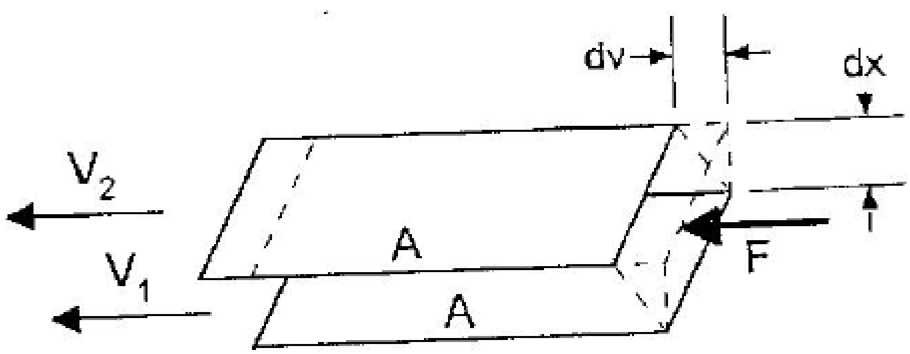
Rheometer

A fluid is defined as a substance that deforms continuously under the action of a shear stress, no matter how small the shear stress may be. Without shear stress, there will be no deformation. Fluids are generally classified by the relation between the applied shear stress and the rate of deformation. Fluids in which the shear stress is directly proportional to the rate of deformation are called “Newtonian” fluids (after Isaac Newton). The term non-Newtonian is used to classify all fluids in which shear stress is not directly proportional to the shear rate. This proportionality constant is called viscosity and can also be thought of as a measure of the internal friction of a fluid. This friction becomes apparent when a layer of fluid is made to move in relation to another layer. The greater the friction, the greater the amount of force required to cause this rate of movement.



Isaac Newton defined viscosity by considering the model represented above. Two parallel planes of fluid of equal area “A” are separated by a distance “dx” and are moving in the same direction at different velocities V_1 and AV_2. Newton assumed that the force required to maintain this difference in speed was proportional to the difference in speed (velocity gradient). Newton surmised:

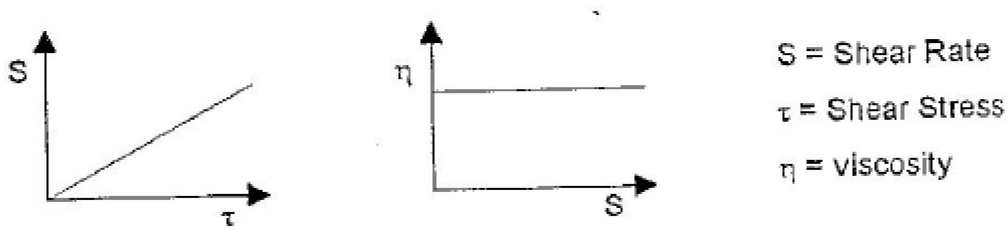
$$\frac{F}{A} = \eta \frac{dv}{dx}$$

Where η is constant for a given material and is called its <u>viscosity</u>. The velocity gradient, $\frac{dv}{dx}$, is a measure of the speed at which the intermediate layers move with respect to each other. It describes the shearing the liquid experiences and thus is called the “shear rate”. The $\frac{F}{A}$ term indicates the force per unit area required to produce the shearing action, and is therefore referred to as “shear stress.” Rearranging the above equation, we have

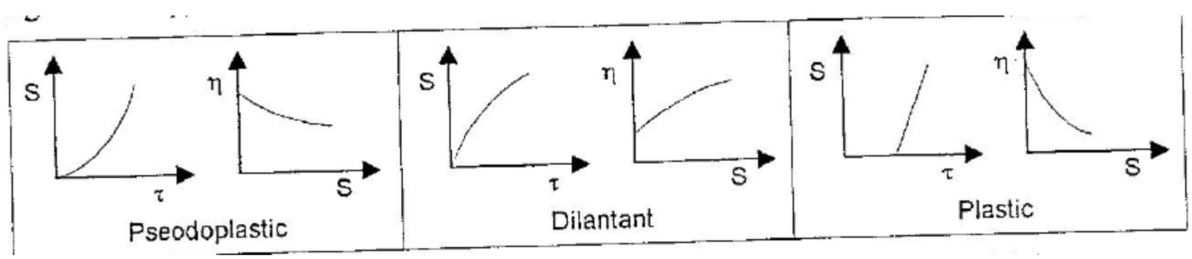
$$\eta = viscosity = \frac{F/_{A}}{dv/_{dx}} = \frac{shear\ stress}{shear\ rate} = \frac{\tau}{S}$$

The fundamental unit of viscosity is the poise and represents one dyne-second per square centimeter. Other units sometimes used are centipoise [cp] (=poise/100), Pascal-second [Pa s] (=10 poise), and milli-Pascal-second [mPa s] (=1 cp).

