1.1 FLUID - DEFINITION

Introduction: In general matter can be distinguished by the physical forms known as solid, liquid, and gas. The liquid and gaseous phases are usually combined and given a common name of fluid. Solids differ from fluids on account of their molecular structure (spacing of molecules and ease with which they can move). The intermolecular forces are large in a solid, smaller in a liquid and extremely small in gas.

Fluid mechanics is the study of fluids at rest or in motion. It has traditionally been applied in such area as the design of pumps, compressor, design of dam and canal, design of piping and ducting in chemical plants, the aerodynamics of airplanes and automobiles. In recent years' fluid mechanics is truly a 'high-tech' discipline and many exciting areas have been developed like the aerodynamics of multistory buildings, fluid mechanics of atmosphere, sports, and micro fluids.

Definition of Fluid: A *fluid* is a substance which deforms continuously under the action of shearing forces, however small they may be. Conversely, it follows that: If a fluid is at rest, there can be no shearing forces acting and, therefore, all forces in the fluid must be perpendicular to the planes upon which they act.

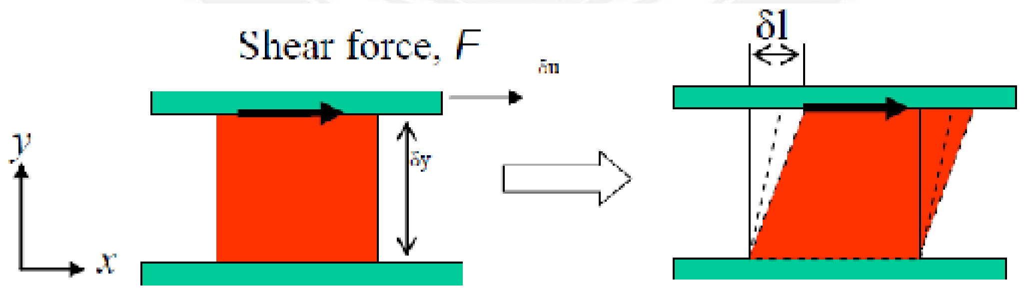


Figure 1.1.1 Deformation of a Solid and a Fluid Exposed to an applied Force

*[Source: "*https://en.wikiversity.org/wiki/Fluid_Mechanics_for_Mechanical_Engineers/Introduction*"]*

Fluid deforms continuously under the action of a shear force

$$\tau_{yx} = \frac{dF_x}{dA_y} = f(\text{Deformation Rate})$$

Shear stress in a moving fluid:

Although there can be no shear stress in a fluid at rest, shear stresses are developed when the fluid is in motion, if the particles of the fluid move relative to each other so that they have different velocities, causing the original shape of the fluid to become distorted. If, on the other hand, the velocity of the fluid is same at every point, no shear stresses will be produced, since the fluid particles are at rest relative to each other.

Differences between solids and fluids: The differences between the behaviour of solids and fluids under an applied force are as follows:

i. For a solid, the strain is a function of the applied stress, providing that the elastic limit is not exceeded. For a fluid, the rate of strain is proportional to the applied stress.
ii. The strain in a solid is independent of the time over which the force is applied and, if the elastic limit is not exceeded, the deformation disappears when the force is removed. A fluid continues to flow as long as the force is applied and will not recover its original form when the force is removed.

Differences between liquids and gases:

Although liquids and gases both share the common characteristics of fluids, they have many distinctive characteristics of their own. A liquid is difficult to compress and, for many purposes, may be regarded as incompressible. A given mass of liquid occupies a fixed volume, irrespective of the size or shape of its container, and a free surface is formed if the volume of the container is greater than that of the liquid.

A gas is comparatively easy to compress (Fig.1). Changes of volume with pressure are large, cannot normally be neglected and are related to changes of temperature. A given mass of gas has no fixed volume and will expand continuously unless restrained by a containing vessel. It will completely fill any vessel in which it is placed and, therefore, does not form a free surface.

