"I have a viscometer, why do I need a rheometer"

Regional Sales Meeting 2022

Presented by: Field Applications

I Have a Viscometer,

Why do I Need a Rheometer?

Faster

More reliable

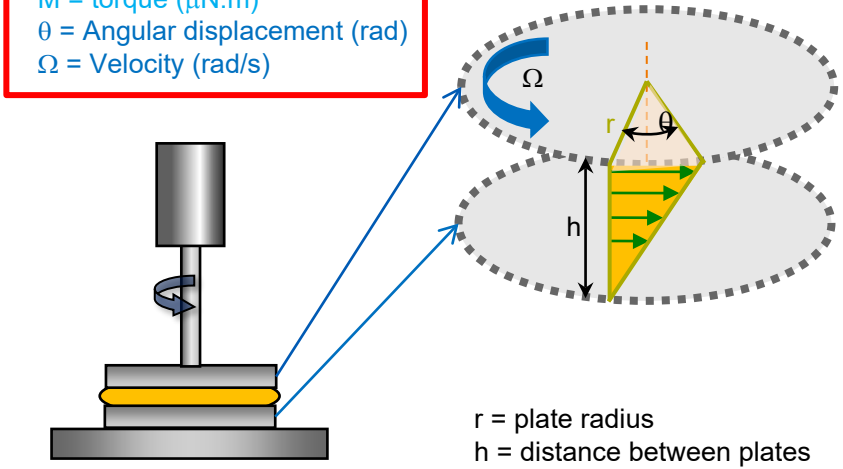
More sensitive

More capable

How does a rheometer work?

Instrument Signals

M = torque (μN.m)
θ = Angular displacement (rad)
Ω = Velocity (rad/s)



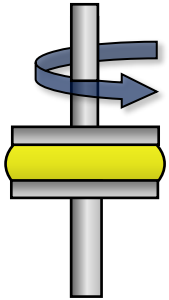
r = plate radius
h = distance between plates

Stress (σ) $\sigma = K_\sigma \times M$

Strain (γ) $\gamma = K_\gamma \times \theta$

Strain rate ($\dot{\gamma}$) $\dot{\gamma} = K_{\dot{\gamma}} \times \Omega$

Rheometers measure **flow** and **deformation**



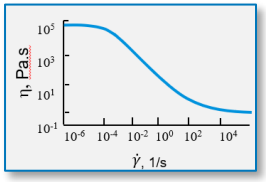
$$\frac{\text{Stress}}{\text{Shear rate}} = \text{Viscosity}$$

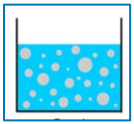
$$\frac{\text{Stress}}{\text{Strain}} = \text{Modulus}$$

What need does rheology fill for the customer?

Measure Flow & Deformation

- Viscosity
- Elasticity
- Yield stress
- Structure formation





Caused by

- Formulation
- Molecular Weight & Distribution
- Molecular structure
- Concentration
- Dispersion microstructure

Understand & Predict

- Processing Characteristics
- Sensory Perception
- Product Performance
- Storage Stability

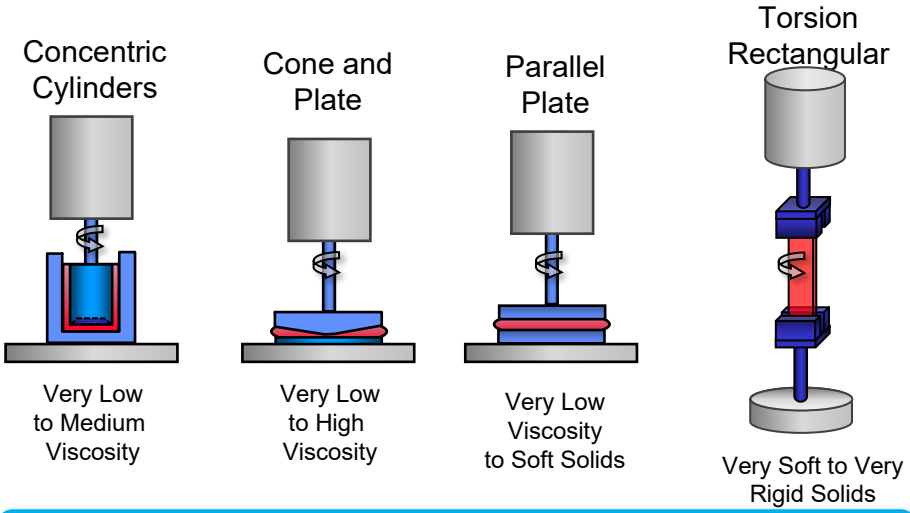
TA rheometers deliver outstanding torque sensitivity

