ABE 304
Bioprocess Engineering Lab

Rheological Properties of Biological Fluids

What is Rheology:

- science of deformation and flow of materials
- apply a stress, how does the material deform or flow?

Why do we care?

- Product properties: function, performance, consumer
- Design of your process: equipment selection, how equipment effects material
- Monitoring reactions or process
- Understanding biological phenomena

How do we measure?

- Instrumentation
- Experiment
- Equations & Data Analysis

basic definitions, intro to viscosity

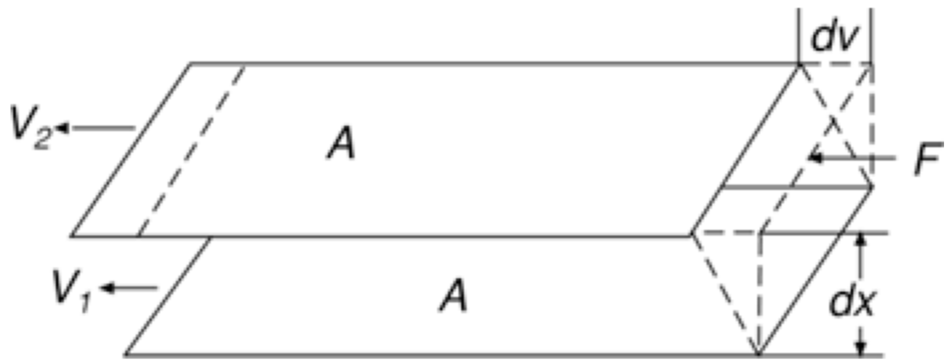


Figure from: http://www.brookfieldengineering.com/education

Newton postulated that the **velocity gradient** would be proportional to the **force** applied.

So we call materials for which this holds true, **Newtonian** fluids.

Viscosity is the proportionality constant

Apply a **force**, F, to move a layer of fluid relative to another

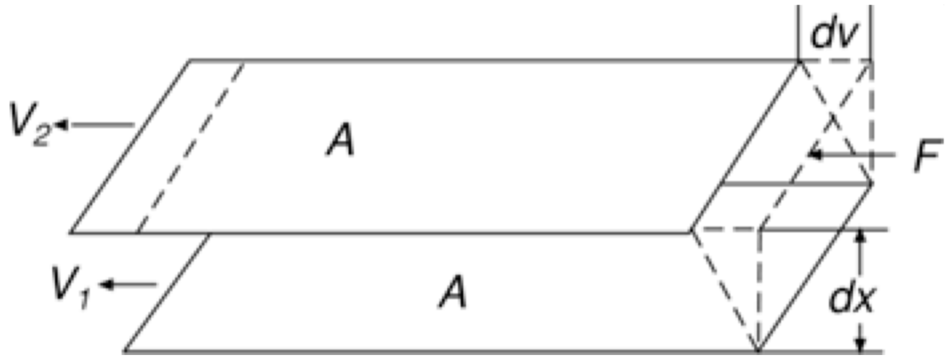
The F per unit area, F/A = **shear stress**, τ, with units of pressure $[Pa]=\left[\frac{N}{m^2}\right]=\left[\frac{kg\cdot m}{s^2\cdot m^2}\right]=\left[\frac{kg}{s^2\cdot m}\right]$

Layers at different distances, **x**, move at different velocities, **v**

There is a **velocity gradient**, **dv/dx**, (difference between how fast the fluid layers flow)
This gradient is the shear rate, with units of s^{-1}