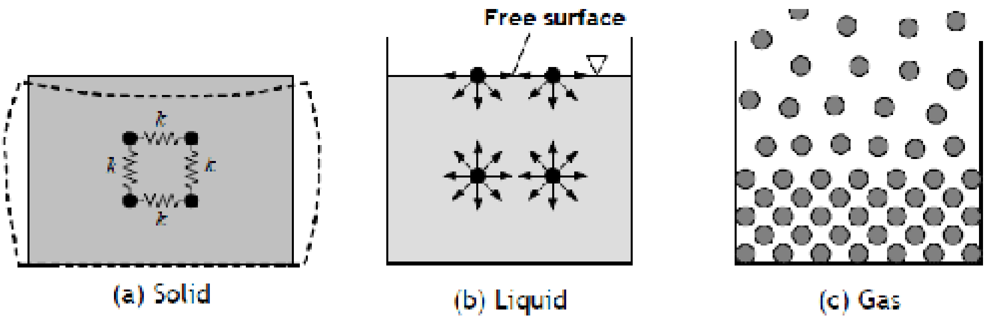


Figure 1.1.2 Comparison of Solid, Liquid and Gas

*[Source: "*https://en.wikiversity.org/wiki/Fluid_Mechanics_for_Mechanical_Engineers/Introduction*"]*

1.2 FLUID PROPERTIES:

1.Density or Mass density(ρ) : Density or mass density of a fluid is defined as the ratio of the mass of a fluid to its volume. Thus mass per unit volume of a fluid is called density.

$$\therefore \quad \rho = \frac{Mass}{Volume}$$

$$\rho = \frac{M}{V} \text{ or } \frac{dM}{dV}$$

The unit of density in S.I. unit is kg/m^3. The value of density for water is 1000kg/m. With the increase in temperature volume of fluid increases and hence mass density decreases in case of fluids as the pressure increases volume decreases and hence mass density increases.

2.Specific weight or weight density (γ): Specific weight or weight density of a fluid isthe ratio between the weight of a fluid to its volume. The weight per unit volume of a fluid is called weight density.

$$\therefore \quad \gamma = \frac{Weight}{Volume} = \frac{W}{V} \text{ or } \frac{dW}{dV}$$

The unit of specific weight in S.I. units is N/m^3. The value of specific weight or weightdensity of water is 9810N/m^3.

With increase in temperature volume increases and hence specific weight decreases.

With increases in pressure volume decreases and hence specific weight increases.

Note: Relationship between mass density and weight density:

$$\text{We have } \gamma = \frac{Weight}{Volume}$$

$$\gamma = \frac{mass \ x \ g}{Volume}$$

$$\gamma = \rho \text{ x } g$$

3.Specific Volume ($\forall$): Specific volume of a fluid is defined as the volume of a fluidoccupied by a unit mass or volume per unit mass of a fluid.

$$\therefore \quad \forall = \frac{Volume}{mass} = \frac{V}{M} \; or \; \frac{dV}{dM}$$

As the temperature increases volume increases and hence specific volume increases. As the pressure increases volume decreases and hence specific volume decreases.

4.Specific Gravity(S): Specific gravity is defined as the ratio of the weight density of afluid to the weight density of a standard fluid.

$$S = \frac{\rho_{fluid}}{\rho_{standard\ fluid}}$$

Unit: It is a dimensionless quantity and has no unit.

In case of liquids water at 4ºC is considered as standard liquid. $\rho_{water} = 1000\ kg/m^3$

Problem1: Calculate specific weight, mass density, specific volume and specific gravity of a liquid having a volume of $4m^3$ and weighing 29.43 kN. Assume missing data suitably.

$$\gamma = ?$$
$$\rho = ?$$
$$\forall = ?$$
$$S = ?$$
$$V = 4\ m^3$$
$$W = 29.43\ kN = 29.43 \times 10^3\ N$$

$$\gamma = \frac{W}{V} = \frac{29.43 X 10^3}{4}$$

$$\gamma = 7357.58\ N/m^3$$

To find ρ - Method 1:

$$W = mg$$

$$29.43 \times 10^3 = m \times 9.81$$

$$m = 3000\ kg$$

$$\therefore \rho = \frac{m}{v} = \frac{3000}{4}$$

Method 2:

$$\gamma = \rho g$$

$$7357.5 = \rho\ 9.81$$

$$\rho = 750\ kg/m^3$$

$$\rho = 750\ \text{kg/m}^3$$

$$\rho = \frac{M}{V}$$

i) $$\forall = \frac{V}{M}$$

$$\forall = \frac{V}{M}$$

$$= \frac{4}{3000}$$

$$\forall = \frac{1}{\rho} = \frac{1}{750}$$

$$\forall = 1.33 \times 10^{-3}\,\text{m}^3/\text{kg}$$

$$\forall = 1.33\text{X}10^{-3}\,\text{m}^3/\text{kg}$$

$$S = \frac{\gamma}{\gamma_{\text{Standard}}} \qquad S = \frac{\rho}{\rho_{\text{Standaard}}}$$

$$= \frac{7357.5}{9810} \quad \text{or} \quad S = \frac{750}{1000}$$

$$S = 0.75 \qquad S = 0.75$$

Problem2: Calculate specific weight, density, specific volume and specific gravity and if one liter of Petrol weighs 6.867N.

