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The Deformation of Polymers and the Correlation to non-Newtonian Behavior

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Overview

- Intro to fluids
- Shear force and deformation
- Newton's Law of Viscosity
  - Newtonian vs. non-Newtonian fluids
- Dilatant fluids
  - Ooblek and Polymers
- Polymer deformation and flexibility
- Hydroclustering

What is a “fluid”?

A substance that deforms when a force is applied to it (liquids and gases), this resultant deformation occurs as different rates for different fluids.

Viscosity

Viscosity is a property of the fluid that measures the resistance to flow when an external force has been applied.

A fluid with a lower viscosity will flow faster than a fluid with a high viscosity.

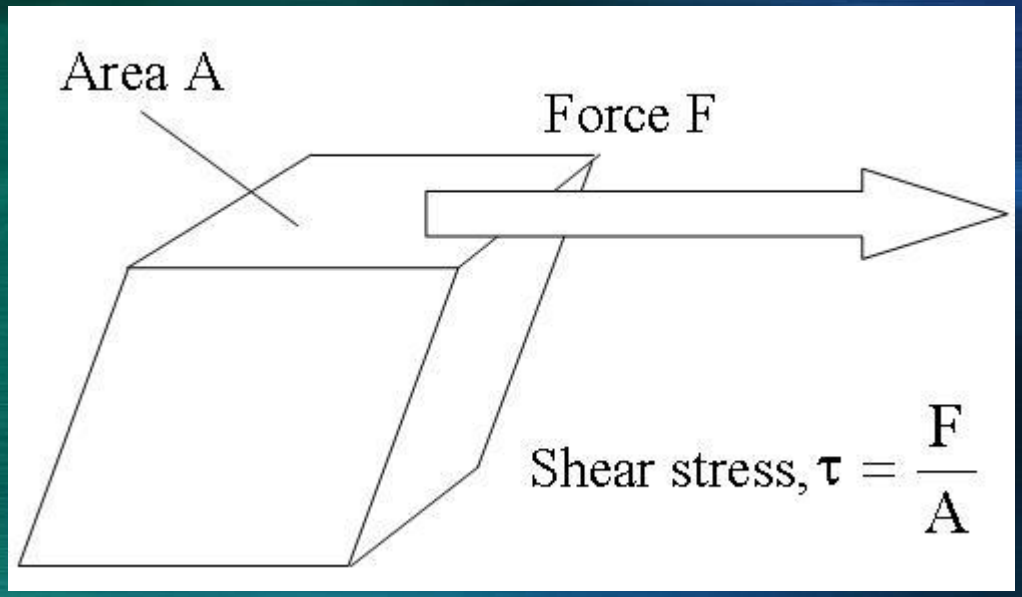
The Shearing Effect

shear force

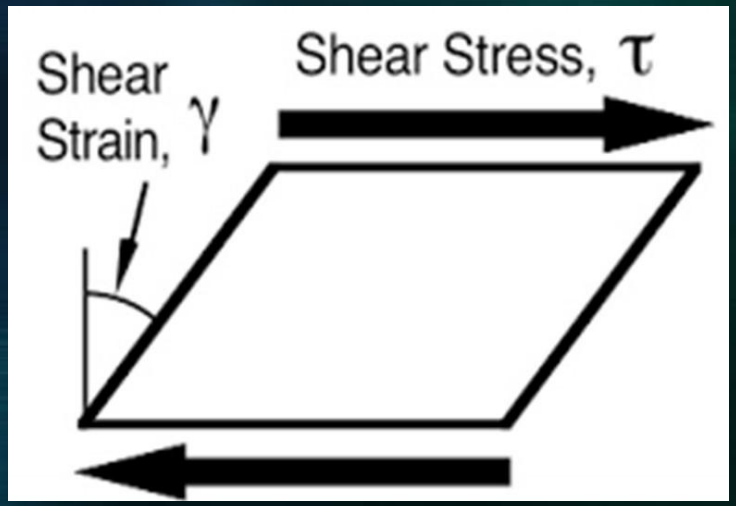
→ shear deformation (shearing effect)

