➢ Pseudoplastic Fluids

These fluids are characterized by the shape of the flow curve illustrated in Figure (12). **When the shear stress/shear rate plot of such fluids is made on logarithmic scale, a straight line is obtained**. The effective viscosity of a pseudoplastic fluid **decreases** with **increasing** shear rates. For drilling fluids, pseudoplastic behavior is usually defined by using the **Power Law** equation. The Power Law equation uses two parameters, "**K**" and "**n**". K is a measure of a mud's consistency at very low shear rates. The **larger the value of K, the more "viscous"** is the fluid at low shear rates. **n** is a measure of the degree of non-Newtonian behavior. For n = 1, the fluid is Newtonian. For pseudoplastic fluids;

$$\tau = k\gamma^{n} \qquad 0 < n < 1 \qquad \text{(37)}$$

Where:

K = laminar flow consistency factor (constant for a particular fluid)

n = laminar flow behavior index

Plotted on a log-log graph, a Power Law fluid shear stress/shear rate relationship forms a straight line in the ***log-log plot***. The **"slope"** of this line is **"n"** and **"K"** is the intercept of this line. The Power Law index "n" indicates a fluid's degree of non-Newtonian behavior over a given shear rate range.

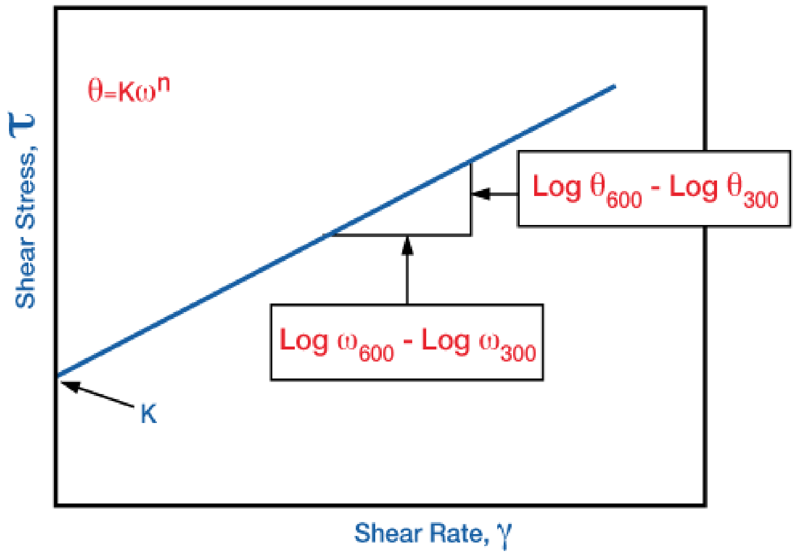


Figure 12

$$\log \tau = \log k + n \log \gamma$$

Power – law model parameters:

$$n = 3.32 \log \frac{\theta_{600}}{\theta_{300}} \quad \text{-- (38)}$$

$$k = \frac{\theta_{300}}{(511)^n} \quad \text{--- (39)}$$

- **Dilatant Fluids**

The behavior of dilatant fluids is characterized by the flow curve in Figure (6) and can be represented by the Power Law model where **n is greater than 1**.

$$\tau = k\gamma^n \qquad n > 1 \quad \text{-- (40)}$$

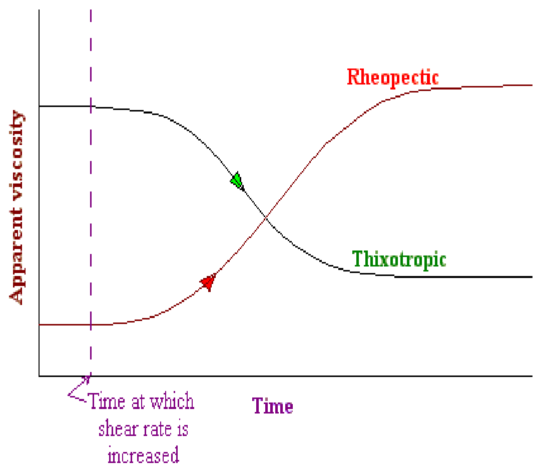
The effective viscosity of a dilatant fluid **increases** with **increasing** shear rate. This is not a desirable characteristic for drilling fluids and such fluids are rarely encountered.

