Zwick testXpo 2017

Optimizing rheology for paint and coating applications

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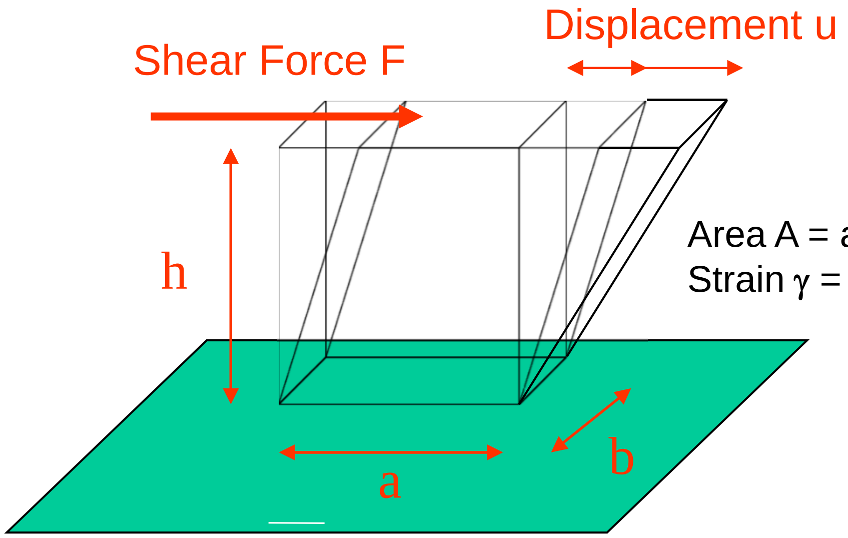
Outline

- Typical Process Conditions for Paints and Coatings
- How to measure the Viscosity?
- Impact of Particle Properties: Size, Volume, Polydispersity
- Storage Stability
- Summary

Shear Flow Properties: Overview of Basic Terms

- Temperature
- Pressure
- Shear Rate (Speed)
- Shear Stress (Force)
- Time



Area A = a• b
Strain $\gamma = u / h$

Dynamic Shear Viscosity*:

$$\eta\,(T, p, t, \dot{\gamma}) = \frac{\sigma}{\dot{\gamma}}$$

Unit: $[\eta] = 1$ Pas

$$\dot{\gamma} = \frac{d\gamma}{dt}$$ Shear rate [1/s]

$$\sigma = \frac{F_{\tan}}{A}$$ Shear stress [Pa=N/m^2]

* *Isothermal, isobaric, steady state dynamic shear viscosity of an incompressible, isotropic fluid*