- **N.m**
  - An apple (about 150 g) on the end of a meter stick
  - **1.5 N.m**

- **µN.m**
  - A grain of salt (about 0.5 mg) on the end of a meter stick)
  - **5 µN.m**

- **nanoN.m**
  - A speck of dust (1 µg) on the end of a meter stick
  - **10 nanoN.m**

Test Geometries



Geometries enable wide **viscosity** range (centipoise)

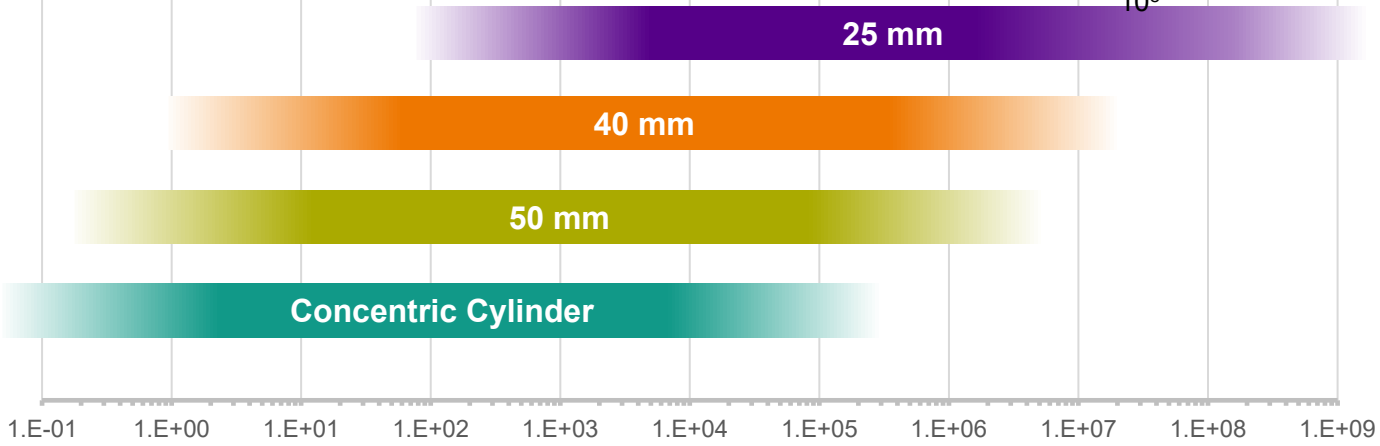
Water: 1

Olive Oil: 100

Honey: 10^4

Polymer Melt: 10^6

Asphalt Binder: 10^8



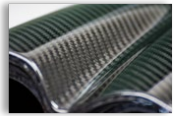
Geometries enable wide **modulus** range (Pa)


Suspensions


Hydrogel


Polymer Melt


Elastomer


Composite


Metal

Torsion

8 mm

25 mm

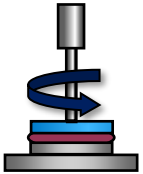
40 mm

Pa kPa MPa GPa TPa

1.E+00 1.E+01 1.E+02 1.E+03 1.E+04 1.E+05 1.E+06 1.E+07 1.E+08 1.E+09 1.E+10 1.E+11 1.E+12

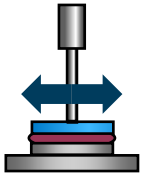
Rheology test methods measure critical material behaviors