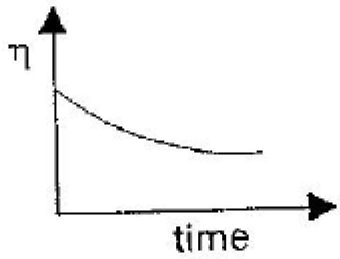
Since Newton thought viscosity was constant (independent of the shear rate), fluids that exhibit this property are classified as "Newtonian". Typical Newtonian fluids include water, thin motor oil, gasoline, and air. The characteristics of a Newtonian fluid are graphed as follows:



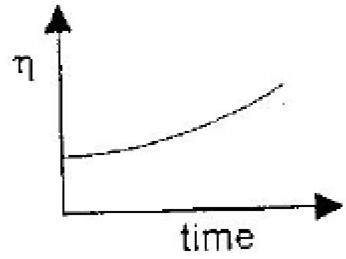
Non-Newtonian fluids are broadly defined as those in which the shear stress is not directly proportional to the deformation rate (shear rate). The most common types of non-Newtonian fluids include pseodoplastic, which have decreasing viscosity as the shear rate increases; dilantant, which have increasing viscosity as the shear rate increases, and plastic, which require a certain amount of force to be applied before any flow is induce (e.g. like ketchup).



Another factor that affects viscosity in non-Newtonian fluids is time. Fluids in which the viscosity decreases with time are known as thixotropic, and are more common than those in which viscosity increases with time – known as rheopectic. Both thixotrophy and rheopexy may occur with any of the previously discussed flow behaviors.



Thixotropic



Rheopectic

<u>Rheometer:</u>

Webster's defines rheology as "the study of the change in form and the flow of matter embracing elasticity, viscosity, and plasticity." Along these lines, the Brookfield Rheometer measures the fluid parameters of shear stress and viscosity and given shear rates. The principle of operation of the DV-III is to drive a spindle (which is immersed in a test fluid) through a calibrated spring. The viscous drag of the fluid against the spindle causes the spring to deflect, which is measured by a rotary transducer. The output of this transducer is used (along with the rotational speed and spindle geometry) to calculate the shear stress and the viscosity.

<u>Procedure:</u>

<u>Part A:</u> Viscosity v Time

1. Turn on the Rheometer using the switch located at the back of the base.
2. Be sure to select "EXTERNAL CONTROL" on the Rheometer.
3. Turn on the computer.
4. Run the "RheoCalc" program.
5. Click on the "Tests" tab.
6. Load the desired program file.
7. Modify the existing program for the necessary parameters.
    a. SSP: Set Spindle
    b. SSN: Set Speed
8. Save and then begin the program.
9. Zero the rheometer without spindles if the program asks you to.
10. Record parameters and viscosity values in the table below. Be sure to include units!
11. Repeat for parts B-E.
12. Graphically represent how viscosity changes with respect to each parameter.
13. Classify each material from each section using the aforementioned fluid types.

Spindle #: 4/7 Fluid Number: 5000/60000 Fluid Viscosity: __________ ___

Speed: 30 RPM Temperature: __________ Time: 10 min

Reading #	Time (min)	Viscosity (cP)	Time (min)	Viscosity (cP)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Part B: Viscosity v Speed

Spindle #: 2 Fluid Number: 500 Fluid Viscosity: __________ ___

Speed: 0-30 RPM Temperature: __________ Time: __________________

Reading #	Speed (RPM)	Viscosity (cP)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Part C: Viscosity v Surface Area

Spindle #: 2-6 Fluid Number: 1000 Fluid Viscosity: ___________ ___

Speed: 30 RPM Temperature: ___________ Time: 1 min per spindle

Reading #	Spindle Number	Spindle Surface Area (in^2)	Viscosity (cP)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Part D: Viscosity v Temperature

Spindle #: 6 Fluid Number: 30000 Fluid Viscosity: ___________ ___

Speed: 30 RPM Temperature: Room Temp-50°C Time: 10 min

Reading #	Temperature (°C)	Viscosity (cP)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Part E: Viscosity v Fluid

Spindle #: 3/7 Fluid Number: 1000/60000 Fluid Viscosity: __________ ___

Speed: 30 RPM Temperature: __________ Time: 1 min per fluid

Fluid #	Theoretical Viscosity (cP)	Experimental Viscosity (cP)
1		
2		

Questions:

1. What is a fluid?
2. What is viscosity? What is the general formula for it? What are its units?
3. Which requires more force to move pump a highly viscous fluid or a low one?
4. A fluid whose viscosity increases with the shear rate is called ____________________.
5. A fluid whose viscosity decreases with time is called ____________________.