Plastic Viscosity (PV): Drilling muds are usually composed of a continuous fluid phase in which solids are dispersed. **Plastic viscosity is that part of the resistance to flow caused by mechanical friction.**

The friction is caused by:

1. Solids concentration,
2. Size and shape of solids,
3. Viscosity of the fluid phase.

For practical field applications, plastic viscosity is regarded as a guide to solids control. Plastic viscosity **increases** if the volume percent of solids **increases**, or if the volume percent remains constant, and the size of the particle **decreases**. **Decreasing** particle size **increases** surface area, which **increases** frictional drag. Plastic viscosity can be **decreased** by **decreasing** solids concentration or by **decreasing** surface area. Plastic viscosity is **decreased** by reducing the solids concentration **by dilution or by mechanical separation**. As the viscosity of water **decreases** with temperature, the plastic viscosity **decreases proportionally**. Therefore, controlling PV of a mud in practical terms involves **controlling size, concentration and shape of the solids and minimizing the viscosity of the liquid phase - such as avoiding viscosifying polymers and salts unless absolutely needed**.

The value of plastic viscosity is obtained by subtracting the θ_{300} RPM reading from the θ_{600} rpm reading Figure (9).

PV = $\theta_{600} - \theta_{300}$ -- (29)

PV of a mud is the theoretical minimum viscosity a mud can have because it is the effective viscosity as shear rate approaches infinity. **The highest shear rate occurs as the mud passes through the bit nozzles**; therefore, PV will approximate the mud's viscosity at the nozzles. This is illustrated in Figure (10), where **the effective viscosity of the mud approaches the value of plastic viscosity at high shear rates**.