$$\gamma = \frac{W}{V}$$

$$V = 1\,\text{Litre}$$

$$= \frac{6.867}{10^{-3}}$$

$$V = 10^{-3}\,\text{m}^3$$

$$W = 6.867\text{N}$$

$$\gamma = 6867\,\text{N/m}^3$$

$$S = \frac{\gamma}{\gamma_{\text{S tan dard}}}$$

$$\rho = s\ g$$

$$= \frac{6867}{9810}$$

$$6867 = \rho \times 9.81$$

$$S = 0.7$$

$$\rho = 700\text{kg/m}^3$$

$$\forall = \frac{V}{M}$$
$$= \frac{10^{-3}}{0.7}$$
$$\forall = 1.4x10^{-3} m^3 / kg$$

$$M = 6.867 \div 9.81$$
$$M = 0.7 \text{ kg}$$

***Problem* 3:** Specific gravity of a liquid is 0.7 Find i) Mass density ii) specific weight. Also find the mass and weight of 10 Liters of liquid.

$$S = \frac{\gamma}{\gamma_{Standard}}$$

$$\gamma = \rho g$$

$$S = 0.7$$
$$V = ?$$
$$\rho = ?$$
$$M = ?$$
$$W = ?$$
$$V = 10 \text{ litre}$$
$$= 10x10^{-3} \text{m}^3$$

$$0.7 = \frac{\gamma}{9810}$$

$$6867 = \rho \text{ x } 9.81$$

$$\rho = 700 \text{ kg/m}^3$$

$$\gamma = 6867 N / m^3$$

$$S = \frac{\rho}{\rho_{Standard}}$$

$$0.7 = \frac{\rho}{1000}$$

$$\rho = 700 \text{kg/m}^3$$

$$\rho = \frac{M}{V}$$

$$700 = \frac{M}{10x10^{-3}}$$

$$\rho = \frac{M}{V}$$

$$700 = \frac{M}{10x10^{-3}}$$

$$M = 7 \text{kg}$$

5. Viscosity: Viscosity is the property by virtue of which fluid offers resistance against the flow or shear deformation. In other words, it is the reluctance of the fluid to flow. Viscous force is that force of resistance offered by a layer of fluid for the motion of another layer over it.

In case of liquids, viscosity is due to cohesive force between the molecules of adjacent layers of liquid. In case of gases, molecular activity between adjacent layers is the cause of viscosity.

Newton's law of viscosity:

Let us consider a liquid between the fixed plate and the movable plate at a distance 'Y' apart, 'A' is the contact area (Wetted area) of the movable plate, 'F' is the force required to move the plate with a velocity 'U' According to Newton's law shear stress is proportional to shear strain.