$$\frac{dv}{dx}=\dot{\gamma},\left[\frac{m/s}{s}\right]=[s^{-1}]$$

Newtonian Fluids



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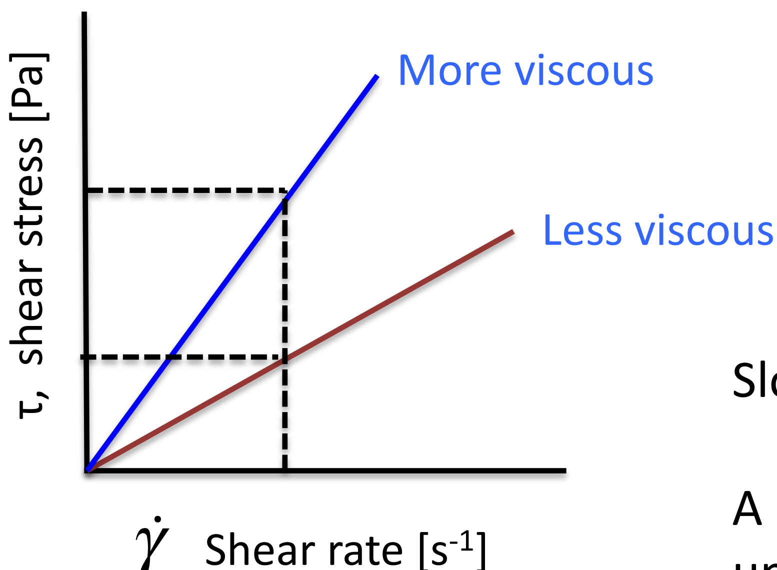


$$\tau = \mu\dot{\gamma}$$

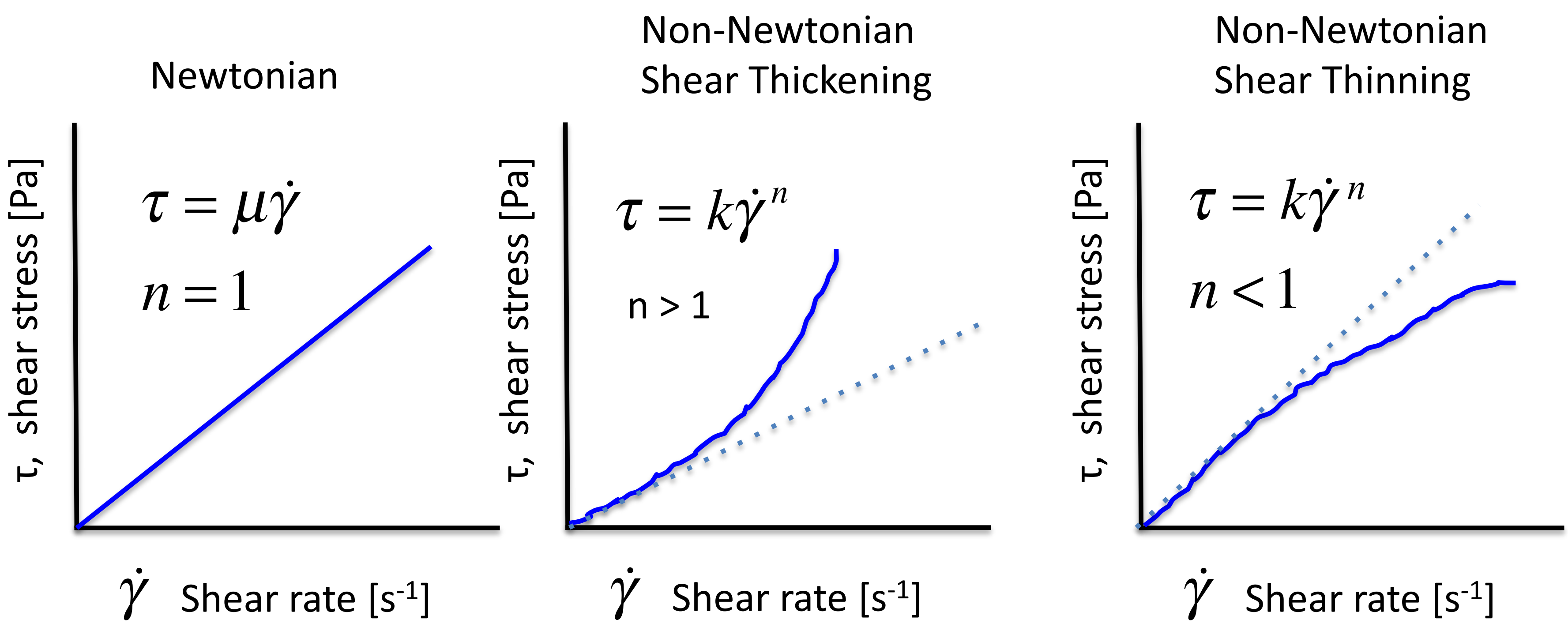
$$[Pa] = [Pa \cdot s][s^{-1}]$$

Slope is the viscosity in units Pa*s

A more viscous fluid requires more force per unit area to create the same velocity gradient

