

Chapter OneProperties of Fluids**1.1 / Introduction :**

Fluid mechanics is that branch of science which deals with the behavior of the fluids (liquids or gases) at rest as well as in motion.

1.2 / Properties of fluids :**1. Mass density (ρ)(rho) :**

It is defined as the ratio of the mass of the fluid to its volume .

$$\rho = \frac{m}{v} \quad \text{kg/m}^3 \quad (1.1)$$

in which ,

m mass (kg) .

v volume (m^3) .

ρ of water is 1 gm/cm^3 or 1000 kg/ m^3 .

2. Specific weight or Weight density (γ) (gama) :

It is define as the ratio of a weight of the fluid to its volume .

$$\gamma = \frac{W}{V} \quad \text{N /m}^3 \quad (1.2)$$

In which ,

W weight N (Newton)

V volume m^3

From Second law of Newton ($F = ma$) , in which

F - Force (N) , m – mass (kg) , a – acceleration (m/s^2) ,

If the force is weight (w) , the acceleration (a) becomes (g) ,

g - gravity acceleration (m/s^2), therefore from second law of Newton ($w = m g$), substituting this value in eq.(1.2) ,

(1)

$$\gamma = \frac{mg}{v} \quad , \quad \text{from eq. (1.1) (} \rho = \frac{m}{v} \text{)}$$

$$\gamma = \rho g \quad N/m^3 \quad (1.3)$$

Therefore , if the value of g is $9.81 m/s^2$, γ of water is $1000 * 9.81 = 9810 N/m^3$

3. Specific volume (v_s):

It is defined as the volume of a fluid occupied by a unit mass or volume per unit mass of a fluid .

$$v_s = \frac{\text{volume}}{\text{mass}} = \frac{1}{\frac{\text{mass}}{\text{volume}}} = \frac{1}{\rho} \quad m^3 / kg \quad (1.4)$$

4. Specific gravity or Relative density (S) :

It is defined as the ratio of the weight density or mass density of a fluid to the weight density or mass density of water (for liquids) , and for gases to the weight density or mass density of air .

$$S \text{ (for liquids)} = \frac{\gamma \text{ of liquid}}{\gamma \text{ of water}} = \frac{\rho \text{ of liquid}}{\rho \text{ of water}} \quad (1.5)$$

$$S \text{ (for gases)} = \frac{\gamma \text{ of gas}}{\gamma \text{ of air}} = \frac{\rho \text{ of gas}}{\rho \text{ of air}} \quad (1.6)$$

(S is without units)

5 . Viscosity(μ)(μ) :

Viscosity is defined 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 $u + du$ as shown in Fig.(1.1) , the viscosity together with relative velocity causes a shear stress acting between the fluid layers. This shear stress is proportional to the rate of change of velocity with respect to y . It is denoted by symbol τ called Tau .

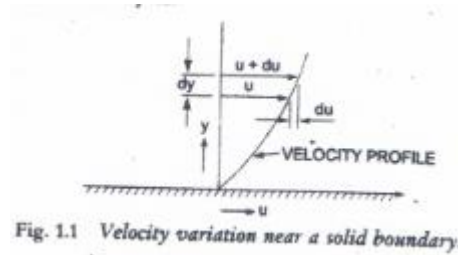


Fig. 1.1 Velocity variation near a solid boundary.

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

$$\tau = \mu \frac{du}{dy} \text{ (Newton's law of viscosity) } \quad (1.7)$$

Where, μ (called mu) is the constant of proportionality and is known as dynamic viscosity, $\frac{du}{dy}$ represents the rate of shear deformation or velocity gradient.

$$\text{From eq. (1.7) } \mu = \frac{\tau}{\frac{du}{dy}} \quad (1.8)$$

Unit of viscosity in SI unit is (N s / m²) or (Pa.s) .

The unit of viscosity in (C G S) (centimeter – Gram – Second) is called Poise which is equal to $\frac{\text{dyne-second}}{\text{cm}^2}$.

(One poise = 0.1 N.s / m²) and (one poise = 100 centipoise)

Kinematic Viscosity (ν) is defined as the ratio between the dynamic viscosity and mass density of fluid :

$$\nu = \frac{\text{viscosity}}{\text{density}} = \frac{\mu}{\rho} \quad (1.9)$$

The unit of kinematic viscosity in SI unit is (m² / s) , and in (CGS unit) is Stoke , one Stoke is one cm²/ s and equal 10⁻⁴ m²/s .

(One Stoke = 100 centistoke) .

Variation of Viscosity with temperature :

1. The viscosity of liquid decreases with increase of temperature.
2. The viscosity of gases increase with increase of temperature.