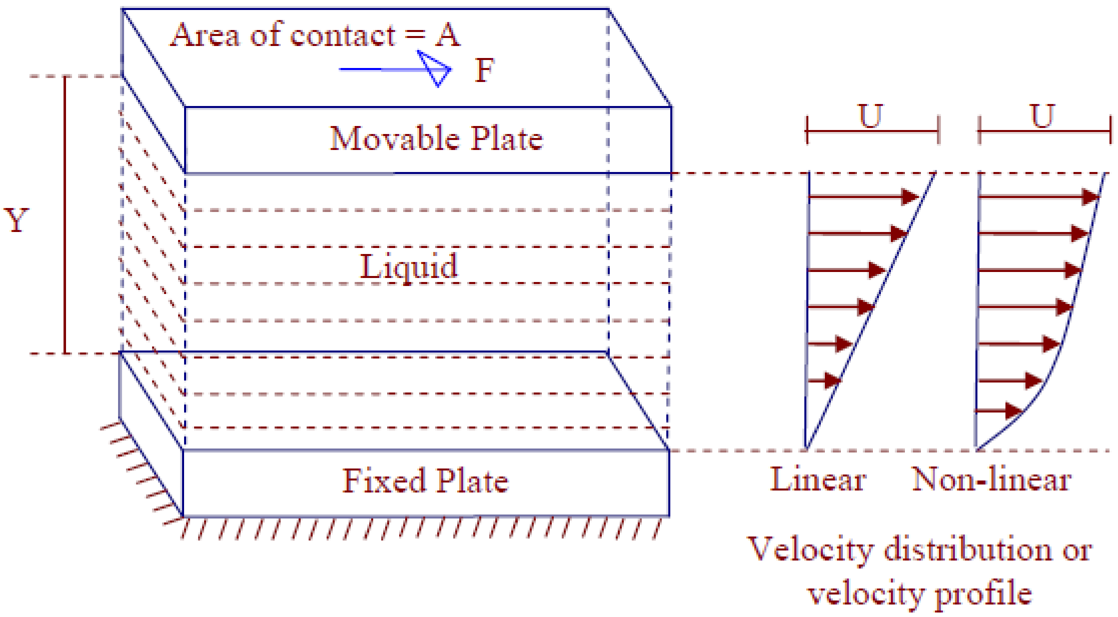


Figure 1.3.1 Definition diagram of Liquid viscosity

*[Source: "*https://en.wikiversity.org/wiki/Fluid_Mechanics_for_Mechanical_Engineers/fluid Properties*"]*

- $F \alpha A$
- $F \alpha \frac{1}{Y}$
- $F \alpha U$

$$\therefore F \alpha \frac{AU}{Y}$$

$$F = \mu . \frac{AU}{Y}$$

'μ' is the constant of proportionality called Dynamic Viscosity or Absolute Viscosity or Coefficient of Viscosity or Viscosity of the fluid.

$$\frac{F}{A} = \mu . \frac{U}{Y} \longrightarrow \therefore \tau = \mu \frac{U}{Y}$$

'τ' is the force required; Per Unit area called 'Shear Stress'. The above equation is called Newton's law of viscosity.

Velocity gradient or rate of shear strain:

It is the difference in velocity per unit distance between any two layers.

If the velocity profile is linear then velocity gradient is given by U/Y . If the velocity profile is non – linear then it is given by du/dy

Unit of force (F): N

- Unit of distance between the twp plates (Y): m
- Unit of velocity (U): m/s
- Unit of velocity gradient : $\frac{U}{Y} = \frac{m/s}{m} = /s = s^{-1}$
- Unit of dynamic viscosity (τ): $\tau = \mu \frac{u}{y}$

$$\mu = \frac{\tau y}{U}$$

$$\Rightarrow \frac{N/m^2 . m}{m/s}$$

$$\mu \Rightarrow \frac{N\text{-sec}}{m^2} \quad \text{or} \quad \mu \Rightarrow P_a\text{-S}$$

NOTE: In CGS system unit of dynamic viscosity is $\frac{\text{dyne . S}}{\text{Cm}^2}$ and is called poise (P).

If the value of μ is given in poise, multiply it by 0.1 to get it in $\frac{NS}{m^2}$.

1 Centipoises = 10^{-2} Poise.

- ***Effect of Pressure on Viscosity of fluids:***

  Pressure has very little or no effect on the viscosity of fluids.

- ***Effect of Temperature on Viscosity of fluids:***

  - *Effect of temperature on viscosity of liquids:* Viscosity of liquids is due to cohesive force between the molecules of adjacent layers. As the temperature increases cohesive force decreases and hence viscosity decreases.

- *Effect of temperature on viscosity of gases*: Viscosity of gases is due to molecular activity between adjacent layers. As the temperature increases molecular activity increases and hence viscosity increases.

Kinematics Viscosity: It is the ratio of dynamic viscosity of the fluid to its mass density.

$$\therefore \text{Kinematic Viscosity} = \frac{\mu}{\rho}$$

Unit of Kinematics Viscosity

$$KV \Rightarrow \frac{\mu}{\rho}$$

$$\Rightarrow \frac{NS/m^2}{kg/m^3}$$

$$= \frac{NS}{m^2} x \frac{m^3}{kg}$$

$$= \left(\frac{kg\,m}{s^2}\right) x \frac{s}{m^2} x \frac{m^3}{kg} = m^2/s$$

$$F = ma$$

$$N = Kg.m/s^2$$

$\therefore$ Kinematic Viscosity $= m^2/s$

NOTE: Unit of kinematics Viscosity in CGS system is cm^2/s and is called stoke (S)

If the value of KV is given in stoke, multiply it by 10^{-4} to convert it into m^2/s.