Flow



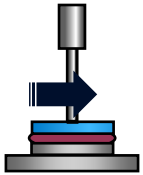
- **Rotational** deformation
- Measures **Viscosity**
  - Vary shear rate, shear stress, temperature

Oscillation



- **Sinusoidal** deformation
- Measures **Modulus, dynamic properties** (G', G", Tan Delta)
  - Vary strain, stress, frequency, temperature

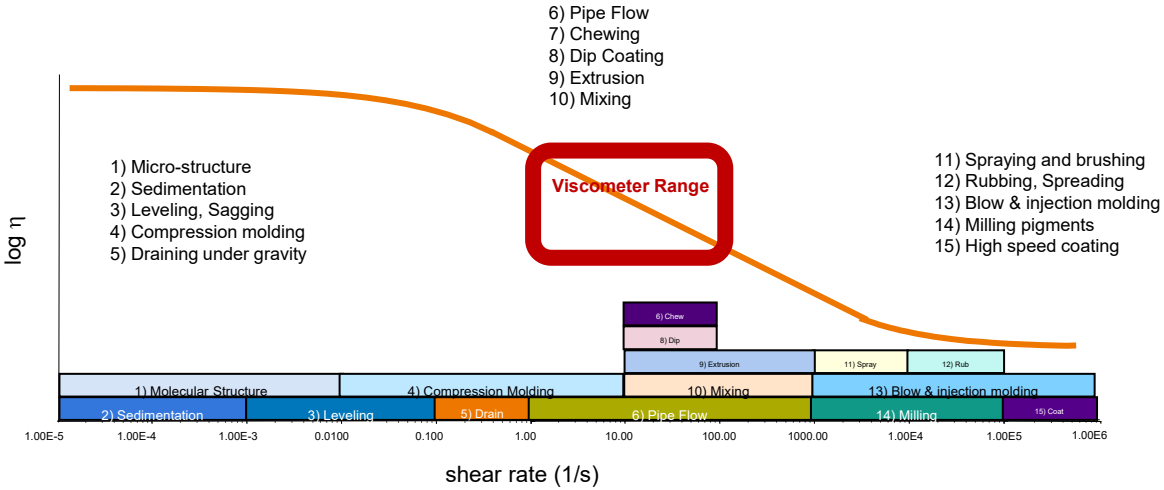
Transient



- **Constant stress** or **strain** deformation
- Measures **Compliance J(t)**, or **Relaxation Modulus G(t)**

Viscometer or Rheometer!

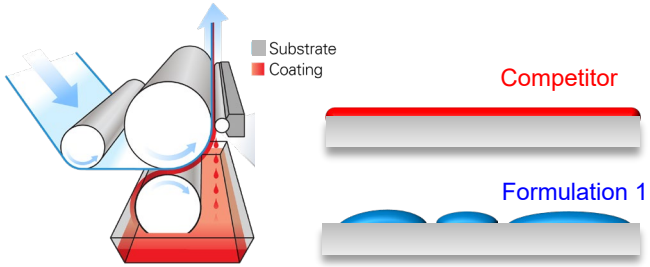
A **rheometer** is an instrument used to measure the way a liquid flows in response to applied stress, whereas a **viscometer** is an instrument used to measure the viscosity of a fluid.



A rheometer provides the whole flow curve, while a viscometer provide data at a very small portion of the flow curve

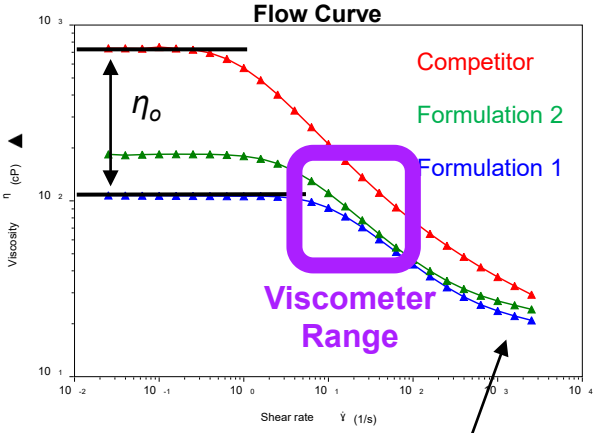
Optimizing liquid emulsion adhesive for high-speed coating

- User's **Formulation 1** under-performs the **Competitor's** product in high-speed coating process, leaving voids on the metal substrate
- User suspects issue with high-shear viscosity?