Why is rheology so important to biological engineering?

Most biological fluids are Non-Newtonian



Viscosity is actually changing with shear rate

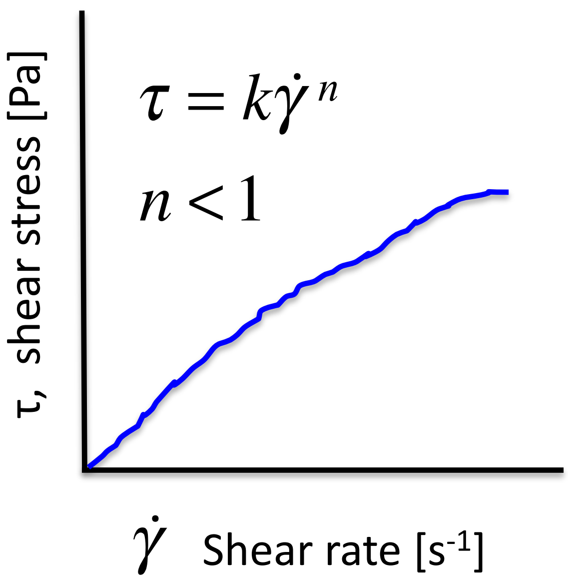
Shear thickening $\dot{\gamma}\uparrow, \mu\uparrow$

Shear thinning $\dot{\gamma}\uparrow, \mu\downarrow$

Why is rheology so important to biological engineering?

Shear thinning: common biological materials

Non-Newtonian
Shear Thinning



Dispersions
- cells in broth

Emulsions
- mayonnaise
- salad dressings

Polymeric Materials
- Extracellular environments
- Food polymers

Why does this happen?
Shear forces are changing the intermolecular interactions and organization in the material

Why Do We Care?
Properties of a Product: Consumer Preferences
Example: Mayonnaise, oil in water emulsion

How a food product feels on your tongue = “mouth-feel”

Your tongue produces the stress, how does the product flow?

Can quantify and map rheological properties to consumer descriptors and preferences.

When you put a knife into the jar, how much stress do you have to exert before the product flows? = ***Yield Stress***

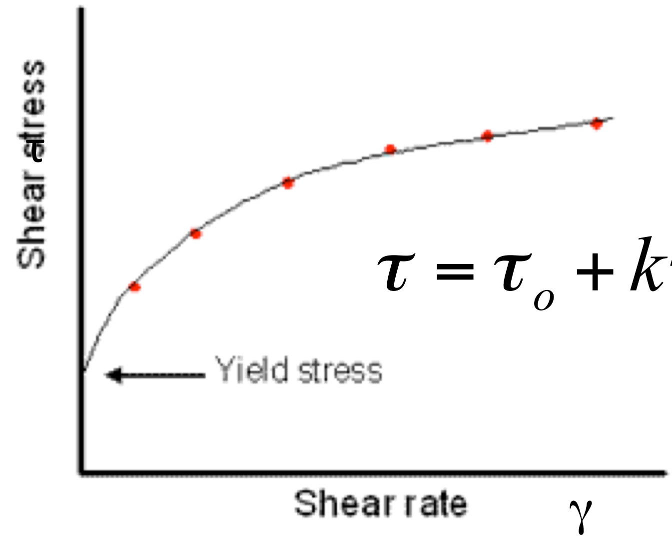
You don’t want your mayonnaise too “runny” or too “stiff” Consumers think this is kind of gross. There is an ideal or acceptable yield stress range.