→ shear stress

→shear strain

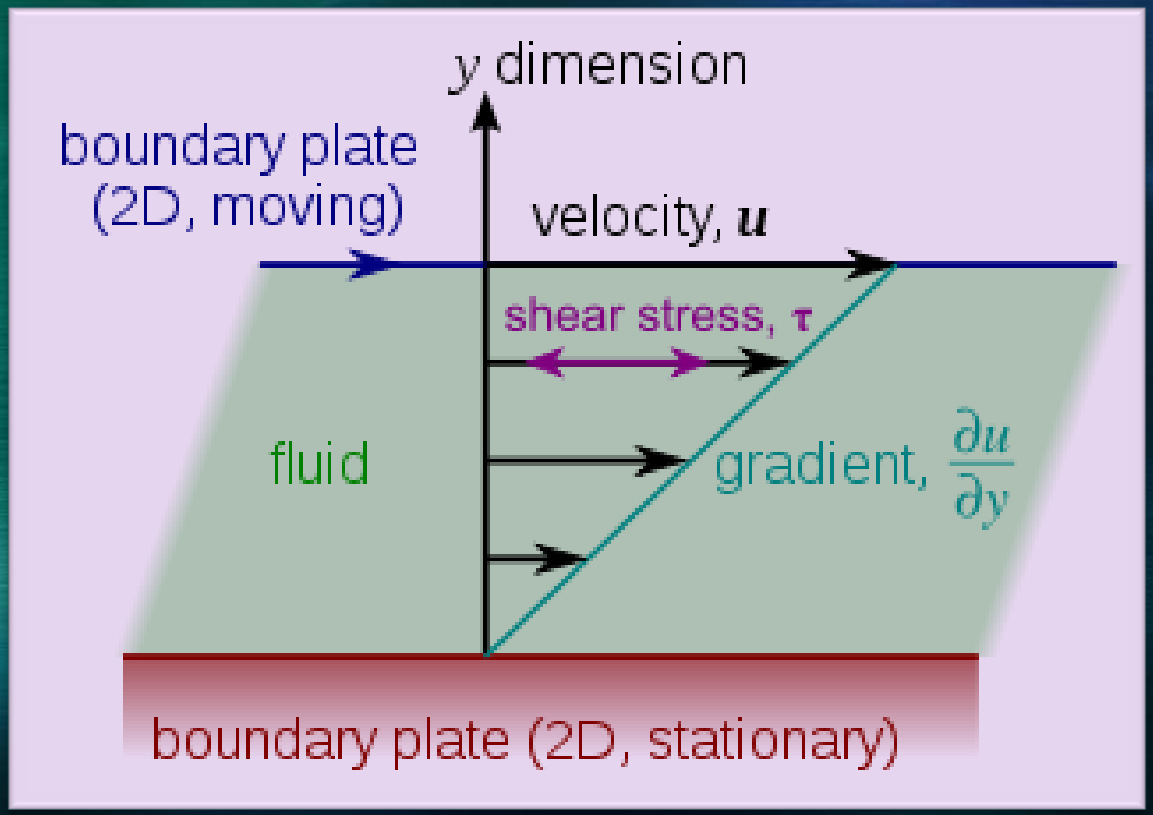


$$G = \frac{\tau}{\tan\alpha} = \frac{\tau}{\gamma}$$



Newton's Law of Viscosity

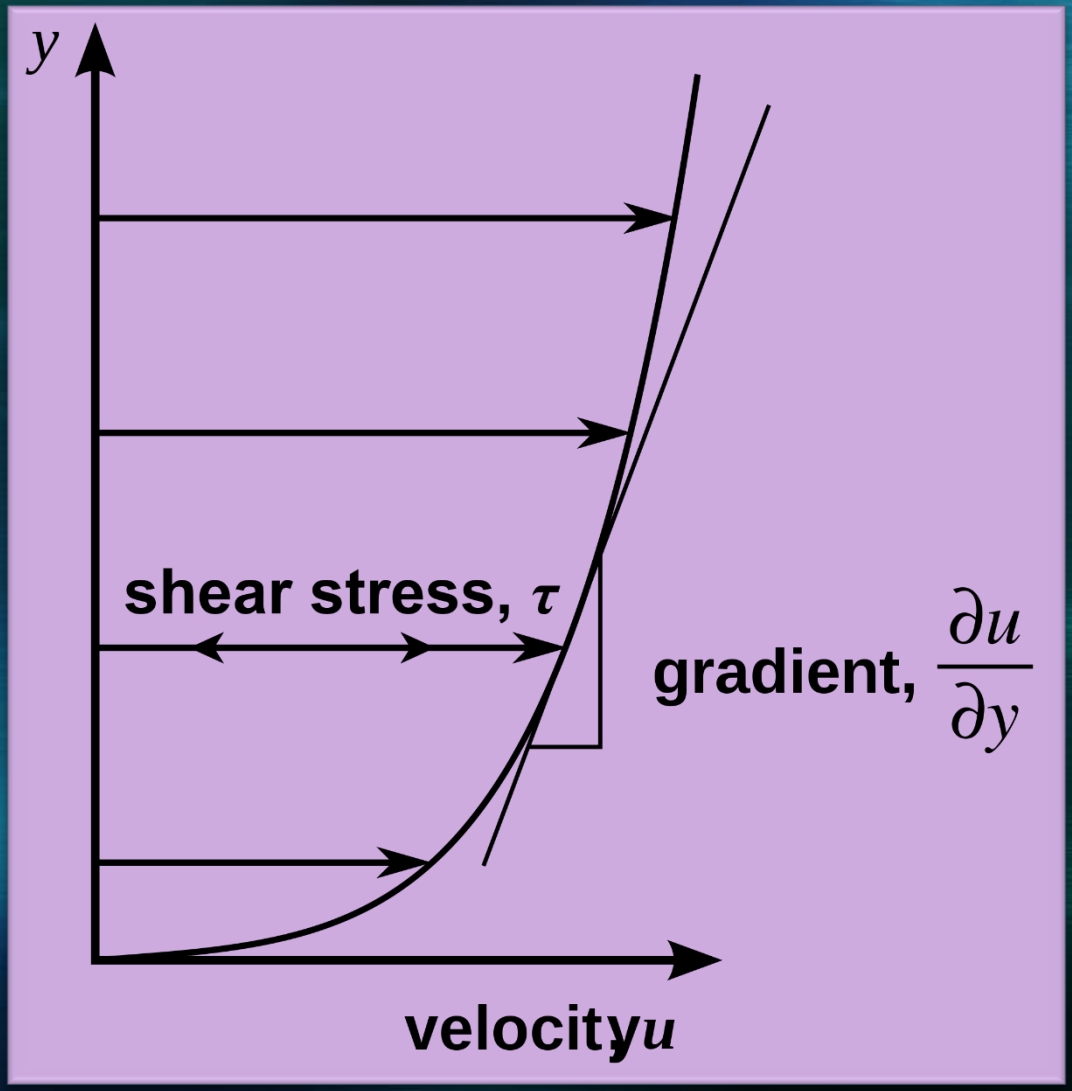