Solution: use rheology to evaluate new formulations and optimize performance

Insight: Low-shear viscosity is critical for coating performance

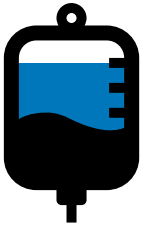


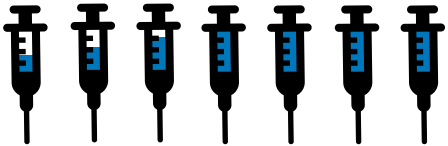
- Similar viscosity at high shear rate
- 8x difference in **Zero-Shear Viscosity** η_o
  - Related to flow at rest, ability to stay in place
  - Low-torque sensitivity critical for this application

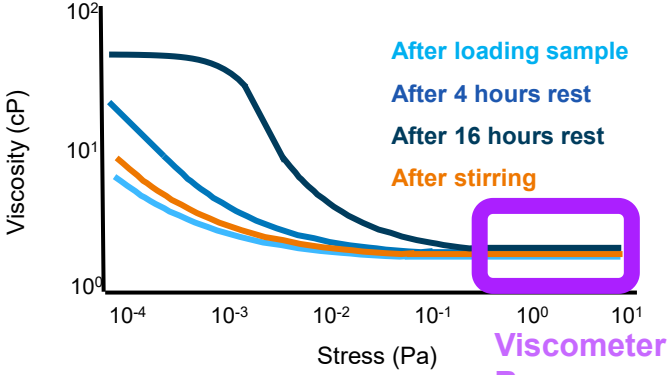
Solving a high-cost drug packaging problem

Insight: Time-dependent change in microstructure

- A break-through new biologic drug is being scaled-up for commercialization
- Syringes filled at the start of each day are underfilled
- Improperly-dosed syringes must be scrapped.
- Significant **loss of revenue**





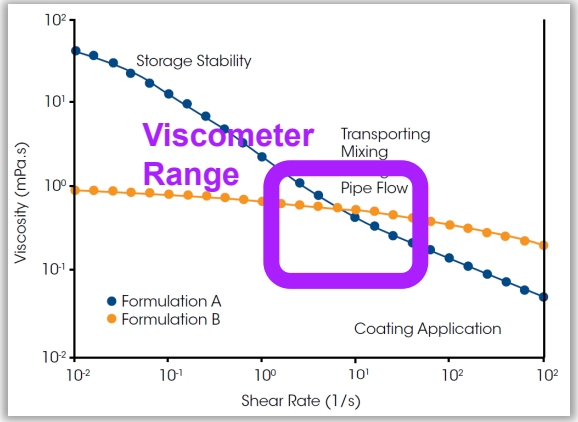


- At rest, suspension develops weak microstructure, creating a **yield stress**.
- At the start of production, flow is slower than expected, dispensing low volumes

Solution: Agitation of the bulk storage vessel prevents increase in yield stress

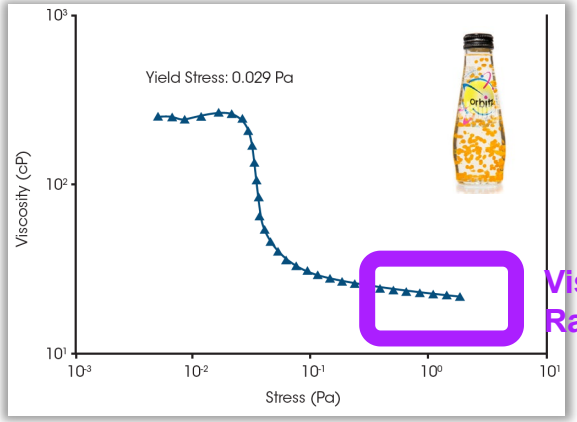
Flow measurements quantify observed behavior