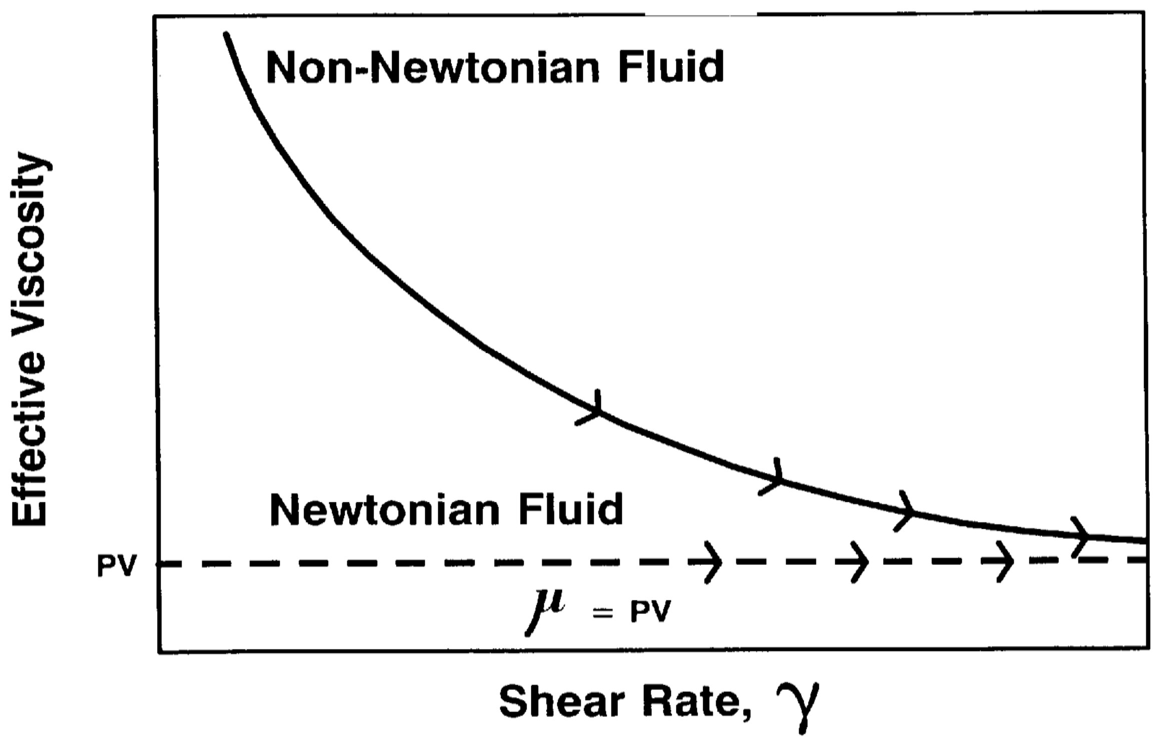

Fig. (10): Comparison of Effective Viscosity Newtonian vs. Non-Newtonian.

Yield Point (YP): The yield point is the initial resistance to flow caused by **electrochemical forces between the particles.** This electrochemical force is due to

charges on the surface of the particles dispersed in the fluid phase. **Yield point is a measure of these forces under flow conditions** and is dependent upon:

1. The surface properties of the mud solids
2. Ionic environment of the liquid surrounding the solids
3. The volume concentration of the solids

High viscosity resulting from high yield point is caused by:

- Introduction of soluble contaminant (ions) such as: **salt, cement, anhydrite or gypsum**, which interact with the negative charges on the clay particles.
- Breaking of the clay particles through mechanical grinding action creating new surface area of the particles. These new charged surfaces (positive and negative) pull particles together as a flocs.
- **Introduction of inert solids (barite) into the system**, **increasing the yield point**. This is the result of the particles being forced closer together. Because the distance between the particles is now **decreased**, the attraction between particles is greatly **increased**.
- Drilling hydratable shales or clays which introduces new, active solids into the system, **increasing** attractive forces by bringing the particles closer together and by **increasing** the total number of charges
- Insufficient deflocculant treatment.

Yield point can be controlled by proper chemical treatment. As the attractive forces are reduced by chemical treatment, the yield point will **decrease**. The yield point can be lowered by the following methods:

- Charges on the positive edges of particles can be neutralized by adsorption of large negative ions on the edge of the clay particles. These residual charges are satisfied by chemicals such as: **tannins, lignins, complex phosphates, lignosulfonates, etc.** The attractive forces that previously existed are satisfied by the chemicals, and the negative charge of the clay particles predominates, so that the solids now repel each other.
- In the case of contamination from calcium or magnesium by adding ***(Bicarbonate)*** the ions causing the attractive force are removed as insoluble precipitants, thus decreasing the attractive forces and YP of the mud.
- Water dilution can lower the yield point, but unless the solids concentration is very high, it is relatively ineffective.

Yield point (YP) is calculated from VG measurements as follows:

$$YP = \theta_{300} - (\theta_{600} - \theta_{300}) \quad \text{--} \quad (30)$$

Or

$$YP = \theta_{300} - PV \quad \text{--} \quad (31)$$

The limitation of the Bingham plastic model is that most drilling fluids, being pseudoplastic, exhibit an actual yield stress which is considerably less than calculated Bingham yield point. This error exists because the Bingham plastic parameters are calculated using a VG meter at 600 RPM (1022 sec^{-1}) and 300 RPM (511 sec^{-1}); whereas, typical **annular shear rates** are much less Table (1).

True yield point can be defined using for plastic or Bingham fluids as:

$$\mathbf{Y_t = \frac{3}{4} Yp} \quad \text{-----} \quad \mathbf{(32)}$$

Apparent Viscosity (μ_a): Apparent viscosity, measured by the VG meter, is the viscosity that a drilling fluid has at 600 RPM (1022 sec^{-1}). It is a reflection of **the plastic viscosity and yield point combined**.

An **increase** in either or both will cause a **rise** in apparent viscosity (and probably in funnel viscosity).

This is sometimes called single point viscosity. The equation for apparent viscosity is:

$$\mu_a = \frac{300\,\theta_N}{N} = \frac{300\,\theta_{600}}{600} = \frac{\theta_{600}}{2} \quad \text{-----} \quad \mathbf{(33)}$$

Here:

θ_N= torque reading from the dial at a speed N, rpm

N = rotor speed, rpm

μ_a = apparent viscosity at a speed N rpm, cp

As shown in Figure (11), various muds may have the same μ_a at 1022 sec^{-1}, but the effective viscosities at other shear rates may vary widely.

