PROPERTIES OF FLUID

Fluid Mechanics is that branch of Science that deals with the behavior of fluids at rest as well as in motion.

If the fluid is at rest its behavioral analysis is called as fluid statics.

Fluids in motion where pressure forces are not considered are called as fluid kinematics.

Fluids in motion where pressure forces are considered are called as fluid dynamics.

PROPERTIES OF FLUID:

Density or Mass Density: It is defined as the ratio between mass of a fluid to its volume. Or mass per unit volume is called as density.

It is donated by rho (ρ).

$\rho = \frac{Mass\ of\ the\ fluid(m)}{volume\ of\ fluid(v)}$

unit =kg/m^3, g/cm^3

for water the density is 1g/cm^3, 1000kg/m^3

Density of air is 1Kg/m^3.

Specific Weight or Weight Density: Specific weight of a fluid is the ratio between weight of the fluid to its volume.

Or weight per unit volume is called as specific weight.

$Specific\ weight\ (W) = \frac{Weight\ of\ the\ fluid}{volume\ of\ fluid}$

$W = \frac{m\ X\ g}{V} = \rho\ X\ g =$ *density of the fluid x acceleration due to gravity*

Unit: N/m^3, dyne/cm^3

Specific Volume: Specific volume is defined as the ratio between the volume of the fluid to mass of the fluid.

It is defined as the reciprocal of density. It is denoted by V.

$V=1/\rho = \frac{Volume\ of\ fluid}{mass\ of\ the\ fluid}$

Unit: m^3/Kg

Specific Gravity: Specific gravity is defined as the ratio of the weight density or density of a fluid to the weight density or density of standard fluid.

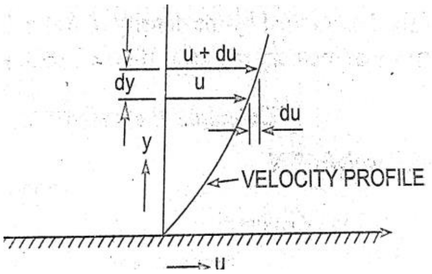
For liquid the standard fluid is taken as water, for gas the standard fluid is taken as air.

It is denoted by S and it is unit less.

$S_{liquid} = \frac{weight\ density\ or\ density\ of\ liquid}{weight\ density\ or\ density\ of\ water}$

$S_{gas} = \frac{weight\ density\ or\ density\ of\ gas}{weight\ density\ or\ density\ of\ air}$

Viscosity: Viscosity is defined as the property of the fluid which offers resistance to the movement of one layer of fluid over another layer of fluid.



When two layers of fluid at a distance dy apart, move one over other at different velocities suppose u and u+du.

The viscosity together with relative velocity causes shear stress acting between fluid layers.

This shear stress is proportional to rate of change of velocity with respect to y.

So, mathematically

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

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

Where, μ= constant of proportionality or coefficient of dynamic viscosity or viscosity.

$\frac{du}{dy}$ **= Rate of shear strain or rate of shear deformation or velocity gradient.**

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

Unit= Ns/m^2 ……………………in SI unit

Dyne. s/cm^2 or **Poise**………………in CGS unit.

$1Ns/m^2$ = 10 poise

The viscosity of water at 20°C is 0.01 Poise or 1 Centipoise.

KINEMATIC VISCOSITY:

It is defined as the ratio between dynamic viscosity and density of fluid.

It is denoted by ν.

$\nu = \frac{\mu}{\rho}$ = Viscosity/Density

Unit= m^2/s ……….in SI unit

cm^2/s or **stoke** ……………in CGS unit

$1m^2/s = (100cm)^2/s = 10000\ cm^2/s = 10^4$ stoke

NEWTON'S LAW OF VISCOSITY:

It states that the shear stress on a fluid element layer is directly proportional to the rate of shear strain.

The constant of proportionality is called as co-efficient of viscosity.

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

The fluid which obeys the above equation is called as Newtonian fluid and the fluid which does not obey is called as Non-newtonian fluid.