Flow Curve to Predict Coating Stability



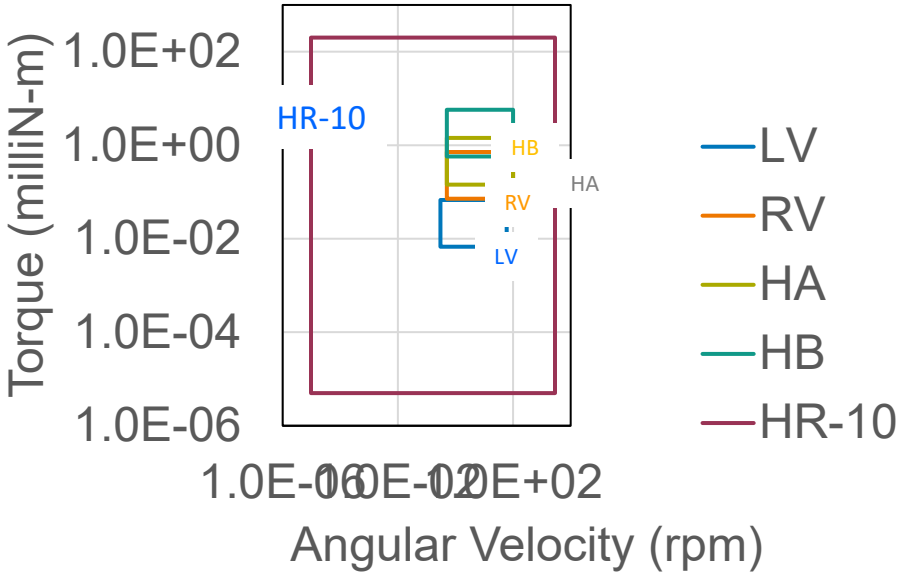
- Low shear rates: High viscosity provides storage stability
- High shear rates: Low viscosity enables fast coating
- Formulation A: Desirable rheological profile

Weak Yield Stress in a Suspension



- Engineered yield stress in complex fluids supports suspended phase, prevents settling/ agglomeration
- Example data on beverage: yield stress suspends dispersed phase; shear-thinning ensures pourability, drinkability

Comparison of Angular Velocity and Torque Ranges of HR-10 versus Common Viscometers



Compared with all the common viscometers, the HR-10 can get more than 2 decades lower in angular velocity and nearly 1 decade higher.
In terms of torque, the HR-10 can get about 3 decades lower and nearly 2 decades higher than the common viscometers.

Viscoelastic Parameters Obtained from Rheology

Complex Modulus:

Measure of materials overall resistance to deformation.

$$G^* = \frac{\sigma}{\gamma}$$

The Elastic (Storage) Modulus:

Measure of elasticity of material. The ability of the material to store energy.

$$G' = \left(\frac{\sigma}{\gamma}\right)\cos\delta$$

The Viscous (loss) Modulus:

The ability of the material to dissipate energy. Energy lost as heat.

$$G'' = \left(\frac{\sigma}{\gamma}\right)\sin\delta$$

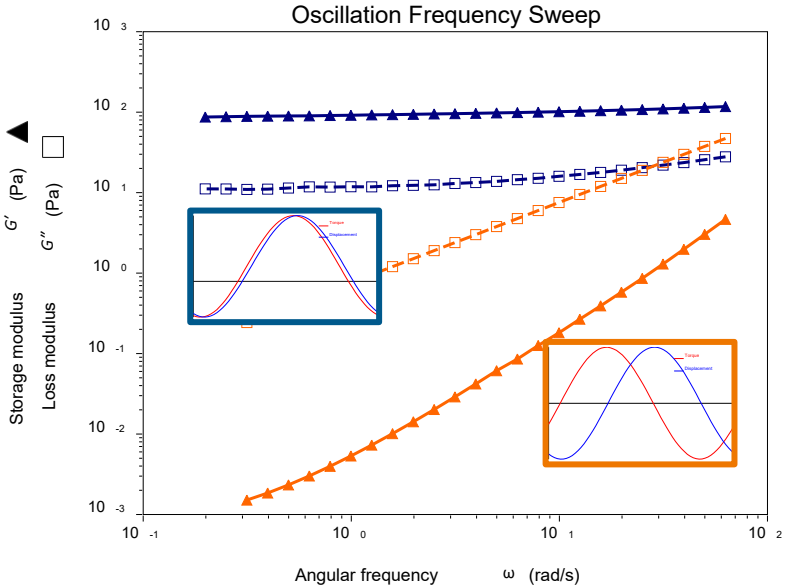
Tan Delta: Measure of material damping. Increasing tan d implies a greater potential for energy dissipation and lower elasticity, and vice-versa. Measure of viscous property while having the appropriate level of stiffness.