- Newton stated that the shear stress of a fluid is directly proportional to the rate of shear strain.



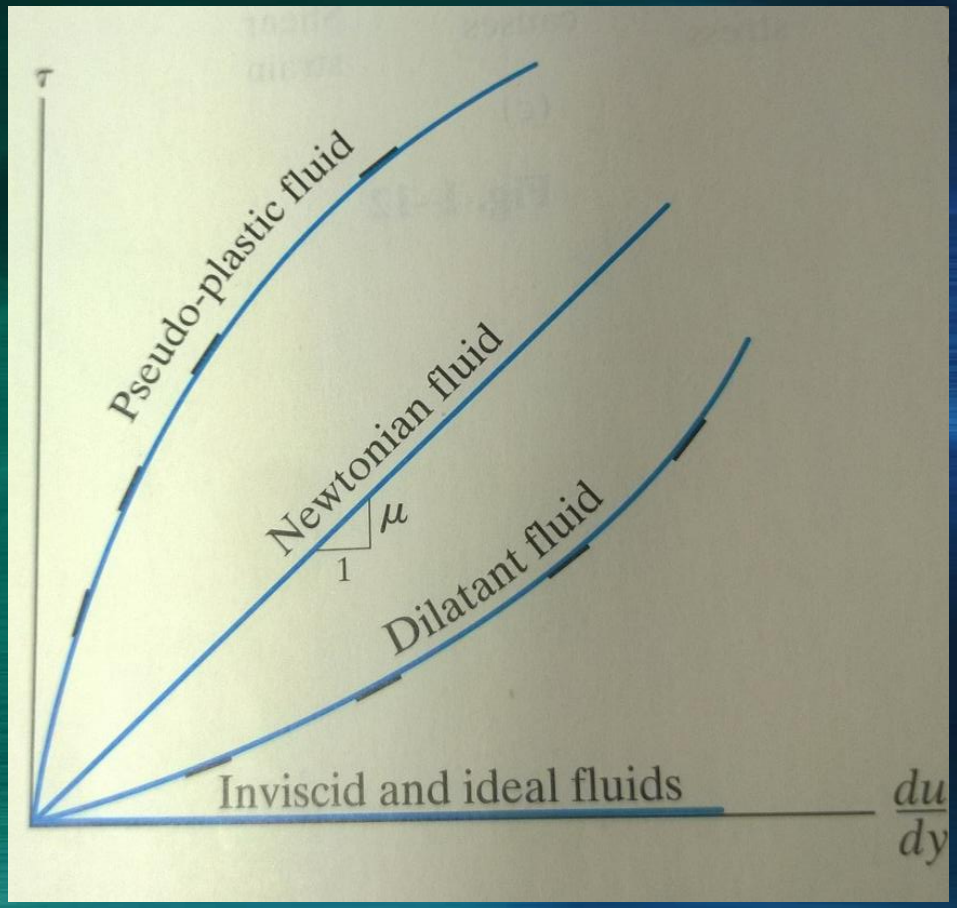
$$\tau = \mu \frac{\partial u}{\partial y}$$