***Problem* 4:** Viscosity of water is 0.01poise. Find its kinematics viscosity if specific gravity is 0.998.

Kinematics viscosity = ?

$S = 0.998$

$$S = \frac{\rho}{\rho_{standrad}}$$

$$0.998 = \frac{\rho}{1000}$$

$$\rho = 998\ kg/m^3$$

$\mu = 0.01P$

$= 0.01x0.1$

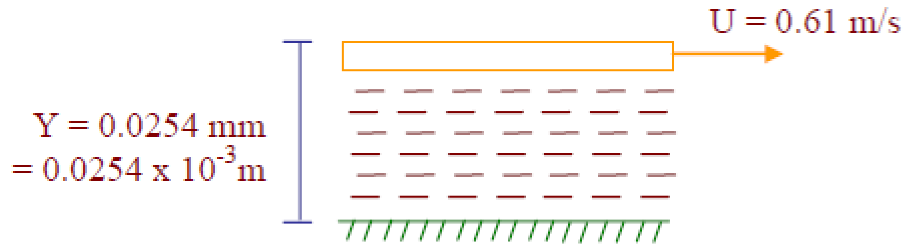
$$\mu = 0.001\ \frac{NS}{m^2}$$

$$\therefore Kinmetic\ Viscosity = \frac{\mu}{\rho}$$

$$= \frac{0.001}{998}$$

$$KV = 1 \text{ x } 10^{6} m^2/s$$

***Problem* 5:** A Plate at a distance 0.0254mm from a fixed plate moves at 0.61m/s and requires a force of 1.962N/m² area of plate. Determine dynamic viscosity of liquid between the plates.



$$\tau = 1.962\ N/m^2$$

$$\mu = ?$$

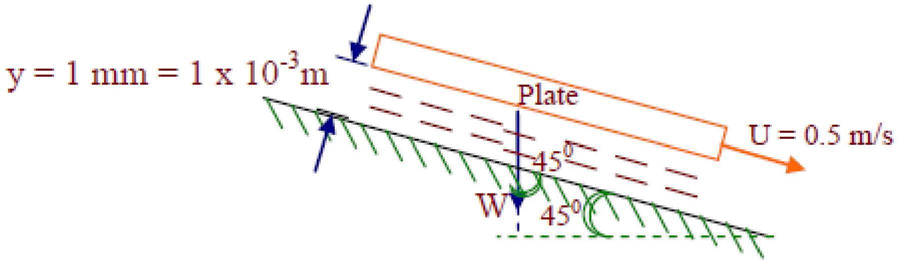
Assuming linear velocity distribution

$$\tau = \mu \frac{U}{Y}$$

$$1.962 = \mu \text{ x } \frac{0.61}{0.0254 \text{ x } 10^{-3}}$$

$$\mu = 8.17 \text{ x } 10^{-5} \frac{NS}{m^2}$$

***Problem* 6 :** A plate having an area of $1m^2$ is dragged down an inclined plane at 45^0 to horizontal with a velocity of 0.5m/s due to its own weight. Three is a cushion of liquid 1mm thick between the inclined plane and the plate. If viscosity of oil is 0.1 PaS find the weight of the plate.



$A = 1m^2$

$U = 0.5m/s$

$Y = 1x10^{-3}m$

$\mu = 0.1NS/m^2$

$W = ?$

$F = W \times \cos 45^0$

$= W \times 0.707$

$F = 0.707W$

$$\tau = \frac{F}{A}$$

$$\tau = \frac{0.707W}{1}$$

$$\tau = 0.707WN/m^2$$

Assuming linear velocity distribution,

$$\tau = \mu.\frac{U}{Y}$$

$$0.707W = 0.1 \times \frac{0.5}{1 \times 10^{-3}}$$

$$W = 70.72N$$

***Problem* 7:** A flat plate is sliding at a constant velocity of 5 m/s on a large horizontal table. A thin layer of oil (of absolute viscosity = 0.40 N-s/m^2) separates the plate from the table. Calculate the thickness of the oil film (mm) to limit the shear stress in the oil layer to 1 kPa.