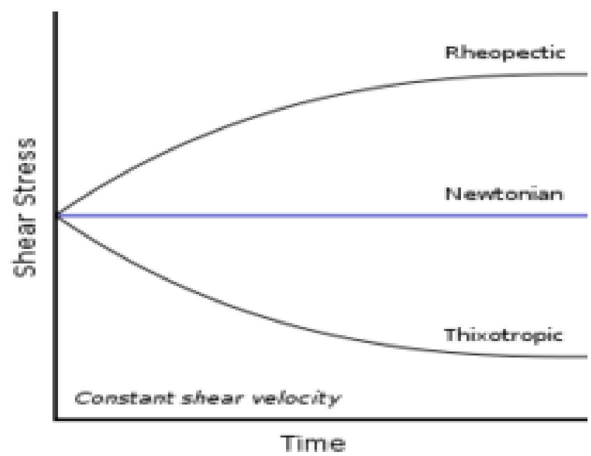
2. Time Dependent, Non-Newtonian Fluids

The viscosity at fixed value of shear rate & temperature changes with duration of shear. There are two types which are:

A) **Thixotropic fluids:** Exhibits a **decreasing** in shear stress with duration of shear at constant shearing rate ($\mu_a \downarrow$ & $\tau \downarrow$ time of duration $\uparrow$). Examples of thixotropic fluids are mayonnaise, drilling fluids, paints and inks.

B) **Rheopectic fluids:** Exhibits **increase** shear stress with duration of shear at given shear rate ($\mu_a \uparrow$ & $\tau\uparrow$ time of duration $\uparrow$).





➢ **Yield-Power Law (Herschel-Bulkley) Fluids**

Virtually all drilling fluids display characteristics of both pseudoplastic and thixotropic fluids. One way to describe the behavior of such fluids is with the Yield-Power Law (YPL) Model:

$$\tau = \tau_y + k\gamma^n \quad \text{--} \quad (41)$$

Where:

τ_y is the YPL yield stress (a better approximation to the true yield stress than the yield point in the Bingham model), and K and n are the YPL consistency index and exponent, respectively. The YPL Model may be thought of as a combination of the Bingham Plastic and Power Law pseudoplastic models, but the Bingham plastic component may also be seen as a manifestation of thixotropic behavior.

When τ_y is **zero**, the YPL model reduces to the Power-Law Model for pseudoplastic flow, and when **n** is **one**, it reduces to the Bingham model.

Ex.15: Given data:

θ_N = torque reading from the dial = 45° for 600 rpm = 26° for 300 rpm

N = rotor speed = 600 and 300 rpm

Calculate: 1) PV 2)Yp 3)Y_t 4) μ_a 5) μ_e.

Solution:

PV= 45-26=19 cp

Yp=26-19=7 lb/100ft^2

$$Y_t = \frac{3}{4} \times 7 = 5.25 \text{ lb}/100 \text{ ft}^2$$

μ_a = 45/2 =22.5 cp

$$\mu_e = \frac{300\times 45}{600} = 22.5 \text{ cp} \quad \text{for RPM 600}$$

$$\mu_e = \frac{300\times 26}{300} = 26 \text{ cp} \quad \text{for RPM 300}$$

Ex.16: Given: - θ_{600} = 36, θ_{300} = 24, dh = 12 ¼", dp = 5", Q (flow rate) = 600 gal /min, (V_{mud} in annulus V_a = 117.5 ft/min). Find effective viscosity μ_e by Bingham plastic and power law models.

Solution:

A) Bingham plastic model

$$\mu_p = \theta_{600} - \theta_{300} = 36 - 24 = 12 \text{ cp}$$

$$Y_p = \theta_{600} - 2\mu_p = 36 - 2*12 = 12 \ {}^{Ib}/_{100ft^3}$$

$$\mu_e = \mu_p + \frac{300\, Y_p(d_h - d_p)}{V}$$

$$\mu_e = 12 + \frac{300*12\,(12.25-5)}{117.5} = 234 \text{ cp}$$

B) Power law model

$$n = 3.32 \log\frac{\theta_{600}}{\theta_{300}}$$

$$n = 3.32 \log\frac{36}{24} = 0.5846$$

$$k = \frac{\theta_{300}}{(511)^n}$$

$$k = \frac{24}{(511)^{0.5846}} = 0.626$$

$$\mu_e = \frac{200k\,(d_h - d_p)}{V}\left[\left(\frac{2.4\,V}{d_h - d_p}\right)\left(\frac{2n+1}{3n}\right)\right]^n$$

$$\mu_e = \frac{200*0.626\,(12.25-5)}{117.5}\left[\left(\frac{2.4*117.5}{12.25-5}\right)\left(\frac{2*0.5846+1}{3*0.5846}\right)\right]^{0.5846} = 74\ \text{cp}$$