$$\tan\delta = \left(\frac{G''}{G'}\right)$$

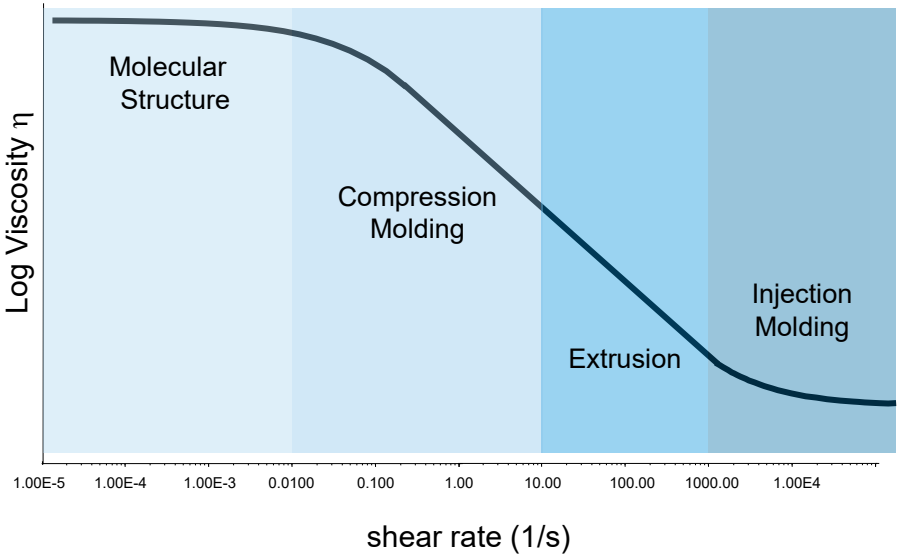
In **oscillation** measurement, which is more **elastic**?