Given : τ = 1 kPa = 1000 N/m2; U = 5m/s; μ = 0.4 N-s/m^2

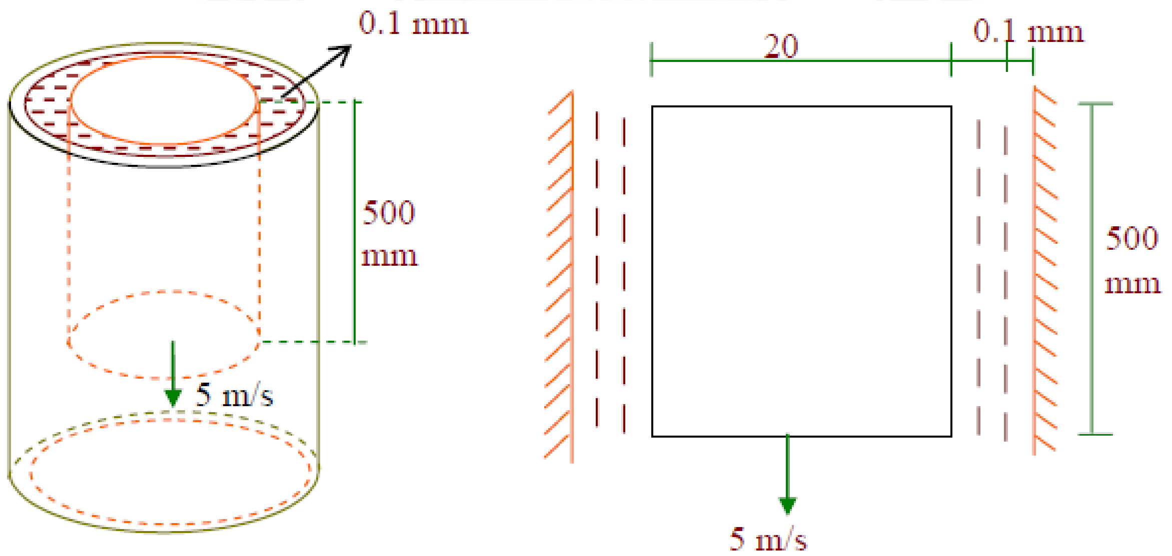
Applying Newton's Viscosity law for the oil film -

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

$$1000 = 0.4 \frac{5}{y}$$

$$y = 2 \times 10^{-3} = 2 \text{ mm}$$

***Problem* 8:** A shaft of ϕ 20mm and mass 15kg slides vertically in a sleeve with a velocity of 5 m/s. The gap between the shaft and the sleeve is 0.1mm and is filled with oil. Calculate the viscosity of oil if the length of the shaft is 500mm.



$D = 20mm = 20x10^{-3}m$

$M = 15\ kg$

$W = 15x\ 9.81$

$W = 147.15N$

$y = 0.1mm$

$y = 0.1\ x\ 10^{-3}mm$

$U = 5m/s$

$F = W$

$F = 147.15N$

$\mu = ?$

$A = \Pi\ D\ L$

$A = \Pi\ \ x\ 20\ x\ 10^{-3}\ x\ 0.5$

$A = 0.031\ m^2$

$$\tau = \mu.\frac{U}{Y}$$

$$4746.7 = \mu\, x \frac{5}{0.1x10^{-3}}$$

$$\mu = 0.095\ \frac{NS}{m^2}$$

$$\tau = \frac{F}{A}$$

$$= \frac{147.15}{0.031}$$

$$\tau = 4746.7N/m^2$$

***Problem* 9 :** If the equation of velocity profile over 2 plate is $V = 2y^{2/3}$ in which 'V' is the velocity in m/s and 'y' is the distance in 'm' . Determine shear stress at (i) y = 0 (ii) y = 75mm. Take $\mu = 8.35P$.