VARIATION OF VISCOSITY WITH TEMPERATURE:

For Liquid $\mu = \mu_0 \left(\frac{1}{1+\alpha t+\beta t^2}\right)$

μ = Viscosity of liquid at t°C , in Poise

μ_0 = Viscosity of liquid at 0°C , in Poise = 1.79×10^{-3} Poise(for water)

α and β are constants. For water α=0.00368 & β= 0.000221

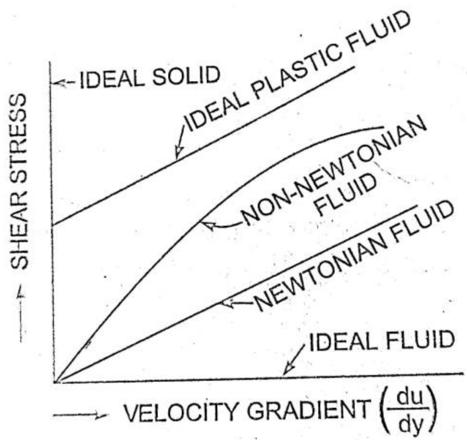
For gas $\mu = \mu_0 + \alpha t - \beta t^2$

For air μ_0= 0.000017 Poise, α= 0.000000056, β= 0.1189×10^{-9}

TYPES OF FLUID:

There are following types of fluid. They are

1. Ideal fluid
2. Real fluid
3. Newtonian fluid
4. Non-newtonian fluid
5. Ideal plastic fluid



Ideal Fluid: A fluid which is incompressible and is having no viscosity is known as an ideal fluid. This type of fluid does not exist.

Real Fluid: A fluid which possesses viscosity is known as real fluid.

Newtonian Fluid: A real fluid in which the shear stress is directly proportional to the rate of change of shear strain it is called as Newtonian fluid.

Non-Newtonian Fluid: A real fluid, which doesn't obey Newton's law of viscosity, is called as Non-newtonian fluid.

Ideal Plastic Fluid: A fluid in which the shear stress is more than the yield value and shear stress is proportional to the rate of shear strain, is known as ideal plastic fluid.

SURFACE TENSION:

Surface tension is defined as the tensile force acting on the surface of liquid in contact with a gas or on the surface between two immiscible liquids, such as contact surface behaves like a membrane under tension.

It is denoted by σ.

Unit: N/m

SURFACE TENSION OF LIQUID DROPLET:

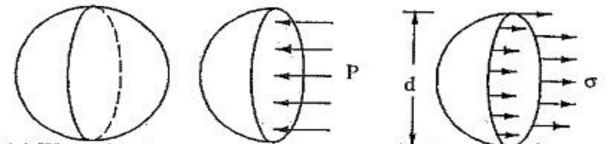
Consider a small spherical droplet of a liquid of radius ‘r’. On the entire surface of the droplet, the tensile force due to surface tension must be acting.

σ = Surface tension of the liquid.

P = pressure intensity inside the droplet (In-excess of the outside pressure intensity)

d = diameter of the droplet.

Let the droplet is cut in to two halves, the force acting on the one half (left half) will be tensile force due to surface tension acting around the circumference to the cut section.



(a) Water droplet (b) Pressure forces (c) Surface tension

Then the force due to surface tension is, F = surface tension X circumference

F = σ x π x d

The pressure force acting on the area=Pressure X Area = P X $\frac{\pi}{4}d^2$

And we know that under equilibrium condition,

The force due to surface tension= force due to Pressure

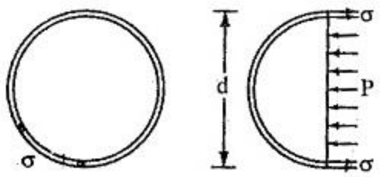
$\sigma \times \pi \times d = P \times \frac{\pi}{4} d^2$

$$P = \frac{4\sigma}{d}$$

It shows that with decrease in diameter of the liquid droplet, the pressure intensity inside the liquid droplet increases.

SURFACE TENSION OF HOLLOW BUBBLE:

The hollow bubble is like a soap bubble in air. It has two contact surfaces with air. One surface is in inside other in outside. Thus two surfaces are subjected to surface tension.



