Rheology Basics

(1) Rheology Variables and Useful Output

(1.1) Rheology Definitions and Scope

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First Steps: Learn the Lingo

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The power of the right vocabulary: Describing samples appropriately helps categorize them by properties relevant to the application.

Soft Solids and Fluids

- **Fluid:** A liquid or gas; a substance that takes the shape of its container because it flows
- **Perfect Liquid:** demonstrates the same flow regardless of the applied stress or strain, has no characteristics of fracture
- **Solid:** A substance that does not take the shape of its container
- **“Soft” Solid:** A solid that is prone to flow under applied stress or strain; may be perceived as “soft” (putty vs. steel)
- **Perfect Solid:** displays no flow, deformation is shown as fracture

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Solid-Like vs. Liquid-Like Materials

Solid-like: Demonstrates more qualities of a solid than a liquid, but not a perfect solid

Attributes of solid-like substances: ability to fracture, maintain shape, adsorb stress instead of moving, bonding or networks contribute to high internal friction

Liquid-like: Demonstrates more qualities of a liquid than a solid, but not a perfect liquid

Attributes of liquid-like substances: ability to flow, loose "structure", bonding not strong enough to prevent substance from moving under applied stress

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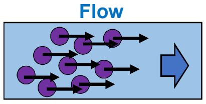
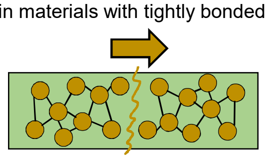
Flow vs. Fracture

- **Flow:** Bonding between molecules is non-existent or so minimal that the substance responds quickly to applied stresses
- **Fracture:** Deformation that occurs in materials with tightly bonded structures

Flow





Fracture

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Viscoelasticity as a classification for "Imperfect" Solids and Liquids

Visco-

"Viscosity"
Describes a liquid
A perfect liquid (water) flows with no solid-like behavior

-Elastic

"Elasticity"
Describes a solid
A perfect solid (rock) breaks when it deforms rather than flowing

Viscoelastic: has characteristics of both a solid and a liquid

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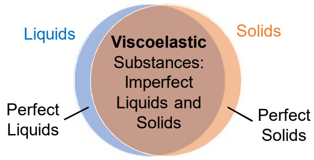
Viscoelastic materials come in a wide spectrum. Some as much more solid (elastic) than liquid (viscous) and other as more liquid (viscous) than solid (elastic).

Soft Solids and Fluids



→The vast majority of liquids we interact with are actually “imperfect” liquids that have some solid-like attributes

→Many materials are somewhere in-between a “perfect liquid” and a “perfect solid”: gels, foams, pastes, dispersions, melts, composites, films, fibers, emulsions, concentrated solutions, and more!

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In-between Perfect Liquids and Solids: Viscoelastic Materials

- **Concentrated solution:** consists of a solvent (water or other liquid) with dissolved chemicals, for example polymers or surfactants. There is enough of the chemical for the properties of the solution to be different from the solvent alone.
- **Gel:** network of bonds that form a structure that has solid-like qualities that may have deformation as flow instead of fracture
- **Foam:** composite consisting of a liquid with high volumes of air (bubbles) that may respond like a fluid or a solid under various stresses or strains
- **Paste:** dense concentration of particulates or networked structures within a liquid that can flow or fracture under stress
- **Dispersion:** a liquid with suspended particles

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In-between Perfect Liquids and Solids: Viscoelastic Materials

- **Emulsion:** a liquid with suspended liquid particles (droplets)
- **Melt:** a soft solid consisting of entangled polymer chains without solvent
- **Composite:** a soft solid with various particulates, droplets, or other non-solid constituents
- **Film:** a soft solid that can maintain both liquid-like and solid-like characteristics with predominant properties stemming from the 2D surface
- **Fiber:** a soft solid that can maintain both liquid-like and solid-like characteristics with predominant properties stemming from the diameter.

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"Non-Newtonian": Another name for Viscoelastic Materials

- **Newtonian:** Refers to a Perfect Liquid; liquids that flow the same regardless of applied stress or strain
- **Non-Newtonian:** a material that is not a perfect liquid because it has some solid-like characteristics

Newtonian Substances:
Water, some oils, dilute solutions


Non-Newtonian Substances:
All other fluids and soft solids




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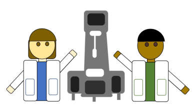
Rheo-

Rheology:
- A science that examines the mechanical behavior of fluids and soft solids
- The study of non-Newtonian fluids and soft solids
- A field that applies physical sciences to flow properties
- An area of physics that examines dynamic physical interactions at the micron and nano scale

- **Rheometry:** The practice of using a Rheometer to collect data
- **Rheologist:** A scientist who studies the mechanics of soft materials using rheology data
- Rheo-Microscopy, Rheo-Tribology, Rheo-gram



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Ancient language: Rheo/rhei is an ancient Greek word meaning "flow". If rheology was named with the Latin word for flow, it would be "fluology." Everyone would think that rheologists were contagious if they were called "fluologists"…

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Viscosity (η)

- A measure of **internal friction**; a measure of the resistance to flow
- Specific to the sample itself, but influenced by the environment:
  - Temperature
  - Pressure
  - Stress
- Measured in a shear rheometer as a function of shear rate ($\dot{\gamma}$) or applied angular velocity (v)

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The difference between rheology and friction studies: Viscosity is a property specific to the internal structure of a sample that is influenced by the environment. Tribology is the study of a sample's friction while in direct contact with other materials to measure friction of the system.