1.3/ Thermodynamic properties :

Gases are compressible fluids and hence thermodynamic properties play an important role , with the change of pressure and temperature , the gases undergo large variation in density. The relationship between absolute pressure , specific volume, absolute temperature (T) of a gas is given by the equation of state as , (R is gas constant) :

$$pv_s = R T \quad (1.10)$$

$$\frac{p}{\rho} = R T \quad (1.11)$$

Units of R in SI unit (J/kg.k) (R for air 287 J/kg.k)

1. Isothermal process :

If the change in density occurs at constant temperature , then process is called isothermal process and relationship between pressure and density is given by :

$$\frac{p}{\rho} = \text{constant} \quad (1.12)$$

2. Adiabatic process :

If the change in density occurs with no heat exchange to and from gas , the process is called adiabatic .

$$\frac{p}{\rho^k} = \text{constant} \quad (1.13)$$

where,

p is pressure .

k is ratio of specific heat of a gas at constant pressure (c_p) and constant volume (c_v) (k = c_p / c_v) . (k for air is 1.4) .

1.4/ Compressibility and Bulk Modulus:

Compressibility is the reciprocal of the bulk modulus of elasticity (K) which is defined as the ratio of compressive stress to volumetric

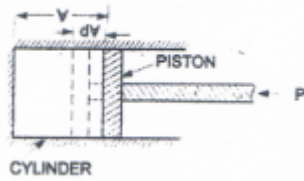


Fig.(1.2)

Consider a cylinder fitted with a piston as shown in Fig.(1.2),

Let V is volume of gas enclosed in the cylinder.

P is pressure of gas when volume is V .

Let the pressure is increased to $p + dp$, the volume of gas decrease from V to $V - dV$,

$$\text{Volumetric strain} = - \frac{dv}{v}$$

$$\text{Bulk modulus (K)} = \frac{\text{increase of pressure}}{\text{volumetric strain}} = \frac{dp}{\frac{-dv}{v}} = \frac{-dp}{dv} v \quad (1.14)$$

$$\text{Compressibility} = \frac{1}{K} \quad (1.15)$$

For Isothermal process ,

$$K = P \text{ (P is pressure)}$$

For Adiabatic process ,

$$K = pk$$

(where k is ratio of specific heat $\frac{c_p}{c_v}$)

1.5/ Surface Tension and Capillarity :

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 . It is denoted by Greek letter σ (called sigma) .

The phenomenon of surface tension is explained by Fig.(1.3) .

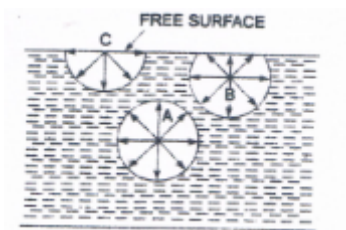


Fig.(1.3) Surface tension

Consider three molecules A , B , C of a liquid in a mass of liquid. The molecule A is attracted in all directions equally by the surrounding molecules of the liquid. Thus the resultant force acting on the molecule 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 a 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 a downward force. Thus the free surface of the liquid acts like a very thin film under a tension of the surface of the liquid act as though it is an elastic membrane under tension .

Types of Surface tensions

1. Surface tension on liquid droplet :

Consider a small spherical droplet of a liquid of radius r , let the droplet is cut into two halves , as shown in Fig.(1.4) .

(1) tensile force due to surface tension acting around the circumference of cut portion as shown in Fig.(1.4) , and this is equal to :

$$\text{Tensile force} = \sigma \cdot \text{Circumference} = \sigma \cdot \pi d$$

$$\text{Pressure force} = p \cdot \frac{\pi d^2}{4}$$

These forces will be equal and opposite under equilibrium conditions , i. e . ,

$$P \cdot \frac{\pi d^2}{4} = \sigma \cdot \pi d$$

Then ,

$$\sigma = \frac{P d}{4} \text{ N / m} \quad (1.16)$$

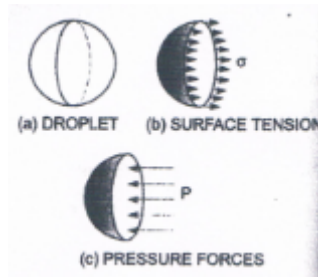


Fig.(1.4) Forces on droplet

2. Surface tension on a hollow Bubble :

A hollow bubble like a soap bubble in air has two surfaces in contact with air, one inside and other outside .Thus two surfaces are subjected to surface tension. In such case, we have ,

