Fluid :- Fluid is a substance which is capable of flowing or moving or deforming under the action of shear force.

Fluid → liquids
Fluid → gases

⇒ Solid can resist an applied shear stress whereas a fluid deforms continuously under the influence of shear stress, no matter how small.

Note: After removal of shear stress, viscoelastic fluid may regain their original shape.

Fluid Mechanics :- It is defined as science that deals with the behaviour of fluid at rest or in motion and the interaction of fluids with solids or other fluids at the boundaries.

Basic Properties of Fluid :-
Certain characteristics of a continuous fluid are independent of the motion of the fluid.

1. Density
2. Specific Volume
3. Specific gravity
4. Viscosity
5. Compressibility
6. modulus of elasticity
7. Capilarity
8. Surface tension

Fluid :- A fluid is a substance which deforms continuously when subjected to external shearing forces.

Fluid → Liquids
Fluid → Gases

Characteristics of Fluid :-

1. It has no definite shape of its own, but conforms to the shape of the containing vessel.
2. Even a small amount of shear force exerted on a fluid will cause it to undergo a deformation which continues as long as the force continues to be applied.
3. It is interesting to note that a solid suffer strain when subjected to shear forces whereas a fluid suffers rate of strain i.e. it flows under similar circumstances.

① **Density :- (ρ)**

$$\text{Fluid density} = \frac{\text{mass of fluid}}{\text{Volume of fluid}}$$

$$\boxed{\rho = \frac{m}{V}}$$

⇒ Density of water at 1 atm & 4.4 °C

$$\boxed{\rho_{H_2O} = 1000 \ \frac{kg}{m^3}}$$

⇒ Density of Hg at 1 atm & 25°C

$$\boxed{\rho_{Hg} = 13,600 \ \frac{kg}{m^3}}$$

Effect of Temp. on Density:-

$$T\uparrow , \ \rho\downarrow$$

Note:- Density of water decrease when increase or decrease in temperature.
(Standard at 4.4°C = 1000 kg/m3 maximum)

Weight density:- [w]

$$\text{Weight density} = \frac{\text{weight of fluid}}{\text{Volume of fluid}} \qquad \left[\frac{N}{m^3}\right] \rightarrow \text{Unit}$$

$$w = \frac{mg}{V} = \frac{m}{V} g = \rho g$$

$$w = \rho g$$

→ Also called specific weight.

② Specific Volume:- [v]

$$v = \frac{1}{\rho} = \frac{V}{m}$$

→ Reciprocal of density.
→ Volume per unit mass.

③ Specific gravity:-

It is the ratio of specific weight or mass density of fluid to specific weight or mass density of standard fluid.

$$s.g. = \frac{\rho_{fluid}}{\rho_{std.\ fluid}}$$

→ For liquids, standard fluid is water at 1 atm & 4.4°C

$$(s.g)_{liq} = \frac{\rho_{liq}}{1000}$$

Specific gravity of water = 1

→ For gases, standard fluid is air at 1 atm & 25°C.

$$(s.g.)_{gas} = \frac{\rho_{gas}}{1.23}$$

Note:- Specific gravity of mercury is 13.6. It means mercury is 13.6 times denser and havier than water.

④ **Viscosity:-** Viscosity is the property of a fluid which determines its resistance to shearing stresses.

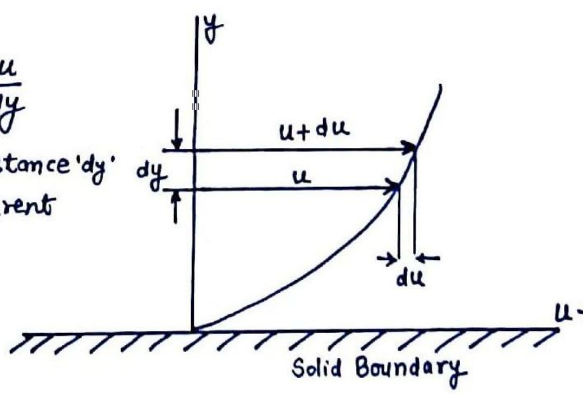
⇒ Cause of viscosity:- It is due to cohesion and molecular momentum exchange between fluid layers.

Newton's Law of Viscosity:- It states that the shear stress (τ) on a fluid element layer is directly proportional to the rate of shear strain (velocity gradient).

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

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

When two layers of fluid, at a distance 'dy' apart, move one over the other at different velocities, say u & u+du



Velocity gradient = $\frac{du}{dy}$

fig: Velocity variation near a solid boundary where τ = constant of proportionality & is known as co-efficient of Dynamic viscosity or only viscosity.

$$\mu = \frac{\tau}{\left[\frac{du}{dy}\right]}$$

⇒ Thus, viscosity defined as the shear stress required producing unit rate of shear strain.