μ is a physical property of the fluid that measures its resistance to movement

Laminar flow



Types of Fluids



The viscosity of a fluid is determined by the slope of the curve.

For a non-Newtonian fluid the viscosity is not constant, as such the apparent viscosity is defined as the slope at a point.

Non-Newtonian fluids

Pseudoplastic and dilatant fluids are two types of non-Newtonian fluids that behave differently when a shear stress is applied.

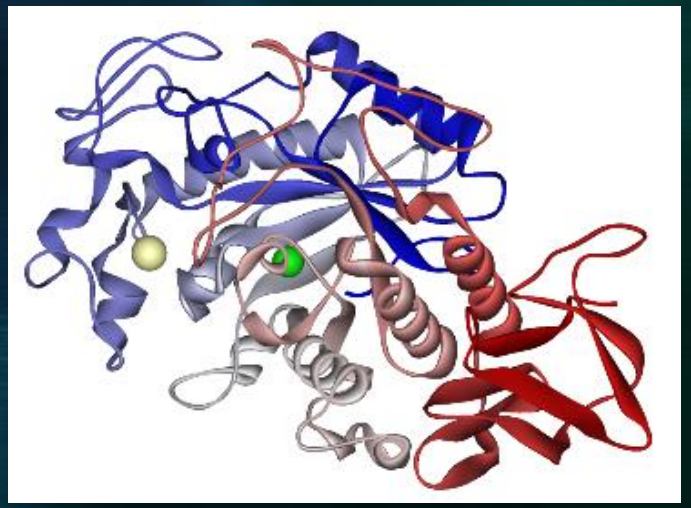
Pseudoplastic

- Shear thinning fluids
- Flow slowly when a small shear stress is applied, but flow rapidly under the application of high shear stress
- Milk, blood, nail polish and other paints

Dilatant

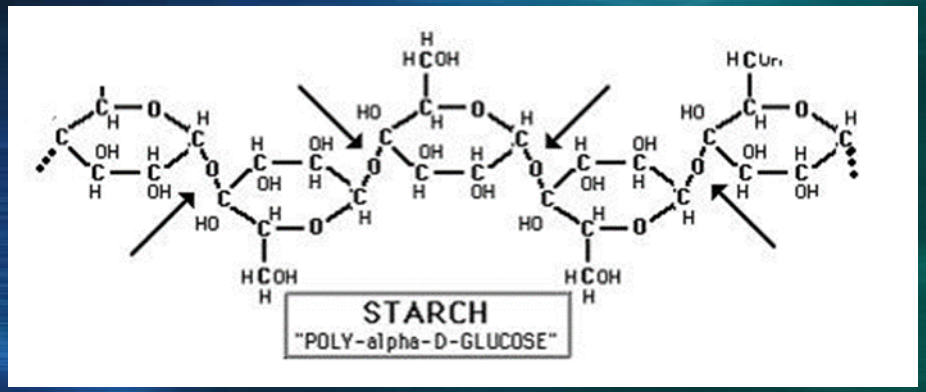
- shear thickening fluids
- the viscosity decreases as the applied rate of strain is increased
- interesting since they behave as a fluid until an external force causes them to exhibit solid-like behavior
- Ooblek (cornstarch and water), magma, soaps, polymer melts and solutions

