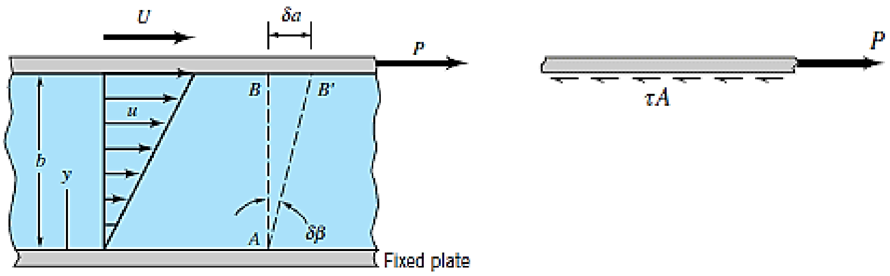
Viscosity

The properties of density and specific weight are measures of the "heaviness" of a fluid. However, these properties are not enough to describe the behavior of the fluid. For example, two fluids such as water and oil can have approximately the same value of density but they behave differently when they flow. This is because they have different viscosity values.

Viscosity: is the property of a fluid which offers resistance to shear of one layer of fluid over another adjacent layer. Simply, it is fluid's resistance to flow.

To determine the viscosity, consider a hypothetical experiment in which a fluid is placed between two very wide parallel plates as show below:



Assumptions:

1. The bottom plate is rigidly fixed while the upper plate is free to move.
2. no-slip condition, *i.e.* fluid "sticks" to the solid boundaries.

A fluid at rest has no shearing forces. When the force P is applied to the upper plate. Shear stresses are developed and the fluid is now in motion. Thus, the particles of the fluid move relative to each other at different velocities and as follow:

- The fluid in contact with the bottom fixed plate has a zero velocity.
- The fluid in contact with the upper plate moves with the plate velocity U,

This means that The fluid between the two plates moves with velocity that vary linearly as follow:

$u = U\,y/b$

U: plate velocity, u: Fluid velocity

b: Film Thickness, y: distance between fluid layers

From the figure, we can conclude that the higher the shear stress the higher the fluid velocity. Thus the shear stress (τ) and the velocity gradient ($\frac{du}{dy}$) can be related with a relationship:

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

$$\boxed{\tau = \mu \frac{du}{dy} \text{ , Newton Law of Viscosity}}$$

μ: The viscosity of the liquid and it is highly affected by the temperature.

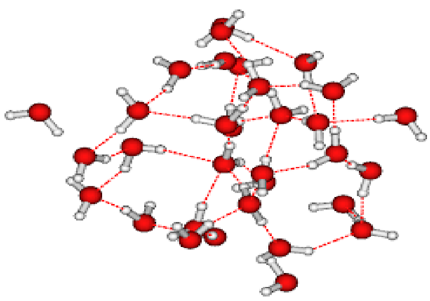
$\mu Water = 0.001\ Pa.s = 1\ m\ Pa.s$

Viscosity & Temperature

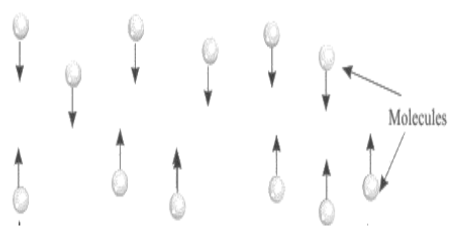
The viscosity of liquids **decreases** with the **increase** of temperature while the viscosity of gases **increases** with the temperature increase.

This difference in the effect of temperature on the viscosity of liquids and gases can again be traced back to the **difference in molecular Structure**.

The liquid molecules are **closely spaced**, with strong cohesive forces between molecules. The resistance to relative motion between adjacent layers of fluid (viscosity) is related to these **intermolecular forces**. As the temperature increases, these cohesive forces are reduced and hence result in reduction in viscosity.

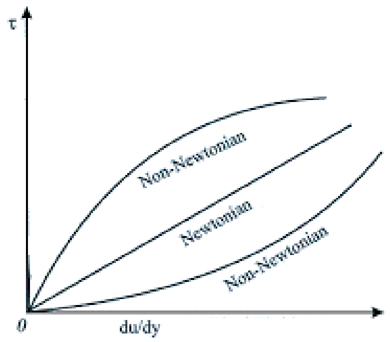


In gases, the molecules are widely spaced and intermolecular forces negligible. In this case resistance to relative motion arises due to the exchange of momentum of gas molecules between adjacent layers. With the increase in temperature, molecular momentum transfer increases and hence viscosity increases.



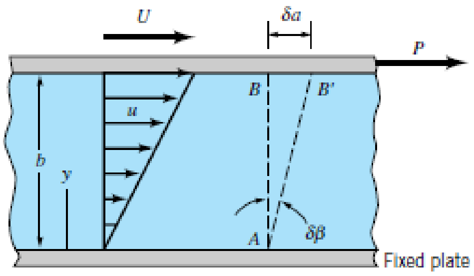
Molecular momentum transfer: is the drag forces between the molecules.

Newtonian and non-Newtonian fluids

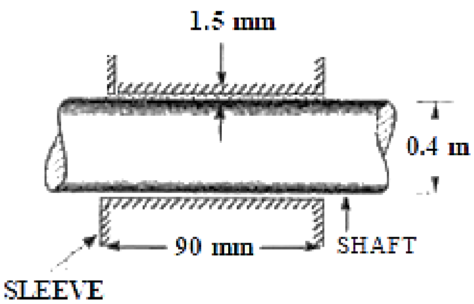


- ***Newtonian Fluids***: The shearing stress is linearly related to the velocity gradient. Fortunately, most common fluids, both liquids and gases are Newtonian.
- ***Non-Newtonian Fluids:*** the shearing stress is not linearly related to the velocity gradient.

Ex) As shown in the figure, certain oil (μ = 1.5 N. S/m^2) is used for lubrication purposes. The distance (b) between the plates is 6 mm. what is the minimum force (p) required to move the plate at 5.5 m/s. knowing that the area of the upper plate is 0.01 m^2.



Ex) The dynamic viscosity of an oil, used for lubrication between a shaft and sleeve is 0.6 Pa.s. The shaft is of diameter 0.4 m and rotates at 190 r.p.m. Calculate the power lost due to shear stress knowing that the sleeve length is 90 mm and thickness of the oil film is 1.5 mm.



Viscosity Grade (Multi – Grade Oil)

In most vehicles, the temperature range the oil is exposed to can be wide, ranging from cold temperatures in the winter before the vehicle is started up to hot operating temperatures when the vehicle is fully warmed up. Thus, the oil will have high viscosity when cold and a lower viscosity at the engine's operating temperature.

The difference in viscosities is too large between the extremes of temperature. To bring the difference in viscosities closer together, special polymer additives called viscosity index improvers (VIIs) are added to the oil. These additives are used to make the oil a multi-grade oil.

The Society of Automotive Engineering **(SAE)** designation for multi-grade oils includes two viscosity grades. For example, 10W-40 designates a common multi-grade oil. The first number (10W) represents oil's viscosity at cold temperature and the second number (40) describes its viscosity at 100 °C. Note that both numbers are grades and not viscosity values. The viscosity value equivalent to each grade is as follow

SAE 10 = 65 m Pa. sec

SAE 40 = 320 m Pa. sec