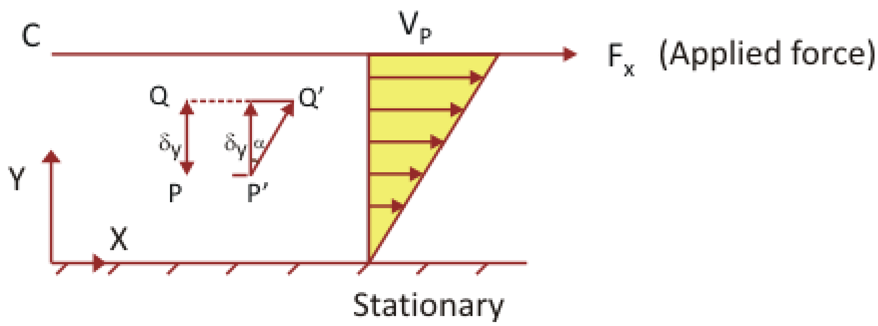
Module 1: Introduction

Lecture 2: Rate of strain, Non-Newtonian fluid

- Rate of strain or strain rate or deformation rate
- Revert to Newton's' 1^{st} Law of viscosity
- Non–Newtonian fluid (Introduction)

Rate of strain or strain rate or deformation rate

- Consider the flow of a fluid between two solid plates under the influence/application of a force in X-direction on the top plate.
- The bottom plate is stationary. The top surface of the fluid has a constant velocity, V_P
- It has been experimentally demonstrated that in such case 'no – slip' condition exists. The fluid layer in contact with the bottom solid surface will be stationary, whereas the layer in contact with the top solid surface will move at the velocity, V_P. The velocity profiles between the plates will be linear.



(Fig. 2a)

As shown in figure 2a, the fluid element QP of length δy at time $t = 0$ becomes $Q'P'$ at time, $t = \delta t$. Difference in the displacements of Q and P to Q' and P', respectively, is because of different velocity at Q and P.

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Therefore,

$$PP' = V_x \delta t$$

$$QQ' = \left(V_x + \frac{dV_x}{dy}.\delta y\right).\delta t$$

Difference in the length of the segments QP and $Q'P'$

$$= (Q'P' - QP)$$

$$\simeq \left(V_x + \frac{dVx}{dy}.\delta y\right)\delta t - V_x \delta_t \text{ elongation}$$

$$= \frac{dv_x}{dy}.\delta y.\delta t$$

$$\left.\begin{matrix}\text{Rate of deformation} \\ \text{or strain rate} \\ \text{or deformation rate}\end{matrix}\right\} \equiv \left(\frac{\begin{matrix}\text{Elongation of the} \\ \text{Fluid Element}\end{matrix}}{\text{Original length}}\right) \times \frac{1}{\delta_t}$$

$$= \frac{\frac{dV_x}{dy}.\delta y.\delta t}{\delta y.\delta t}$$

$$= \left(\frac{dV_x}{dy}\right)$$

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Module 1: Introduction

Lecture 2: Rate of strain, Non-Newtonian fluid

Revert to Newton's' 1st Law of viscosity

$$\boxed{\underset{\text{shear stess}}{\underset{\downarrow}{\tau}} \quad = \underset{\text{viscosity}}{\underset{\downarrow}{\mu}} \quad \underset{\text{strain rate}}{\underset{\downarrow}{\frac{dV_x}{dy}}}}$$

It has been shown that

$\mu \equiv \mu\left(T, \frac{dV_x}{dy}\right)$ in general.

For Newtonian fluid (water, air, glycerin, etc): $\mu \equiv \mu(T)$. For liquids, viscosity increases with temperature. For gases, viscosity decreases with temperature.

For Non-Newtonian fluid: $\mu \equiv \mu\left(\frac{dV_x}{dy}\right)^n$. Examples are sugar solution and polymers. Therefore, General expression for shear stress

$$\boxed{\tau = m \left|\frac{dV_x}{dy}\right|^{n-1} \left(\frac{dV_x}{dy}\right)}$$

where, m is the flow consistency and n is the flow behaviour index.

- Also known as power–Law model
- $m \left|\frac{dV_x}{dy}\right|^{n-1}$ also known as apparent viscosity

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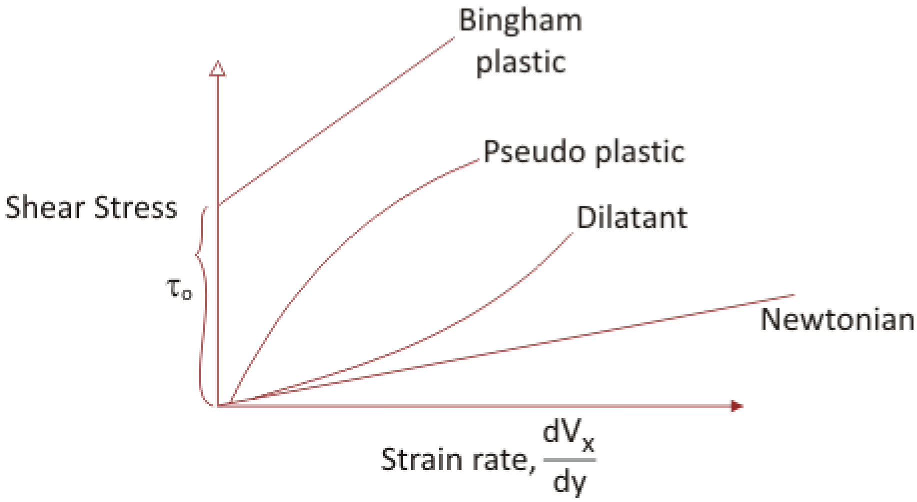
Non – Newtonian fluid (Introduction)



(Fig 2b)

- Newtonian: $\tau = \mu \frac{dV_x}{dy}$: air, water, glycerin
- Bingham Plastic: $\tau = \underbrace{\tau_o}_{\text{yield stress}} + \mu \frac{dV_x}{dy}$: toothpaste

  (Fluid does not move or deform till there is a critical stress)
- Dilatant: $\tau = K \left(\frac{dV_x}{dy}\right)^n, n > 1$: starch or sand suspension

  or shear thickening fluid

  (Fluid starts 'thickening' with increase in its apparent viscosity)
- Pseudo plastic: $\tau = K \left(\frac{dV_x}{dy}\right)^n, n < 1$: paint or shear thinning fluid

  (Fluid starts 'thinning' with decrease in its apparent viscosity)

Note:

1. For some non-Newtonians fluids, viscosity or apparent viscosity may be time- dependent. Such fluids are also called 'Memory' fluids.
2. Rheology is a science of studying flow and behavior of polymeric fluids.

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