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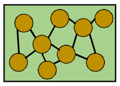
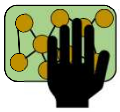
Internal Friction vs. External Friction

Crosslinked Gel



Internal Friction:
Friction between networked polymers



External Friction:
Friction between the gel and the table surface; friction between the gel and your hands

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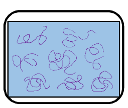
Internal Friction vs. External Friction

Polymer Solution

Internal Friction:
Friction between polymer chains



External Friction:
Friction between the polymer chains and solvent against the glass of the beaker

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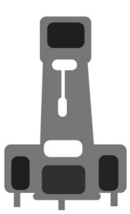
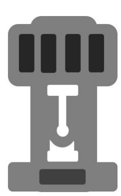
Internal Friction vs. External Friction



Rheometer

The difference between viscosity tests and friction studies: Viscosity and other rheological properties are specific to the internal structure of a sample that is influenced by the environment. **Tribology** is the study of a sample's friction while in direct contact with other materials to measure friction of the system.



Tribometer

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Viscometry vs. Rheometry/Rheology

Viscometry:

- Assumes the sample is Newtonian – constant viscosity regardless of set conditions
- Gives one viscosity value
- Should only be used for Newtonian fluids, such as water, some oils, and very dilute solutions

Viscometers and Rheometers: Articles referencing data from a viscometer will typically give data in terms of rpm while rheometer data will be in terms of shear rate. Non-Newtonian samples can be measured in a rheometer.

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Rheometry and Rheology:

- Account for non-Newtonian behavior
- Considered a dynamic technique because the sample typically changes during the course of the measurement
- Expected to have a changing viscosity, and therefore results are given in a graph

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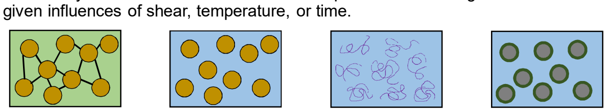
Sample Structure

- All materials have structure; some are more organized than others
- Fluid structures are constantly changing during flow
- Solid-like samples have structures that break down under a given amount of stress
- Rheometry tests reveal how the internal sample structure changes under given influences of shear, temperature, or time.



Gels, Soft Solids | Colloidal Dispersions | Polymer Solutions | Emulsions, Cellular Solutions

Samples with no Structure: They exist, typically as Newtonian fluids. There is “no structure” because either they are (1) solvents without any polymers or particulates or (2) very dilute polymer solutions or colloids that do not have any interactions between the constituents.

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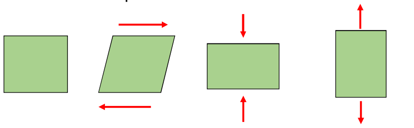
Shear

A shear force is applied **parallel** to the sample - not perpendicular

…like shearing a sheep or petting a puppy!

Tensile and compression forces are NOT shear forces.



No force | Shear forces | Compressive force (Not a shear force) | Tensile force (Not a shear force)

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"Mechanical Behavior" is how any substance responds to a force.
Solids and liquids both have mechanical properties. The mechanical properties we care about most are the **shear properties** because those are involved in **processing and application**.

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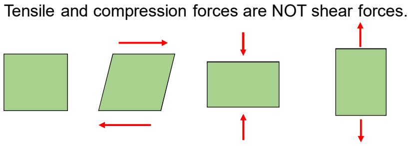

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Shear forces in daily life:
- Applying cosmetics to skin
- Shampooing hair
- Pipe flow
- Coating a surface
- Eating and swallowing
- Blood Circulation
- Air Turbulence

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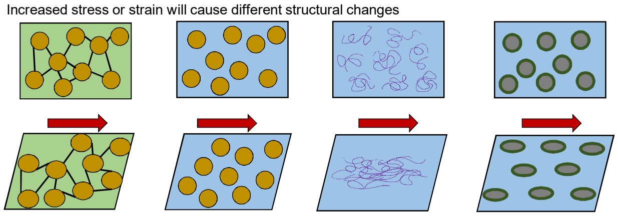
Sample Structure Under Shear

- When a shear stress or strain is applied, the structure may or may no change in order to flow.
- Increased stress or strain will cause different structural changes



Network Deformation | Particles re-arrange | Chain Alignment | Droplet/Cell Elongation

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Combinations of Structures: Gels with unlinked particles, solutions with multiple polymer chemistries, and emulsions with added particles are common in rheology studies.

Rheology Terms Summary

- Very few materials are **perfect liquids**; many consumer products, raw materials, and industrial parts have both **solid-like** and **liquid-like** characteristics.
- These **viscoelastic** substances are measured with a **rheometer** to further investigate their **non-Newtonian** mechanical properties.
- Rheometers record the **viscosity** of the sample, which is based on the **internal friction**.
- Through applying a shear force to the sample, the internal friction can be interpreted in terms of the **sample structure**.

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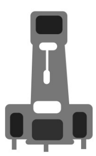
Next Time: Input Variables

Learn which factors are controlled and measured in a rheometer.

Questions from this lecture? Ask Lisa at RheologyExpert@gmail.com



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