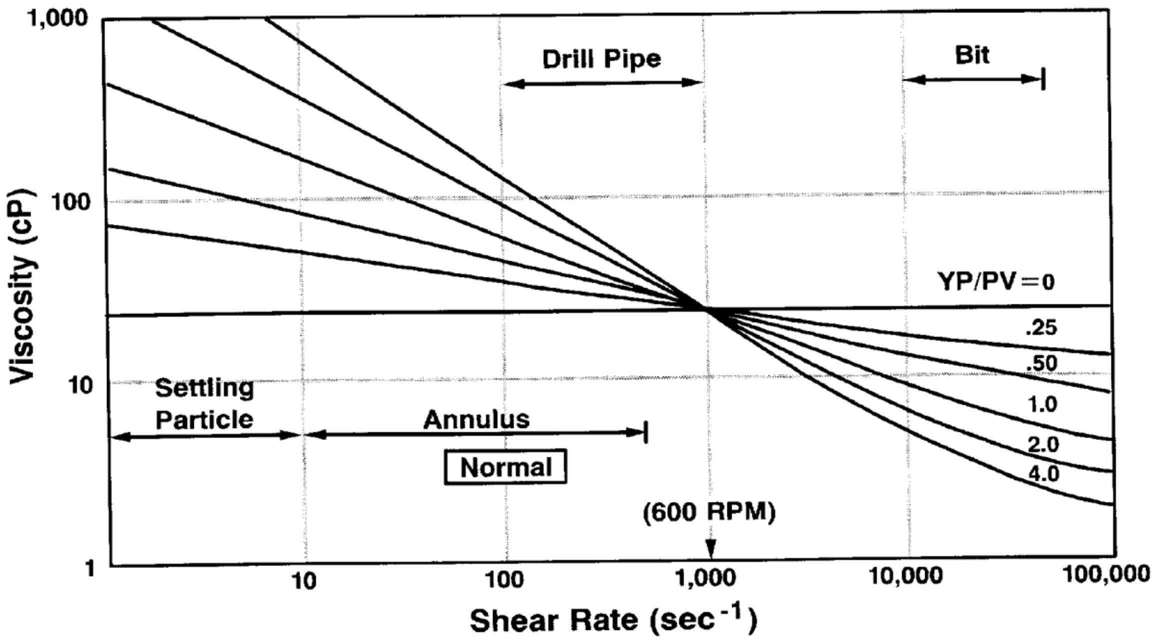

Fig. (11): Viscosity vs. Shear Rate for Various YP/PV Ratios.

Effective Viscosity (μ_e): The effective viscosity from a VG meter is the viscosity of the drilling fluid at that particular RPM. It is calculated by the equation below.

$$\mu_e = \frac{300\,\theta_N}{N} \quad \text{--} \quad (34)$$

Effective viscosity depends on fluid velocity flow pattern, difficult to measure, but calculated;

For **Bingham plastic**

$$\mu_e = PV + \frac{300}{v_a}\left(d_h - d_p\right)Yp \quad \text{--} \quad (35)$$

For **power law**

$$\mu_e = \frac{200k\left(d_h - d_p\right)}{V}\left[\left(\frac{2.4\,V}{d_h - d_p}\right)\left(\frac{2n+1}{3n}\right)\right]^n \quad \text{--} \quad (36)$$

Where:

d_h: hole diameter, in.

d_p: pipe diameter, in.

Funnel Viscosity: The funnel viscosity is measured with the Marsh funnel and is a timed rate of flow in **seconds per quart**. It is basically a quick reference check that is made routinely on a mud system; however, there is no shear rate/shear stress relationship in the funnel viscosity test. Thus, it cannot be related to any other viscosity nor can it give a clue as to why the viscosity may be high or low.