Lecture # 5 PeE 3321

Drilling fluids I

Drilling fluids

1. The fluid circulation system
2. Types of mud
3. Functions of drilling fluids
4. Rheological properties of drilling mud

Will be covered today (items 1–4)

5. Weight of drilling mud
6. Drilling mud additives
7. Selection of drilling mud additives

Will be covered next Lecture (items 5–7)

Covered in Lecture 4

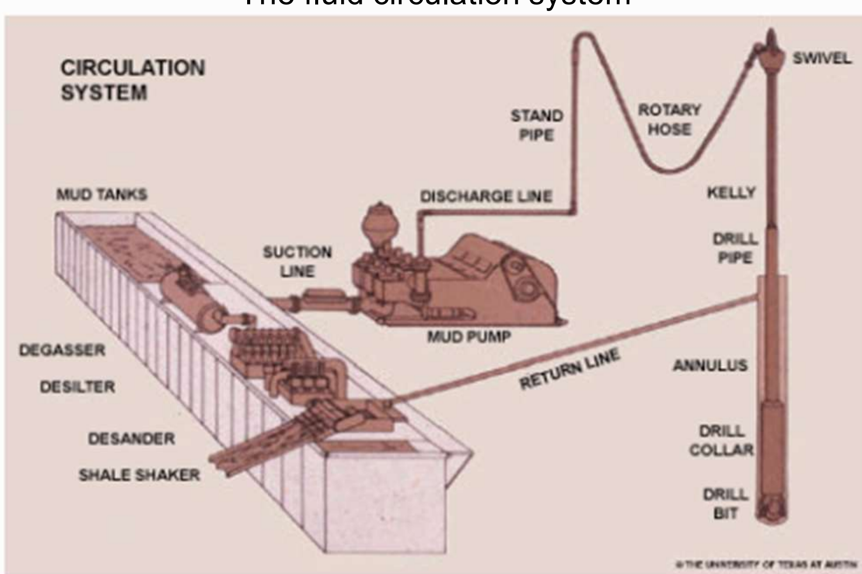
Concepts

- Circulation system
- Functions of drilling fluid
- Rheological properties and models of drilling fluids
- Rotational Viscometer
- Viscosity and Apparent Viscosity

Calculations

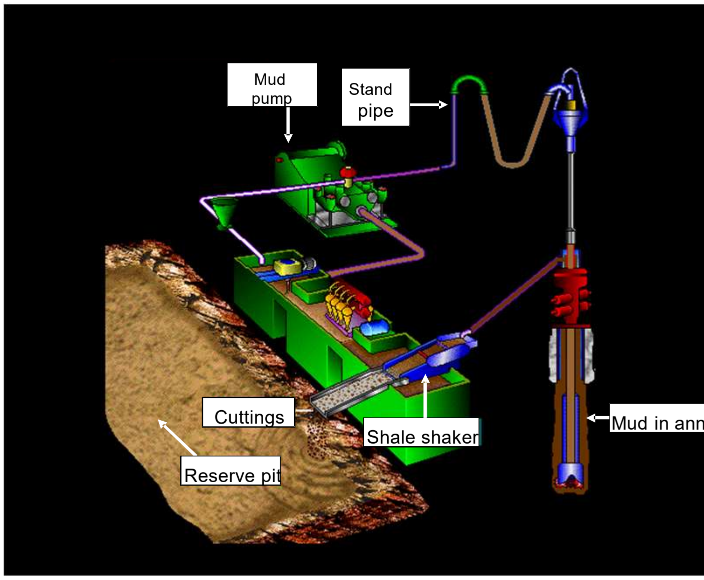
- Viscosity (Ex. 1)
- Apparent viscosity for different readings
- *PV* and *YP* for Bingham Plastic model
- *n*,*K* constants for Power law

The fluid circulation system



A primer of Oilwell Drilling 6th edition

The fluid circulation system



Circulating System Components

Mud tanks — Mud tanks or pits is used by the crew to prepare the mud for circulation

Mud pumps — One or more pumps that circulate the mud up the standpipe and down the drill string. Duplex pumps are most common. Triplex pumps is in use but less common.

Standpipe & Rotary hose — The standpipe takes the mud halfway up the Derrick. The rotary hose is a flexible hose that moves with the swivel as it goes up and down in the mast. The rotary hose is connected to the standpipe and to the Kelly.

Standpipe pressure is the point where the fluid pressure is measured when the fluid is entering the well.