$$P \cdot \frac{\pi d^2}{4} = 2 \cdot \sigma \pi d$$

$$\sigma = \frac{P d}{8} \text{ N / m} \quad (1.17)$$

3. Surface Tension on a liquid Jet :

Consider a liquid jet of diameter (d) and length (L) as shown in Fig.(1.5) ,

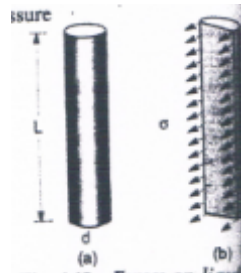


Fig.(1.5) Forces on liquid jet

Consider the equilibrium of the semi jet , we have ,

$$\text{Force due to pressure} = P \cdot Ld$$

$$\text{Force due to surface tension} = \sigma \cdot 2L$$

Equating the two forces ,

$$P \cdot Ld = \sigma \cdot 2L$$

$$\sigma = \frac{Pd}{2} \text{ N/m} \quad (1.18)$$

Capillarity :

Capillarity is defined 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 depression. Its value depends upon the specific weight of the liquid, diameter of the tube and surface tension of liquid.

Expression for capillary Rise :

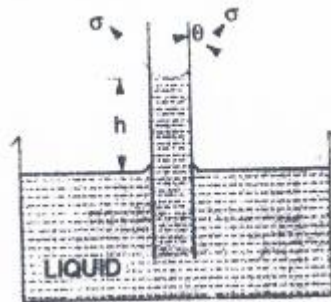


Fig.(1.6) Capillary rise

Consider a glass tube of small diameter (d) opened at both ends and inserted in a liquid (water), as shown in Fig.(1.6). The liquid will rise in the tube above the level of the liquid.

Let h is height of the liquid in the tube. Under a state of equilibrium, the weight of liquid of height h is balanced by the force at the surface of the liquid in the tube. But the force at the surface of the liquid in the tube is due to surface tension.

The weight of liquid of height h in the tube = Area of tube . h . ρg .

$$= \frac{\pi}{4} d^2 h \rho g$$

Vertical component of the surface tensile force = σ . Circumference. $\cos \theta$

$$= \sigma . \pi d . \cos \theta$$

For equilibrium, equating two equations :

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

$$h = \frac{4\sigma \cos\theta}{\rho g d} \quad (1.19)$$

In which (Θ) angle of contact between liquid and glass tube .

The value of Θ between water and clean glass tube is equal to zero ,
($\cos \Theta = 1$) , then , the equation (1.19) becomes :

$$h = \frac{4\sigma}{\rho g d} \quad (1.20) \text{ (if the liquid is water and tube is glass)}$$

Expression for Capillary Fall :

If the glass tube is dipped in mercury , the level of mercury is the
tube will be lower than the general level of the outside as shown in Fig.(1.7)

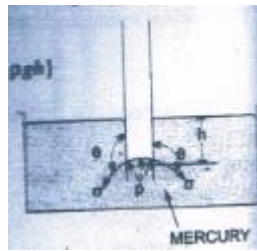


Fig.(1.7)

Let h is height of depression in tube .

There are two forces are acting on the mercury inside the tube.

1. Force due to surface tension acting in the downward direction

$$= \sigma \pi d \cos \Theta$$

- 2 . Force due to hydrostatic force acting upward = $p \cdot \frac{\pi}{4} d^2$

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

Then in equilibrium , equating the two forces ,

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

$$h = \frac{4\sigma \cos\theta}{\rho g d} \quad (1.21)$$

(value of Θ for mercury and glass tube is 128°)

1.6/ Vapor pressure and Cavitation :

A change from the liquid state to the gaseous state is known as vaporization. Consider a liquid (say water) which is confined in closed vessel . Let the temperature of liquid is 20°c and pressure is atmospheric , if the pressure above the liquid surface is reduced by vacuum blower, this value of reduce of pressure reach to vapor pressure or less than the vapor pressure , the boiling of the liquid will start , though the temperature of the liquid is 20°c .

Because , the vaporization takes place , when vapor molecules get accumulated in the space between the free liquid surface and top of the vessel , these accumulated of vapor molecules , exert a pressure on the liquid surface .

this pressure is known as Vapor pressure of the liquid (at this pressure , the liquid is converted into vapor).

If the liquid (say water) is flowing in a system , when the velocity of water is increased , the pressure is decreased , may be this decreasing of pressure reach to the value of vapor pressure of water , then the water start to boiling (molecules of water convert to vapor bubbles) , if these vapor bubbles flowing to the region of higher pressure , they are sudden collapsing , when the collapsing of these vapor bubbles , very high pressure and stress are created , the metallic surfaces which the liquid is flowing is pitting and damage , this process is known Cavitation .