a. at y = 0
b. at y = 75mm

$= 75\ x\ 10^{-3}m$

$$\tau = 8.35\ P$$

$$= 8.35 \text{ x } 0.1\ \frac{NS}{m^2}$$

$$= 0.835\ \frac{NS}{m^2}$$

$$V = 2y^{2/3}$$

$$\frac{dv}{dy} = 2x\frac{2}{3}y^{2/3-1}$$

$$= \frac{4}{3}y^{-1/3}$$

$$\text{at, } y = 0, \frac{dv}{dy} = 3\frac{4}{\sqrt[3]{0}} = \infty$$

$$\text{at, } y = 75x10^{-3}\text{m}, \frac{dv}{dy} = 3\frac{4}{\sqrt[3]{75x10^{-3}}}$$

$$\frac{dv}{dy} = 3.16/\text{s}$$

$$\tau = \mu.\frac{dv}{dy}$$

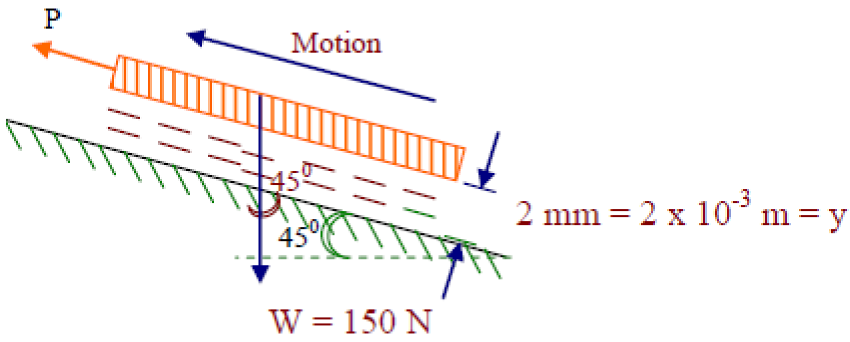
$$at, y = 0,\ \ \tau = 0.835x\infty$$

$$\tau = \infty$$

$$at, y = 75x10^{-3}m, \tau = 0.835\ x\ 3.16$$

$$\tau = 2.64\ N/m^2$$

***Problem* 10 :** A circular disc of 0.3m dia and weight 50 N is kept on an inclined surface with a slope of 45^0. The space between the disc and the surface is 2 mm and is filled with oil of dynamics viscosity $1N/Sm^2$.What force will be required to pull the disk up the inclined plane with a velocity of 0.5m/s.



D = 0.3m

$$A = \frac{\Pi \; x \; 0.3m^2}{4}$$

$\underline{A = 0.07m^2}$

W = 50N

$$\mu = 1 \; \frac{NS}{m^2}$$

$$F = P - 50\cos 45$$

$$F = (P - 35{,}35)$$

$$\underline{y = 2x10^{-3}\,m}$$

$$U = 0.5m/s$$

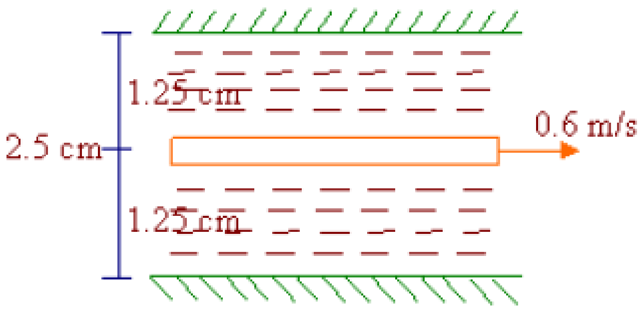
$$\upsilon = \frac{(P - 35.35)}{0.07} N/m^2$$

$$\tau = \mu . \frac{U}{Y}$$

$$\left(\frac{P - 35{,}35}{0.07}\right) = 1x \; \frac{0.5}{2x10^{-3}}$$

$$P = 52.85N$$

***Problem* 10 :** Two large surfaces are 2.5 cm apart. This space is filled with glycerin of absolute viscosity 0.82 NS/m^2. Find what force is required to drag a plate of area 0.5m^2 between the two surfaces at a speed of 0.6m/s. (i) When the plate is equidistant from the surfaces, (ii) when the plate is at 1cm from one of the surfaces.