In such cases

Force due to surface tension = 2 x σ x π x d

Force due to pressure acting on the area = $P \times \frac{\pi}{4} d^2$

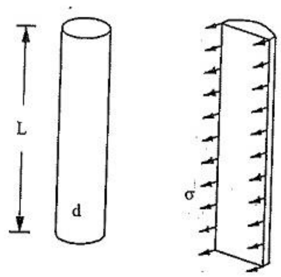
At equilibrium we know the equation i = equation ii

= 2 x σ x π x d = $P \times \frac{\pi}{4} d^2$

= P = $\frac{8\sigma}{d}$

SURFACE TENSION ON LIQUID JET:

Consider liquid jet of diameter 'd' and length 'L'.



P= pressure intensity inside the liquid jet above the outside pressure.

σ = Surface tension of the liquid.

Consider the equilibrium of semi-jet.

Force due to pressure = P x area of the semi-jet

= P x L x d

Force due to surface tension= σ x 2L

And under equilibrium, force due to pressure = force due to surface tension

= P x L x d = σ x 2L

P = $\frac{2\sigma}{d}$

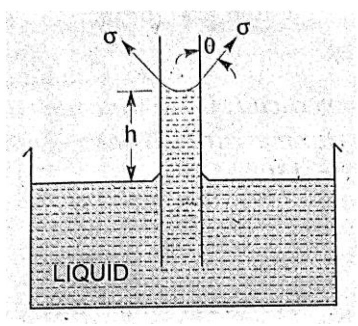
CAPILLARITY:

Capillarity is defined as the phenomenon of rise and fall of a liquid surface in a small tube relative to adjacent general level of liquid when the tube held vertically in the liquid.

The rise is known as capillary rise and the fall of liquid is known as capillary depression.

EXPRESSION OF CAPILLARY RISE:

Small glass tube of diameter 'd' opened at both ends is inserted in water.



Let h = height of the water in tube

Under the state of equilibrium the weight of the 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.

σ = Surface tension of liquid.

ϴ = Angle of contact between liquid and glass tube.

Weight of the liquid in tube = V x ρ x g

$$= \frac{\pi}{4} d^2 \text{ x h x } \rho \text{ x g} \text{ ....i}$$

Vertical component of the surface tension force = (σ x circumference) Cos ϴ

$$= \sigma \text{ x } \pi \text{ x d x Cos } \theta \text{ ....ii}$$

At equilibrium equation i = equation ii

$$\frac{\pi}{4} d^2 \text{ x h x } \rho \text{ x g} = \sigma \text{ x } \pi \text{ x d x Cos } \theta$$

$$h = \frac{4 \text{ x } \sigma \text{ x Cos } \theta}{\rho \text{ x g x d}}$$

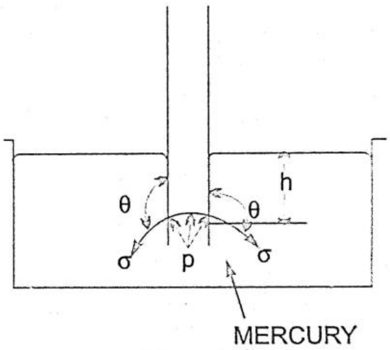
For water and clean glass tube $\theta = 0^\circ$, So, Cos $\theta = 1$

So, the expression becomes

$$h = \frac{4 \text{ x } \sigma}{\rho \text{ x g x d}}$$

EXPRESSION FOR CAPILLARY FALL:

If the same glass tube of diameter 'd' is dipped in mercury, the level of mercury will be lower than the general level.



h = height of fall in the tube.

Then in the equilibrium there will be two forces on the mercury inside the tube.

First force is the surface tension in the downward direction = $\sigma \text{ x } \pi \text{ x d x cos}\theta$ i

Second force is due to hydrostatic force acting upward

= is equal to the intensity of the pressure at the depth h x area

$$= P \text{ x } \frac{\pi}{4} d^2 = \rho \text{ x g x h x } \frac{\pi}{4} d^2 \text{ ....ii}$$

At equilibrium equation i = equation ii

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

$$= h = \frac{4\ \sigma \text{ Cos}\theta}{\rho g d}$$