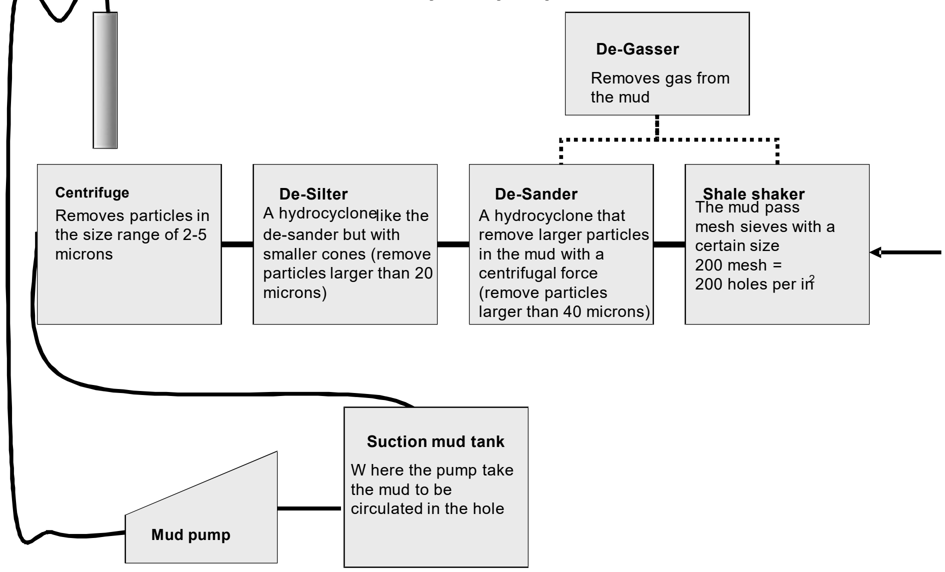
Drill string & bit — The mud pump moves the mud down the drill string to the bit. At the bit the mud goes through the nozzles. The mud cleans the cuttings around the bit.

Annulus — Mud transports the cuttings up in the annulus, first in the open hole annulus and then in the cased section of the annulus.

Flow line — Mud goes through the flow line /return line to the shale shaker.

Shale shaker — The shale shaker has screen that removes cutting and the mud falls into the mud tanks where the mud tanks can pump it up again for next circulation cycle.

Auxiliary Equipment



Three main types of base fluids for drilling

Water based	**Fresh water, seawater, or salt water.**
Oil based **NAF (Non Aqueous Fluids)**	**Diesel, high on aromatics** **Mineral oil** **Synthetics, low on aromatics**
Air or gas based	**Air, nitrogen, mist, foam.**

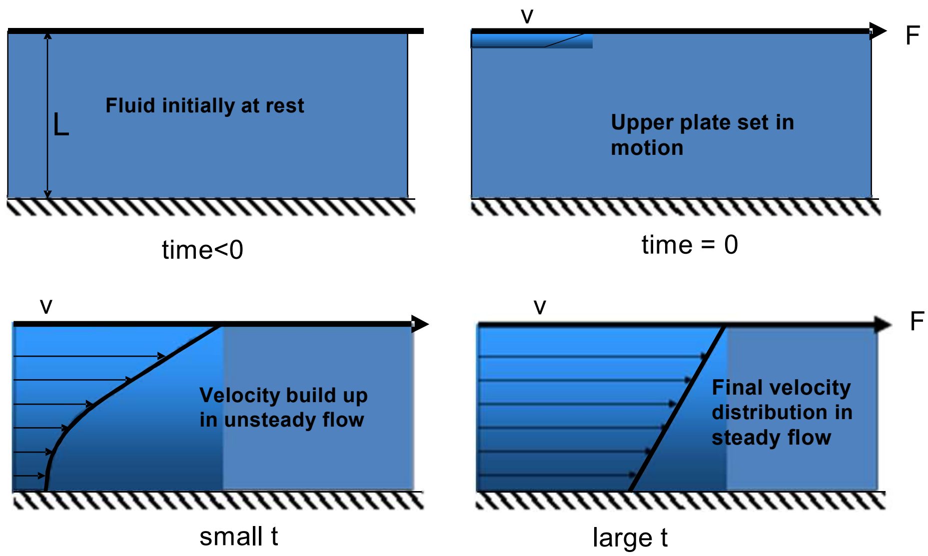
Functions of drilling fluids

Functions	Desired properties
Remove cuttings	Low friction between drill string and hole (Lubricity)
Cool, lubricate, and lower friction for bit and drill string	Keep cutting in suspension when tripping (Gel Strength)
Prevent formation fluids from entering well	Be as non damaging as possible to producing formations
Clean bit	Be as environmentally friendly as possible
Keep wellbore walls from collapsing	Be pumpable at high densities
Create filter cake in permeable formation to prevent wellbore walls from caving in	Be stable at high temperatures and pressures
Maintain stability of open hole – chemically e.g. shale swelling	
Transmit information from tools	
Create weight/torque on bit	
Power down hole directional tools to drill directional wells	