$$U = \frac{\Pi D N}{60}$$

$$= \frac{\Pi \text{ x } 0.4 \text{ x } 190}{60}$$

$$U = 3.979 \text{ m/s}$$

$$\tau = \mu . \frac{U}{Y}$$

$$= 0.6 \text{ x } \frac{3.979}{1.5 \text{ x } 10^{-3}}$$

$$\tau = 1.592 \text{ x } 10^{3} \text{ N/m}^{2}$$

$$\frac{F}{A} = 1.59 \text{ x } 10^{3}$$

$$F = 1.591 \text{x } 10^{3} \text{ x } 0.11$$

$$F = 175.01 \text{ N}$$

$$T = F \, x \, R$$

$$= 175.01 x 0.2$$

$$T = 35 Nm$$

$$P = \frac{2 \Pi N T}{60{,}000}$$

$$P = 0.6964 KW$$

$$P = 696.4 W$$

Let F_1 be the force required to overcome viscosity resistance of liquid above the plate and F_2 be the force required to overcome viscous resistance of liquid below the plate. In this case $F_1 = F_2$. Since the liquid is same on either side or the plate is equidistant from the surfaces.

$$\tau_1 = \mu_1 \frac{U}{Y}$$

$$\tau_1 = 0.82 \text{x} \frac{0.6}{0.0125}$$

$$\tau_1 = 39.36 N/m^2$$

$$\frac{F_1}{A} = 39.36$$

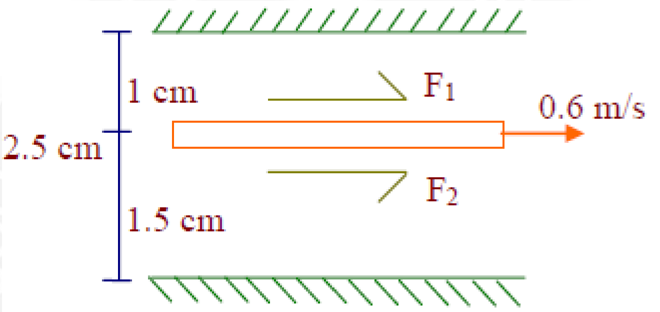
$$F_1 = 19.68N$$

Total force required to drag the plate $=F_1 + F_2 = 19.68+19.68$

$F = 39.36N$

Case (ii) when the plate is at 1cm from one of the surfaces

Here $F_1 \neq F_2$



$F/A=49.2$

$F_1=49.2x0.5$

$F_1=24.6N$

$F_2 /A=32.8$

$F_2=32.8x0.5$

$F_2=16.4N$

Total Force $F = F_1 + F_2 = 24.6 + 16.4$

$F = 41N$

6. Vapour Pressure

Vapour pressure is a measure of the tendency of a material to change into the gaseous or vapour state, and it increases with temperature. The temperature at which the vapour pressure at the surface of a liquid becomes equal to the pressure exerted by the surroundings is called the boiling point of the liquid.

Vapor pressure is important to fluid flows because, in general, pressure in a flow decreases as velocity increases. This can lead to ***cavitation***, which is generally destructive and undesirable. In particular, at high speeds the local pressure of a liquid sometimes drops below the vapor pressure of the liquid. In such a case, ***cavitation*** occurs. In other words, a "cavity" or bubble of vapor appears because the liquid vaporizes or boils at the location where the pressure dips below the local vapor pressure.

Cavitation is not desirable for several reasons. First, it causes noise (as the cavitation bubbles collapse when they migrate into regions of higher pressure). Second, it can lead to inefficiencies and reduction of heat transfer in pumps and turbines (turbo machines). Finally, the collapse of these cavitation bubbles causes pitting and corrosion of blades and other surfaces nearby. The left figure below shows a cavitating propeller in a water tunnel, and the right figure shows cavitation damage on a blade.

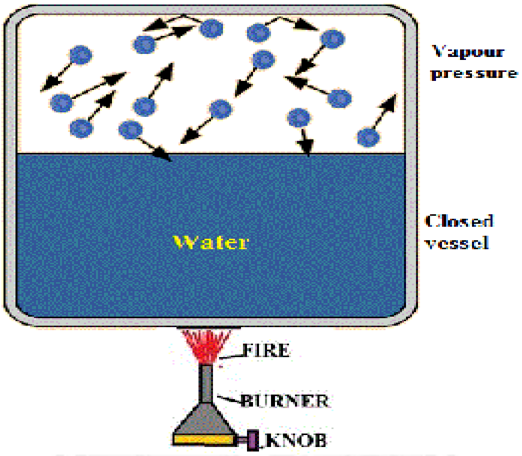


Figure 1.3.5 Vapour Pressure

[Source: "https://www.hkdivedi.com/2017/12/vapour-pressure-and-cavitation.html"]