p \times d \times L$

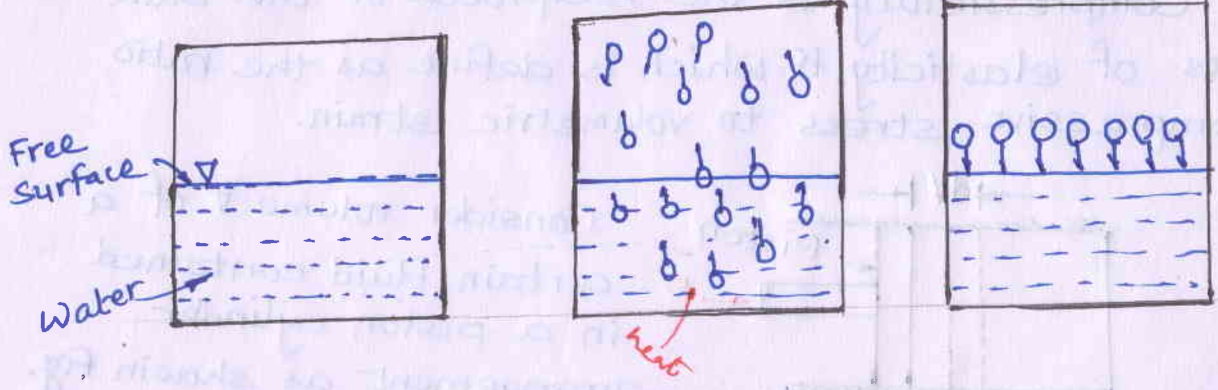
Force due to surface tension

$= \sigma \times 2 \times L$

$$p \times d \times L = \sigma \times 2L$$

$$\boxed{p = \frac{2\sigma}{L}}$$

1.6 Vapour pressure:-



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All liquids have a tendency to evaporate or vaporize. The vaporization depends upon the prevailing pressure and temperature conditions.

Consider a liquid (say water) enclosed in a closed space. Let the temperature and pressure of liquid is standard atmospheric. The liquid molecules having energy, escapes from the free surface of the liquid. These vapour molecules get accumulated in the space between the free liquid surface and top of the vessel. The ejected molecules are in a gaseous state and exert their own partial vapour pressure on the liquid surface. This pressure is known as the vapour pressure of liquid.

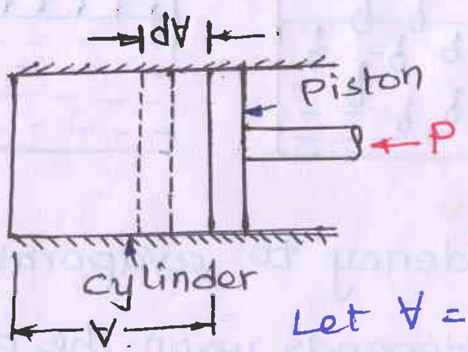
In other words it is the pressure at which the liquid is converted into vapour at given temperature.

1.7 Cavitation:-

If the pressure at any point of the flowing liquid falls below or equal the vapour pressure, there will be local boiling and a cloud of vapour bubbles will form. The cloud of vapour bubbles are carried by the flowing liquid into the region of high pressure where they collapse, giving rise to high impact pressure. If this occurs in contact with solid surface, the material from the adjoining boundaries will get eroded and cavities are formed on them. This phenomenon is known as cavitation.

1.8 Compressibility and Bulk Modulus:-

Compressibility is the reciprocal of the bulk modulus of elasticity, K which is define as the ratio of compressive stress to volumetric strain.



Consider volume V of a certain fluid contained in a piston cylinder arrangement as show in fig.

Let V = volume of a gas enclosed in cylinder

p = pressure of gas when volume is V

Let the volume of gas decreases from V to $(V - dV)$, and the pressure is increased to $(p + dp)$

$$\text{Bulk modulus } K = \frac{\text{Increase of pressure}}{\text{Volumetric strain}}$$

$$= \frac{dp}{-dV/V}$$ (-ve sign means the volume decreases with increase of pressure)

$$\boxed{K = \frac{-dp}{dV} \cdot V}$$

compressibility is given by $= \frac{1}{K}$

→ Relationship between Bulk modulus & Pressure for a Gas

i) For Isothermal process:-

$$\frac{p}{\rho} = \text{constant}$$

$$pV = \text{constant}$$

differentiating $pdV + Vdp = 0 \Rightarrow pdV = -Vdp \Rightarrow p = \frac{-Vdp}{dV}$

$$\boxed{K = p}$$

ii) For adiabatic process:-

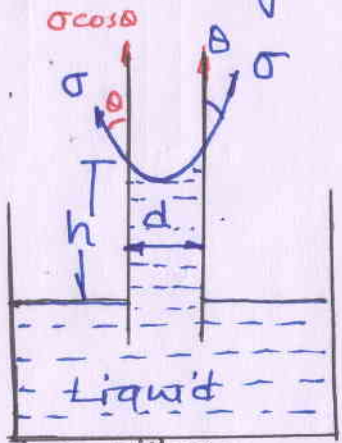
$$\frac{p}{\rho^r} = \text{constant}, \quad pV^r = \text{constant}$$

differentiating $prV^{r-1} dV + V^r dp = 0$

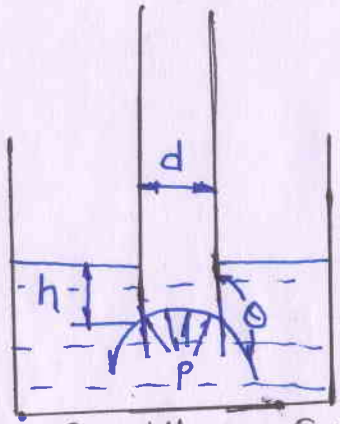
$$prdV + Vdp = 0 \Rightarrow prdV = -Vdp, \; pr = \frac{-Vdp}{dV}$$

$$\boxed{K = rp}$$

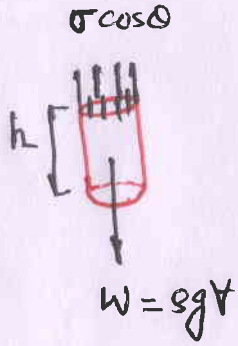
1.9 Capillarity:- Capillarity is define as a phenomenon of rise or fall of a liquid surface in a small tube relative to the adjacent general level of liquid when the tube is held vertically in the liquid. The rise of liquid surface is known as capillary rise while the fall of the liquid surface is known as capillary deression or fall



Capillary rise



Capillary fall



Let h = height of the liquid in the tube
σ = Surface tension of liquid
θ = Angle of contact betn liquid and glass tube

The weight of liquid of height h in the tube

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

Vertical component of the surface tensile force

$$= \sigma \times \text{Circumference} \times \cos\theta$$
$$= \sigma \times \pi d \times \cos\theta$$

For equilibrium

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

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

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