Date & Time of Examination - 30/11/2021, 9:30 AM

Examination Roll No. - 18312911011

Name of the Program - B.tech (IT & MI)

Semester / Year - VII Semester / IV year

Unique Paper Code - 911710

Title of Paper - Fluidity in Nature : Computational Interpretations

Q.4

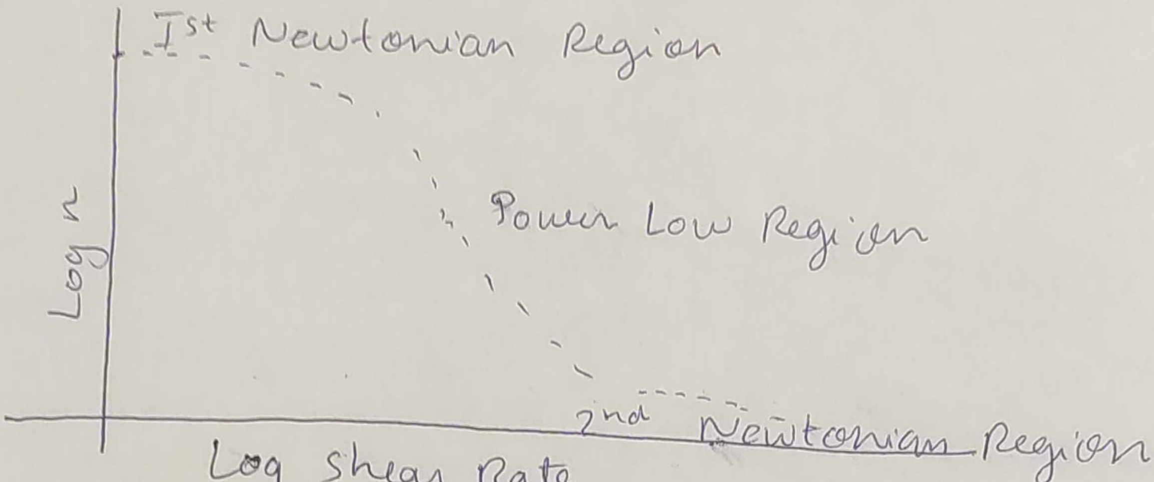
The characteristics of a Newtonian flow is such that a plot of stress versus sheer rate yields a straight line with the slope equal to the viscosity. This behaviour of a Newtonian fluid is shown below:

A viscosity versus shear rate plot yields a horizontal line as the viscosity is independen of shear rate. All gases obey Newton's law and are Newtonian fluids. Mineral oils and blends of mineral oils are also generally Newtonian in flow behaviour. The viscosity of a Newtonian fluid, at a given temperature and pressure, can be determined with a single measurement at any given rate.

Non-Newtonian Flow

Many fluids doesn't obey Newton's law of viscosity. The viscosity will vary with shear rate and a single measurement is not sufficient to characterize the flow properties of the fluid, other factors that may affect flow properties include pressure and temperature.

In general, for non-Newtonian fluids there is a general characteristic shape to the viscosity versus shear rate as shown in figure regardless of the fluid



(General form of the viscosity v/s Shear Rate for non-newtonian fluids)

The diffrence between fluids will reside in the scale of the two axes and at what sheer rates the two Newtonian region appear. There is a low shear Newtonian region followed by a region where the viscosity decrases with shear rate. This is followed by a high shear Newtonian region. Lubricating oils are commonly tested for viscosity in the low shear Newtonian region.

Some of the factors that can determine the degree of Non-Newtonian behaviour include particle size, shape & distribution, volume fraction of particles, electrostatic charges on particles, and electric effect among others. The more the particles can interact with one another, the greater the likelihood of non-Newtonian behaviour.