Brief Overview Of Rheological Models

- Rheological Models
  - ✓Newtonian
  - ✓Bingham Plastic
  - ✓Power-Law

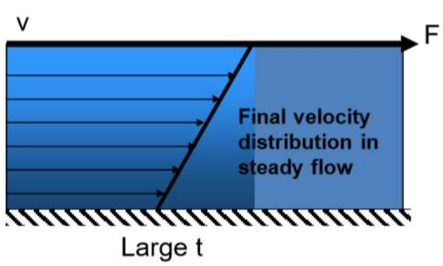
Laminar Flow of Newtonian Fluids



Newtonian Fluid Model

The term F/A is called the shear stress exerted on the fluid and noted as (τ)

The term V/L is called the shear rate and noted as (γ)



Fluid Shear stress = viscosity * shear rate

$$\frac{F}{A} = \mu \frac{V}{L}$$

$$\tau = \mu \gamma$$

$$F = dyne = 10^{-5} N = 1\, g.\frac{cm}{s^2}$$

$$A = cm^2$$

$$Shear\ rate = \gamma = \frac{v\,(\frac{cm}{s})}{L\,(cm)} = \frac{1}{s} = s^{-1}$$

Newtonian Fluid Model

In a Newtonian fluid the shear stress is directly proportional to the shear rate (in laminar flow):

$$\tau = \mu \dot{\gamma} \qquad \frac{dyne}{cm^2} = \mu \left(\frac{1}{\text{sec}} \right)$$

i.e.,

The constant of proportionality, μ is the viscosity of the fluid and is **independent of shear rate**.

So, what is the unit for viscosity?

$$\mu = \frac{\tau}{\dot{\gamma}} \qquad \frac{\text{dyne} \bullet \text{sec}}{\text{cm}^2}$$

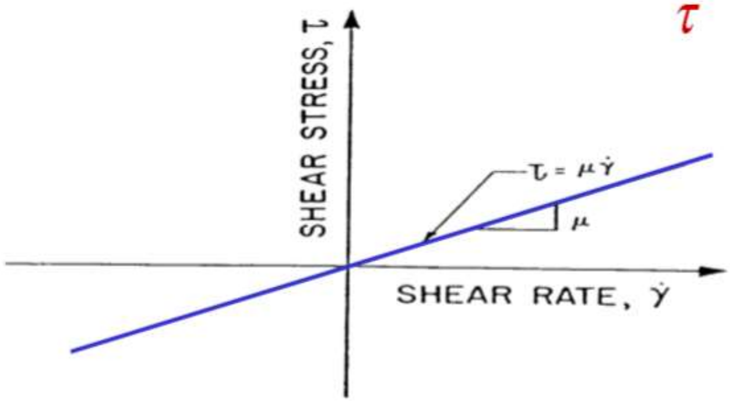
Viscosity may be expressed in poise or centipoise.

$$1 \text{ poise} = 1 \frac{\text{dyne} \times \text{s}}{\text{cm}^2} = 1 \frac{g}{cm \times s}$$

$$1 \text{ centipoise} = 0.01 \text{ poise}$$

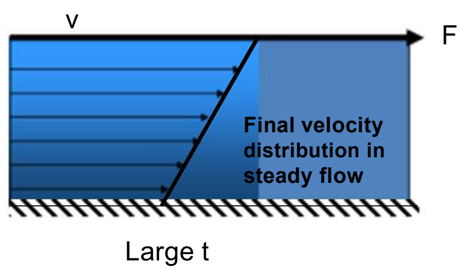
Shear Stress vs. Shear Rate for a Newtonian Fluid

$$\tau = \mu \dot{\gamma}$$



Slope of line $= \mu$

Example # 1



Area of upper plate = 20 cm^2

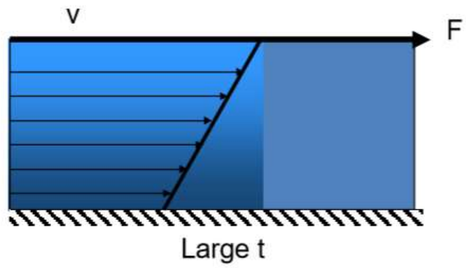
Distance between plates = 1 cm

If the force required to move the upper plate at a constant velocity of 10 cm/s is 100 dynes.