Units of viscosity :-

① SI Unit:

$$\mu = \frac{\tau}{\left(\frac{du}{dy}\right)} = \frac{(F/A)}{\left(\frac{du}{dy}\right)} = \frac{N/m^2}{\left(\frac{m/s}{m}\right)} = \frac{N\cdot s}{m^2} = Pa\cdot s$$

$$\boxed{\mu \rightarrow \frac{kg}{m\cdot s} \text{ or } Pa\cdot s}$$

② CGS Unit:

$$\mu \rightarrow \frac{1\ N\cdot s}{m^2} = \frac{10^5\ dyne\cdot s}{10^4\ cm^2} = 10\ \frac{dyne\cdot s}{cm^2}$$

$$\boxed{\text{Poise} \rightarrow \frac{dyne\cdot s}{cm^2}}$$

$$\mu \rightarrow 10 \text{ Poise} = 1\ \frac{N\cdot s}{m^2} = 1\ Pa\cdot s$$

$$1 \text{ Poise} = 10^{-1}\ Pa\cdot s = 0.1\ Pa\cdot s$$

$$\boxed{1 \text{ Poise} = 0.1\ Pa.Sec}$$

$$1 \text{ Poise} = 100 \text{ Centipoise}$$

③ MKS Unit:

$$\boxed{\mu \rightarrow \frac{kgf\ Sec}{m^2} = 9.81\ \frac{N\cdot S}{m^2} = 98.1 \text{ Poise}}$$

Note:- Viscosity of Water:- (at 20°C)

$$\mu_{water} = 1\ cp = 0.01\ poise = 0.001\ pa.s$$

⇒ Viscosity property is important only when fluid is in motion, so, viscosity property has no significance when the fluid is at rest.

Kinematic Viscosity:- It is the ratio between the dynamic viscosity and density of fluid and denoted by ν.

$$\nu = \frac{\text{dynamic viscosity}}{\text{density}} = \frac{\mu}{\rho}$$

→ Also called momentum diffusivity.

Units:-

① SI Unit:-

$$\nu = \frac{\mu}{\rho} = \frac{\left(\frac{Ns}{m^2}\right)}{(kg/m^3)} = \frac{\frac{kg\,m}{s^2} \times \frac{s}{m^2}}{\left(\frac{kg}{m^3}\right)} = \frac{m^2}{s}$$

$$\boxed{\nu \rightarrow \frac{m^2}{s}}$$

② CGS Unit:

$$\nu \rightarrow 1\ \frac{cm^2}{s} = 1\ \text{stoke}$$

$$\boxed{\nu \rightarrow \text{stoke}}$$

$$1\ \frac{m^2}{s} = 10^4\ \frac{cm^2}{s} = 10^4\ \text{stoke}$$

$$\boxed{1\ \text{stokes} = 10^{-4}\ \frac{m^2}{s}}$$

Effect of Temperature on viscosity:-

Viscous forces in the fluid is due to-

① Cohesive force (force b/w two molecules of same substance)

② Molecular momentum force.

⇒ Due to strong cohesive forces between the molecules, any layer in a moving fluid tries to drag the adjacent layer to move with an equal speed and thus produces the effect of viscosity.

⇒ The individual molecules of a fluid are continuously in motion and this motion makes a possible process of a exchange of momentum b/w different moving layer of the fluid.

Viscosity of Liquids:-

In case of liquids, the intermolecular force is very large because they are closely spaced. Hence, the cohesive force is very large. With rise in temperature, the cohesive force decreases and hence the resistance to flow also decreases. So, the viscosity of the liquid decreases with increase in temp.

With increase in Temp ⇒ Viscosity of Liquids decreases

$$T \uparrow, \mu \downarrow$$

The viscosity of liquid is a strongly non-linear function of the temperature but a approximation for temp. below the normal

Viscosity of Gases :-

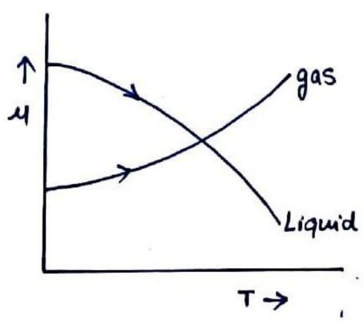
In the case of gases, cohesive force are negligible but with the rise in the temp, the molecular disturbance increases and hence because of this, the resistance to flow increases and therefore viscosity of the gas increases with increase in temp.

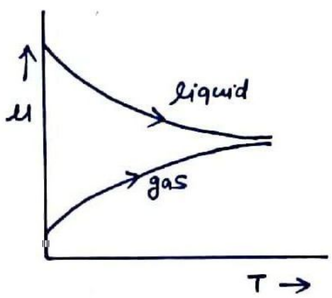
With increase in Temp. ⇒ Viscosity of gases increase

$$T\uparrow, \mu\uparrow$$

⇒ From kinetic theory of gases, $\mu \propto \sqrt{T}$

where, T → Absolute temp in K





Note :-
1. Temperature response are neglected in case of mercury.
2. The lowest viscosity is reached at the critical temp.
3. The viscosity of liquids are much greater than these of gases (H_2, benzene vapour etc.) at the same temp.

At 20°C $\mu_{H_2O} = 1$ cp $\mu_{air} = 0.018$ cp

Ideal and Real Fluids :-

1. Ideal Fluid : An fluid is one which has
   - → no viscosity
   - → no surface tension
   - and incompressible.