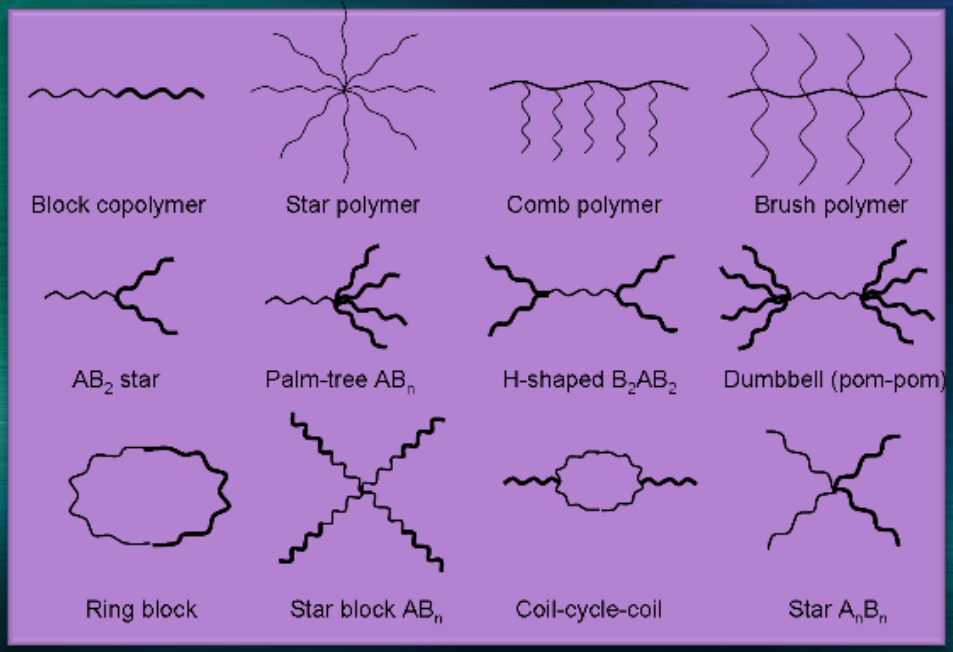
Ooblek



Polymers

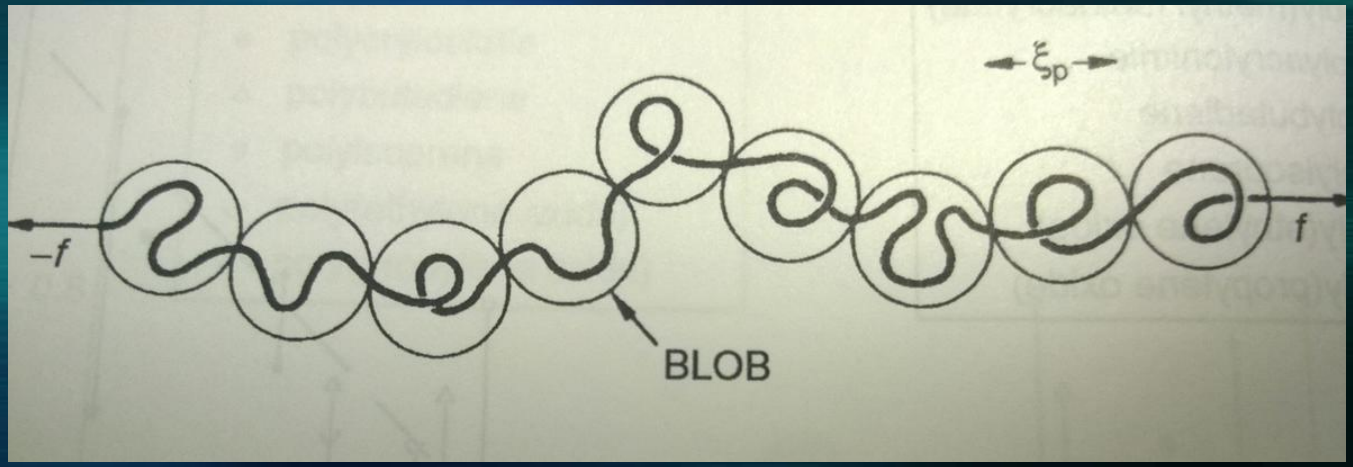
- Often hydrocarbons that form a long chain which is referred to as the “backbone” of the polymer
- Carbon can have up to four bonds which allows for branching and side groups