Calculate the fluid viscosity?

Example # 1 (4.16 ADE)

$\tau = \mu \gamma$



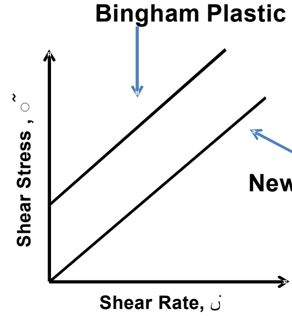
$$\mu = \frac{\text{shear stress}}{\text{shear rate}} = \frac{F/A}{V/L} = \frac{100/20\ (\text{dynes/cm}^2)}{10/1\ \text{sec}^{-1}}$$

$$= \frac{5}{10} = 0.5\frac{dyne * s}{cm^2} = 0.5\ \text{poise}$$

$$\boxed{\mu = 50\ \text{cp}}$$

Bingham Plastic Model

- The major difference between Bingham and Newtonian fluids is the presence of a Yield stress or “Yield point”.



Bingham Plastic Model

- Will not flow until the applied shear stress (τ) exceeds the yield point (τ_y)

τ_y **= Yield Stress**

τ **= Shear Stress**

$\dot{\gamma}$ **= Shear Rate**

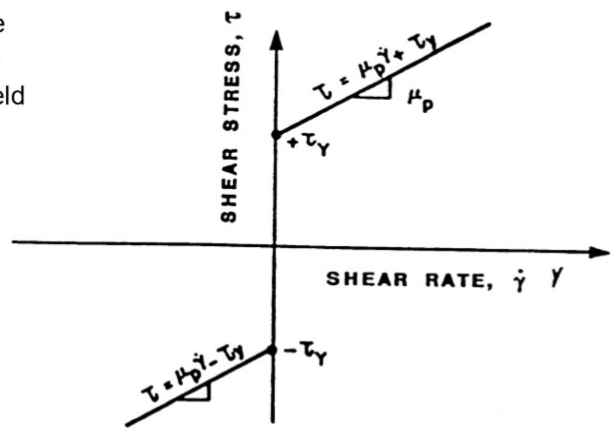


Fig. 4.23—Shear stress vs. shear rate for a Bingham plastic fluid.

Bingham Plastic Model

The Bingham Plastic model is defined by:

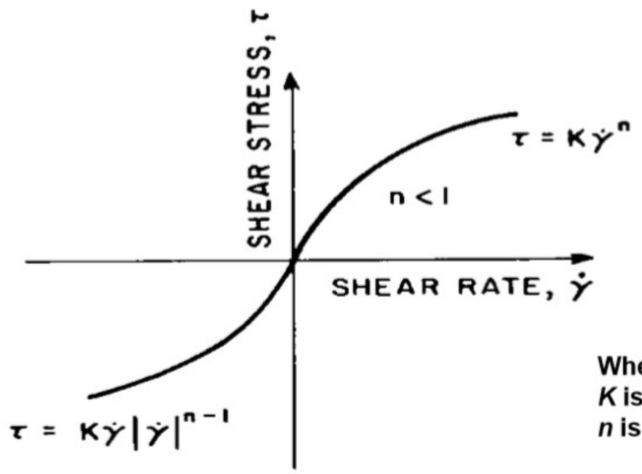
$\tau = \mu_p \dot{\gamma} + \tau_y$	if $\tau > \tau_y$
$\dot{\gamma} = 0$	if $-\tau_y \le \tau \le \tau_y$
$\tau = \mu_p \dot{\gamma} - \tau_y$	if $\tau < -\tau_y$