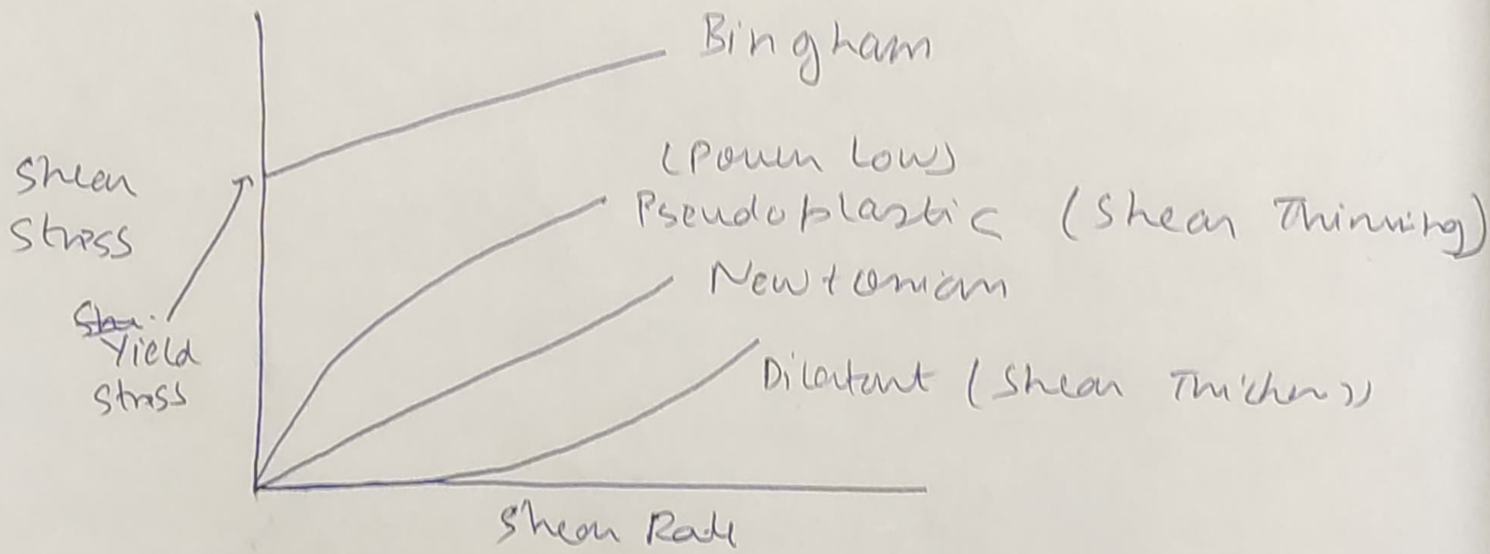


Fig. - Types of non-Newtonian behaviour

Derivation :

The conservation of mass in the Eulerian description is expression as

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0 \quad \text{—} \quad (1)$$

or for two - dimensional flow

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) = 0 \quad \text{—} \quad (2)$$

where ρ is the density (in $kg\,m^{-3}$) and (u, v) are the velocity components in (ms^{-1}) in the x & y directions.

In the steady state case, we have $\frac{\partial}{\partial t} = 0$ and (1) & (2) become

$$\nabla \cdot (\rho u) = 0 \;, \; \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) = 0 \quad \text{—} \quad (3)$$

For incompressible fluids

$$\nabla \cdot u = 0 \;, \; \frac{\partial u}{\partial x} + \frac{\partial v}{y} = 0 \quad \text{—} \quad (4)$$

And hence for incompressible fluids the conservation of linear momentum results in the following eqn of motion

$$\nabla \cdot \sigma + f = \rho \left(\frac{\partial u}{\partial t} + u \cdot \nabla u \right) \quad -⑤$$

or for two-dimensional ~~sy~~ systems

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \sigma_{xy}}{\partial y} + f_x = \rho \left(\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right)$$

$$\frac{\partial \sigma_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y} + f_y = \rho \left(\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} \right)$$

$$-⑥$$

where $(\sigma_x, \sigma_y, \sigma_{xy})$ are the total stress components in (Nm^{-2}) and (f_x, f_y) are the x, y components of the body force ~~factor~~.

The total stress components can be expressed in terms of the viscous stress components $(\tau_x, \tau_y, \tau_{xy})$ and hydrostatic pressure p (in Nm^{-2})

$\sigma_x = \tau_x - p$, $\sigma_y = \tau_y - p$, $\sigma_{xy} = \tau_{xy}$ — (7)

The viscous components of stress are related to the velocity gradients by Newton's law of viscosity.

For isotropic, Newtonian fluids there are

$$\tau_x = 2\mu \frac{\partial u}{\partial x} , \quad \tau_y = 2\mu \frac{\partial u}{\partial y}$$

$$\tau_{xy} = \mu\left(\frac{\partial u}{\partial y} + \frac{\partial u}{\partial x}\right) \quad — (8)$$

where μ is the viscosity

Combining (5), (6) & (8) we have the Momentum eqn which are as follows:

$$\frac{\partial}{\partial x}\left(2\mu \frac{\partial u}{\partial x} - p\right) + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right] + f_x = \rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right)$$

and

$$\frac{\partial}{\partial x}\left(\mu\left(\frac{\partial u}{\partial y} + \frac{\partial u}{\partial x}\right)\right] + \frac{\partial}{\partial y}\left(2\mu \frac{\partial v}{\partial y} - p\right) + f_y = \rho\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right)$$

These are the x & y components of the momentum eqn