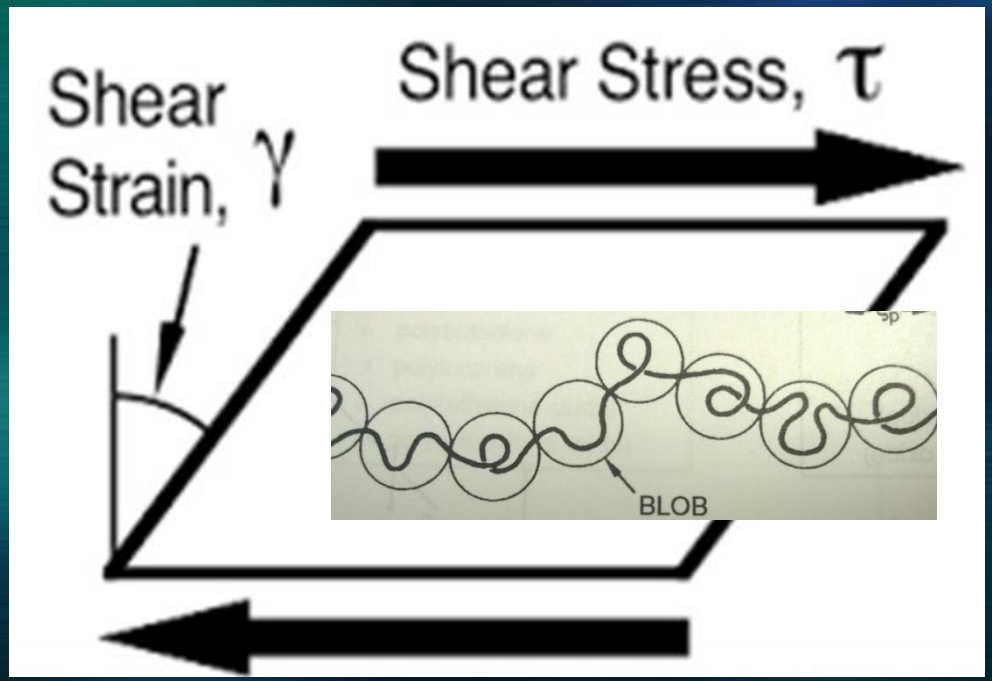
Polymers Under Stress

- Synthetic and natural polymers undergo a change in molecular configuration as a result to an applied external force
- When a coiled polymer chain under large tension will form into a series of hard spheres, causing the conformation to become a string of these “blobs”



Dynamic flexibility

- The dynamic flexibility of a polymer is important to consider when determining the rate of deformation since it is a measurement of the skeletal chain's ability to change configuration or shape.



Flexibility in a Polymer

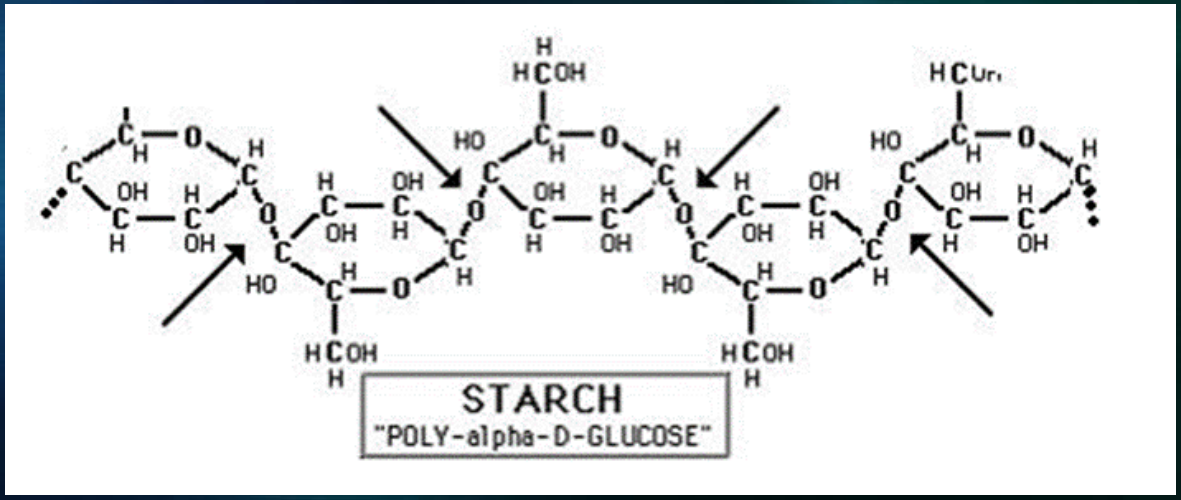
The flexibility of a polymer depends the rotation or torsional mobility of the bonds within the skeletal chain and less on the side groups that are attached.