τ and τ_y (yield point) are often expressed in **lb/100 sq.ft**

Power-Law Model

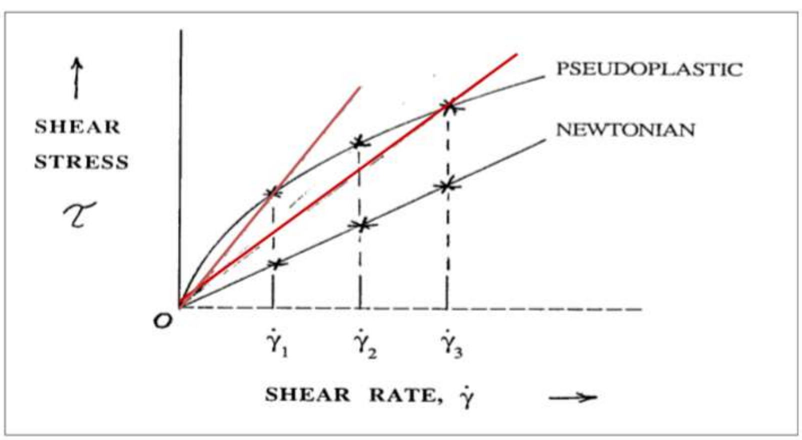
This model is defined by: $\tau = K(\dot{\gamma})^n$

It describes the thickness or pumpability of the fluid



Where:
K **is the** *consistency index*
n **is the** *flow behavior index*

Apparent Viscosity



Apparent viscosity = $(\tau / \dot{\gamma})$
is the slope at each shear rate, $\dot{\gamma}_1, \dot{\gamma}_2, \dot{\gamma}_3$.

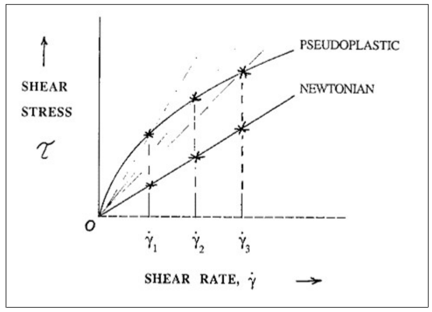
Apparent Viscosity

Is not constant for a pseudo plastic fluid

The apparent viscosity decreases with increasing shear rate (Shear thinning)

(for a power-law fluid)

(and also for a Bingham Plastic fluid)



Summary of Rheological Models

1. Newtonian Fluid:

$$\tau = \mu \dot{\gamma}$$

τ = shear stress

μ = absolute viscosity

$\dot{\gamma}$ = shear rate

2. Bingham Plastic Fluid:

$$\tau = \tau_y + (\mu_p) * \dot{\gamma}$$

τ_y = yield point

μ_p = plastic viscosity

What if $\tau_y = 0$?

Rheological Models

3. Power Law Fluid:

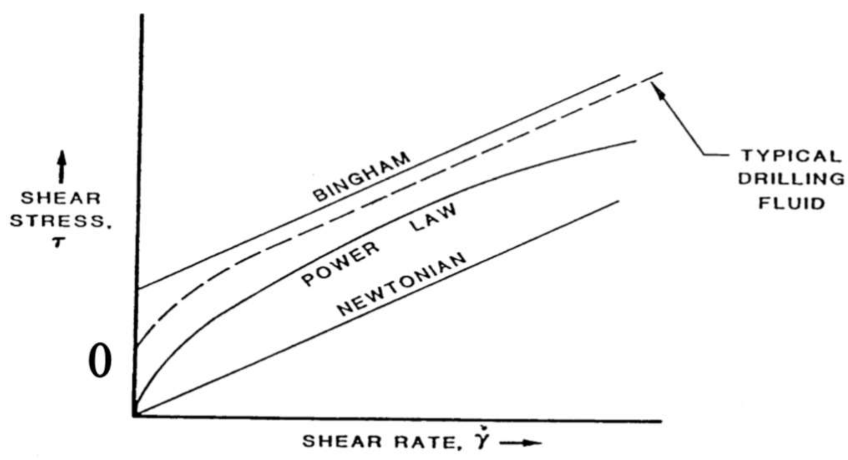
$$\tau = K(\dot{\gamma})^n$$

K = consistency index

n = flow behavior index

- When n = 1, fluid is Newtonian and *K =slop* = μ
- We shall use power-law model(s) to calculate pressure losses (mostly).