Honey

Mayonnaise

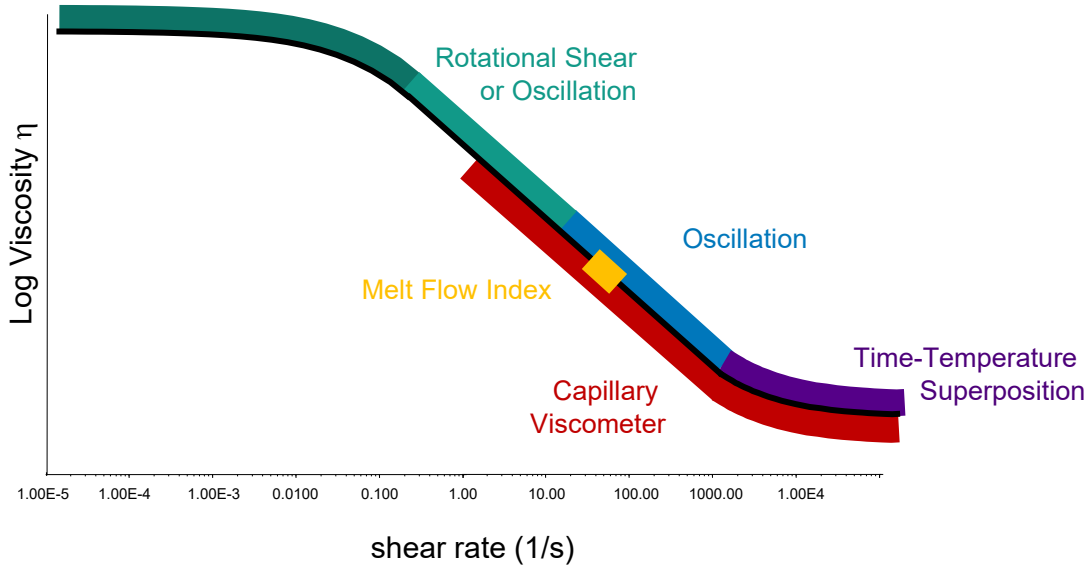


Viscosity Profile of Thermoplastics

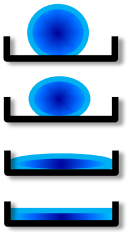


Viscosity Profile of Thermoplastics

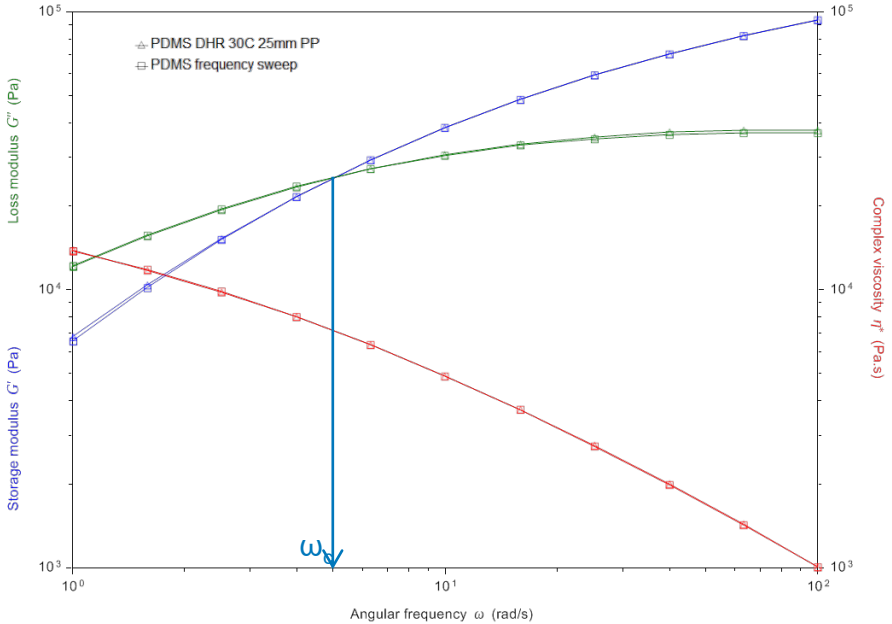
Testing Range of Rotational Rheometers and Capillary Rheometers

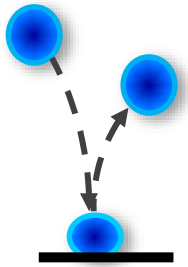


Frequency-dependent dynamic properties reveal time-scales of viscous vs. elastic behavior



t is long
[> $1/\omega_c$]





t is short
[< $1/\omega_c$]

Why do I need a Rheometer?

Reason	Why It's Useful
Shear Rate Range	Low Shear Rate Range → Stability, Sedimentation, Leveling Medium Shear Rate Range → Mixing, Pipe Flow High Shear Rate Range → Brushing, Roll Coating
Torque Range	7 decades of Torque Low Torque → Water High Torque → Some asphalt materials
Rate Ramp Up/Down	Common estimate of thixotropic (structure breakdown) nature of materials.
Stress Control	Yield stress for structured materials
Dynamic Oscillatory Testing	This is HUGE! These properties relate to: Stability Buildup of structure after flow Inherent strength of the structure "Non-Destructive" test to fingerprint formulations
Transient Tests	Creep and stress relaxation. Creep is useful for predicting the deformation of a material under a constant load during its usage.
Temperature Control	Superior temperature control for most accurate viscosity and modulus measurements
Accessories	Many fixtures to get viscosity and modulus values, along with other properties that might be important for predicting the performance of materials.

Thank You!