In Skeletal chain ("Backbone")

- Ladder structure
- Aromatic rings
- Amide links
- -[C-C]-
- -[C-N]-
- -[C-O]-
- -[S-S]-
- -[S-O]-

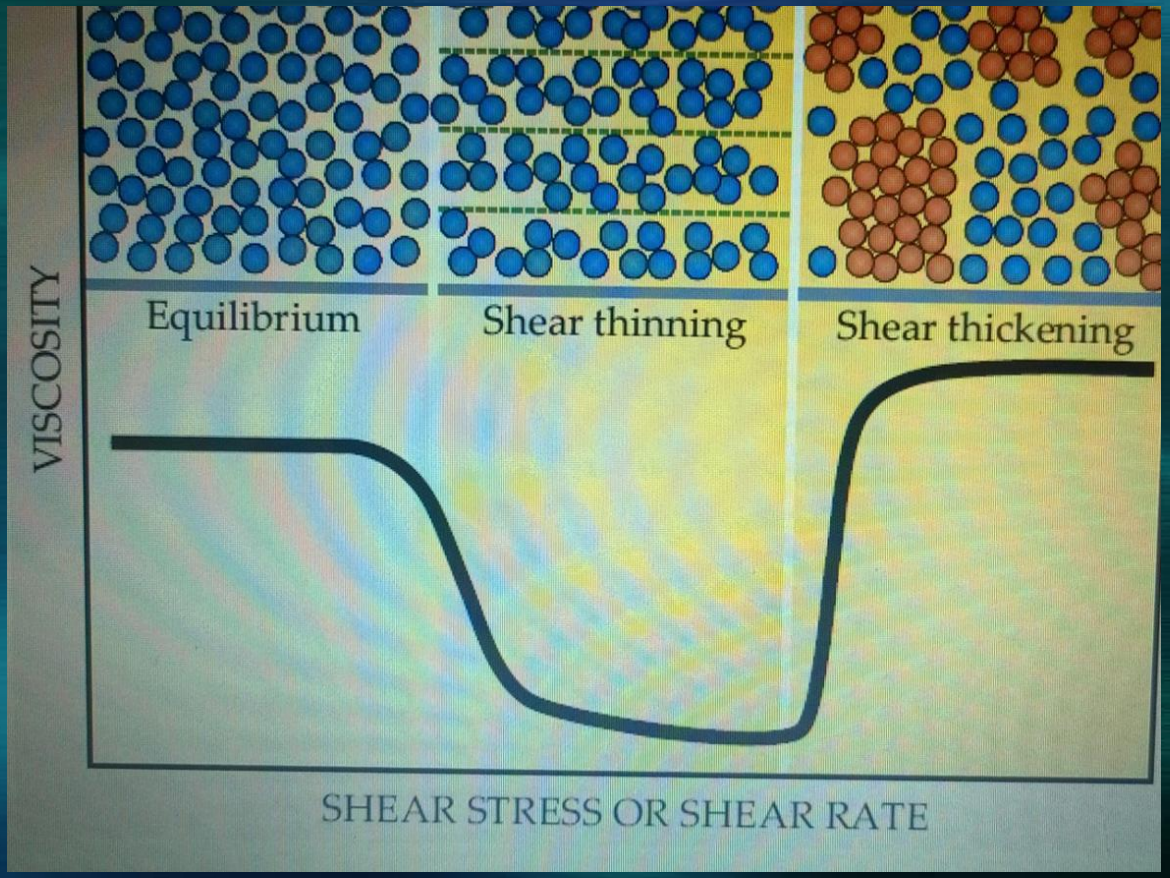
As a Side Group

- Aryl groups
- Hydroxyl groups
- Cyano groups
- Alkyl and Alkyl Ethers
- Hydrogen



Hydroclustering

Hydroclustering occurs when the molecule can no longer maintain its original configuration, this results is collections of hydroclusters that impede the flow of the fluid.



Summary

- Cornstarch is a natural polymer that deforms to a series of hard spheres when an external force has been applied. This microscopic behavior as well as the effect of hydroclustering describes the solid behavior ooblek displays when an external force is applied.

Acknowledgements

- Dr. Woolard
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