Typical Drilling Fluid Vs. Newtonian, Bingham and Power Law Fluids



(Plotted on linear paper)

Rotational Viscometer

Rheometer

We determine rheological properties of drilling fluids in this device

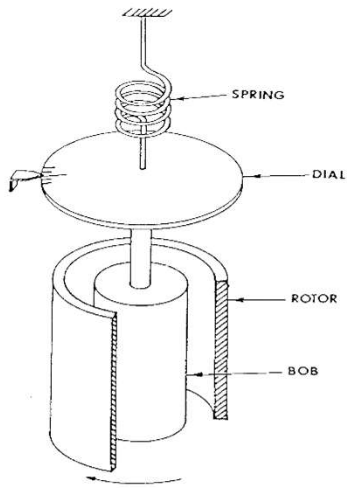
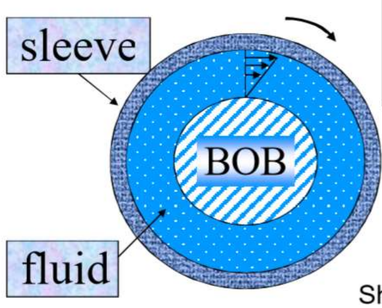


Figure 3-6. Schematic diagram of the direct indicating viscometer. The deflection in degrees of the bob is read from the graduated scale on the dial. (*Courtesy of J.D. Fann.*)



Rheometer (Rotational Viscometer)

$$\tau = f(\dot{\gamma})$$

Shear Stress = Dial Reading

Shear Rate = Sleeve RPM

$\tau(TAU)$, the Shear Stress depends on the value of $\dot{\gamma}$ (GAMMA), the Shear Rate

Rheometer - base case

RPM	sec^{-1}
3	5.11
6	10.22
100	170
200	340
300	511
600	1022

RPM * 1.703 = sec^{-1}

Set up for Viscometer

- At 300 RPM Reading the viscometer is set up to read apparent viscosity in CP.

$$\mu_a = \theta_N$$

- For any other reading the following formula can be used to calculate the apparent viscosity.

$$\mu_a = \frac{300 * \theta_N}{N}$$

Where:
θ_N **is the dial reading at N**
N is the rotational speed in RPM

Example # 2

A rotational viscometer containing a **Bingham plastic fluid** gives a dial reading of 12 at a rotor speed of 300 RPM and a dial reading of 20 at a rotor speed of 600 RPM

Compute plastic viscosity and yield point.

$$\theta_{600} = 20$$
$$\theta_{300} = 12$$

Solution:

$$\mu_p = \theta_{600} - \theta_{300}$$
$$= 20 - 12$$
$$\mu_p = 8 \text{ cp}$$

$$\tau_y = \theta_{300} - \mu_p$$
$$= 12 - 8$$
$$\tau_y = 4 \text{ lbf/100 ft}^2$$

Rotational Viscometer, Power-Law Model

Example # 3

A rotational viscometer containing a non-Newtonian fluid gives a dial reading of 12 at 300 RPM and 20 at 600 RPM.

Assuming **power-law fluid**, calculate the flow behavior index and the consistency index.

Example # 3

$$\theta_{600} = 20$$
$$\theta_{300} = 12$$

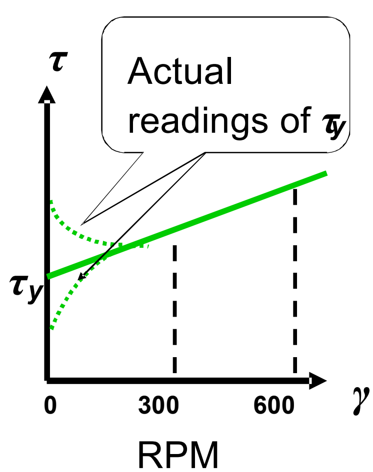
$$n = 3.322 \log\left(\frac{\theta_{600}}{\theta_{300}}\right) = 3.322 \log\left(\frac{20}{12}\right)$$

$$n = 0.7370$$

$$K = \frac{510 \quad \theta_{300}}{511^{n}} = \frac{510 * 12}{511^{0.737}} = 61.75 \text{ eq. cp}$$

Gel Strength

= shear stress when fluid movement begins



- The yield strength, extrapolated from the **300** and **600** RPM readings is not a good representation of the gel strength of the fluid
- Gel strength may be measured by turning the rotor at a low speed and noting the dial reading at which the gel structure is broken (usually at 3 RPM)

Gel Strength

The gel strength is the maximum dial reading when the viscometer is started at 3 rpm.

$$\tau_g = \theta_{max,3}$$ $lbf / 100\ ft^2$

Just a reminder for this week

- HW 1 due Wednesday.
- HW 2 will be posted Wednesday.