Yield Stress therefore is a critical measurable rheological property that correlates with consumer preferences.

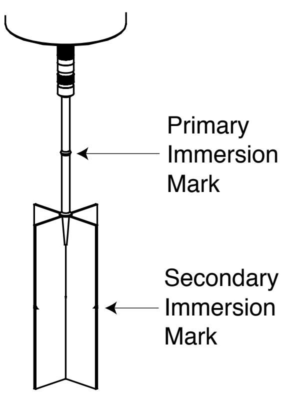
Can use as a measure for product formulation or reformulation.

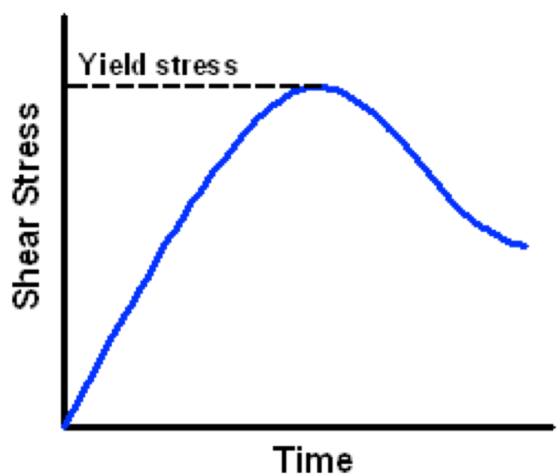
How do we measure?

Example: Brookfield YR-1



$$\tau = \tau_o + k\dot{\gamma}^n$$





1. Insert into sample
2. Slowly rotate/torque the spindle
3. Measure the stress over time

Yield stress is the stress where product “yields”

Reference: http://www.brookfieldengineering.com/education/rheology_papers_yield_stress.asp

Why Do We Care?
Designing our Process: How do the forces we exert on our product during our process effect its properties?

Unit Operations:

Pumping
Mixing
Homogenization

All exert stresses

Heating
Cooling

Rheological properties are temperature dependent

Do your product's properties change?

Shear Thinning or Shear Thickening
Time dependent? With time mixing?
Is effect reversible or irreversible?

Equipment Selection
Pump selection and sizing

Energy requirements
Take more energy to pump a viscous fluid

Brookfield Viscometer

- Spindle/bob rotates within sample.
- Measure:
  - Angular velocity
  - Bob/spindle dimensions

Lab Procedure

- *Samples*
  - hair conditioner
  - liquid yoghurt
  - 85% glycerol
  - corn starch in 85% glycerol
  - fermentation products with/without cells present

Lab Procedure

- ***<u>Spindle</u>***

Spindle	Viscosity range / cP	Code	Fluid
LV 1	15 – 20 000	61	Glycerol 85% w/w, xanthan gum
LV 2C	50 – 100 000	66	Liquid yoghurt, Corn starch 55% w/w in glycerol
LV 3C	200 – 400 000	67	Hair conditioner

Lab Procedure

- <u>*Measure viscosity*</u>
  - Pour 200 mL of the test liquid into the 250 mL beaker
  - Choose a right spindle code for each fluid
  - Read the viscosity on different RPM (from 0.3-100 rpm)

Lab Procedure

- <u>*Decide a “RIGHT” viscosity*</u>
  - I. when the torque % readings ***exceed 100%*** the screen will display ***“EEEE”*** for both viscosity and torque %, this data can not be used. ***You need either reduce the speed or use a smaller size spindle.***
  - II. when the torque % readings ***below 10.0%*** the screen will display both torque % and viscosity with ***flashing*** unit, this data can not be used. ***You need either increase the speed or use a larger size spindle.***
  - III. when the torque % readings is ***negative***, viscosity will be displayed as ***“____”***, this data ***can not be used***

Lab Procedure

- <u>*Measure viscosity*</u>
  - Clean the beaker and spindle after you test each liquid.
  - Repeat the procedure for all the liquid samples.
  - You will need ***three replicates*** of each fluid tested for accurate statistical analysis.