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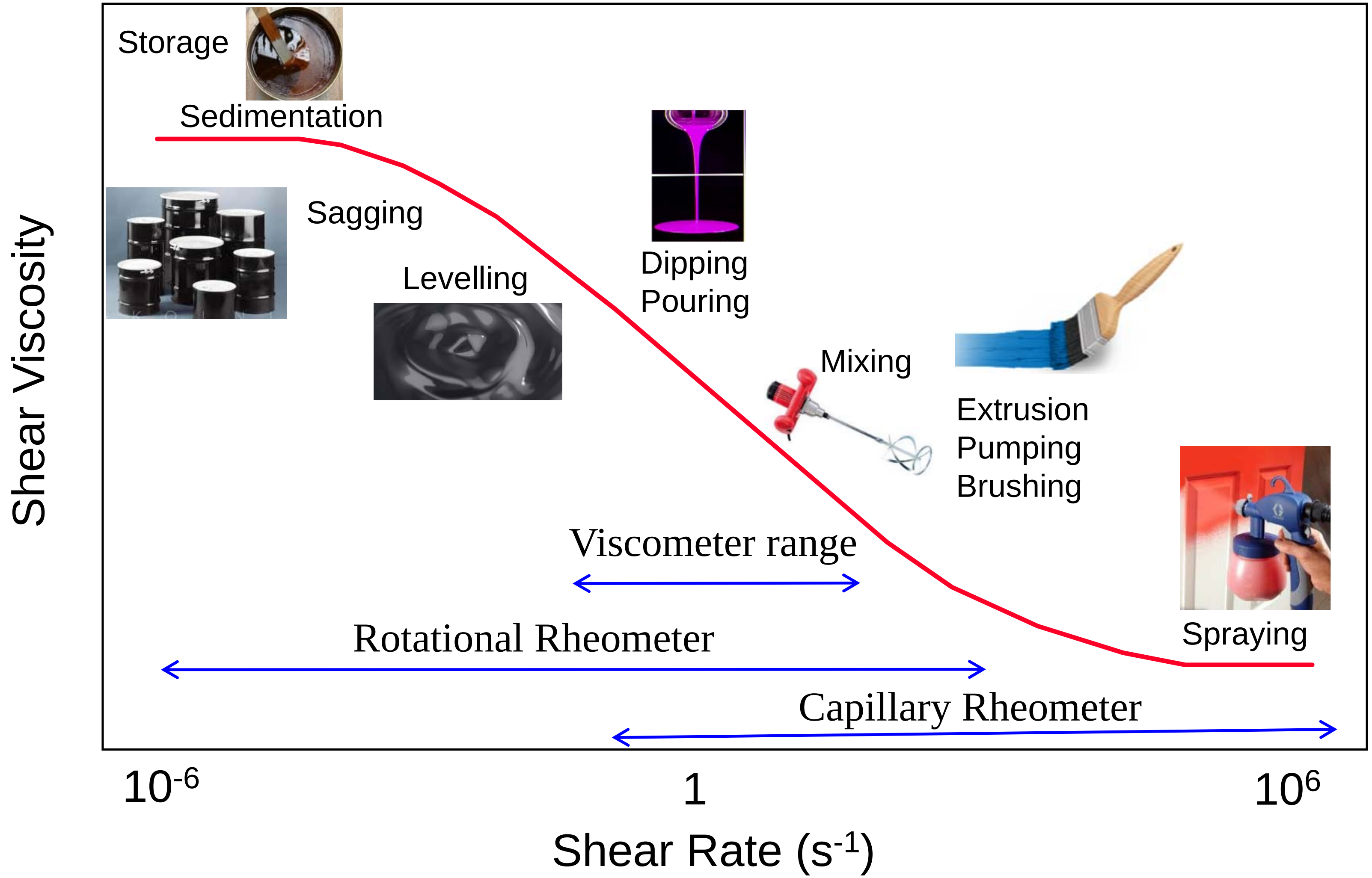
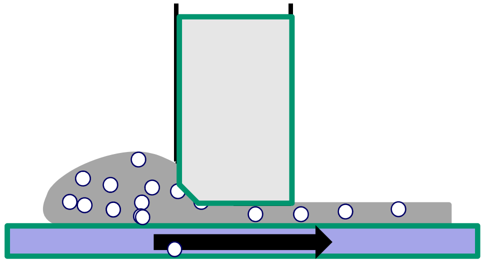
Typical Shear Rate Ranges for Paints and Coatings



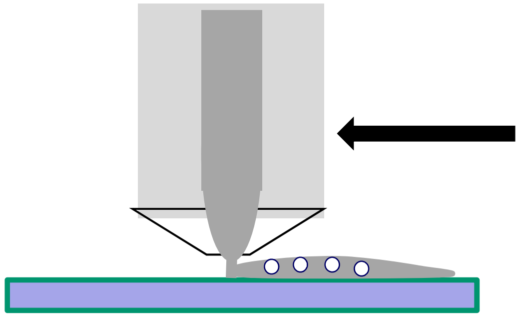
How to calculate the Shear Rates?

Blade Coating, Brushing



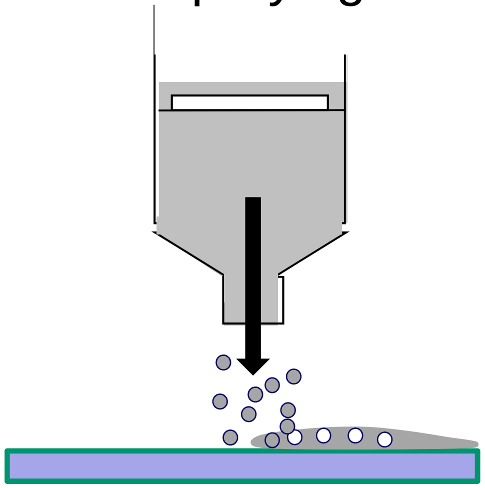
$$\dot{\gamma} = \frac{v}{h}$$

Slot Die Coating



$$\dot{\gamma}_{app} = \frac{6 \cdot Q}{b\,h^2}$$

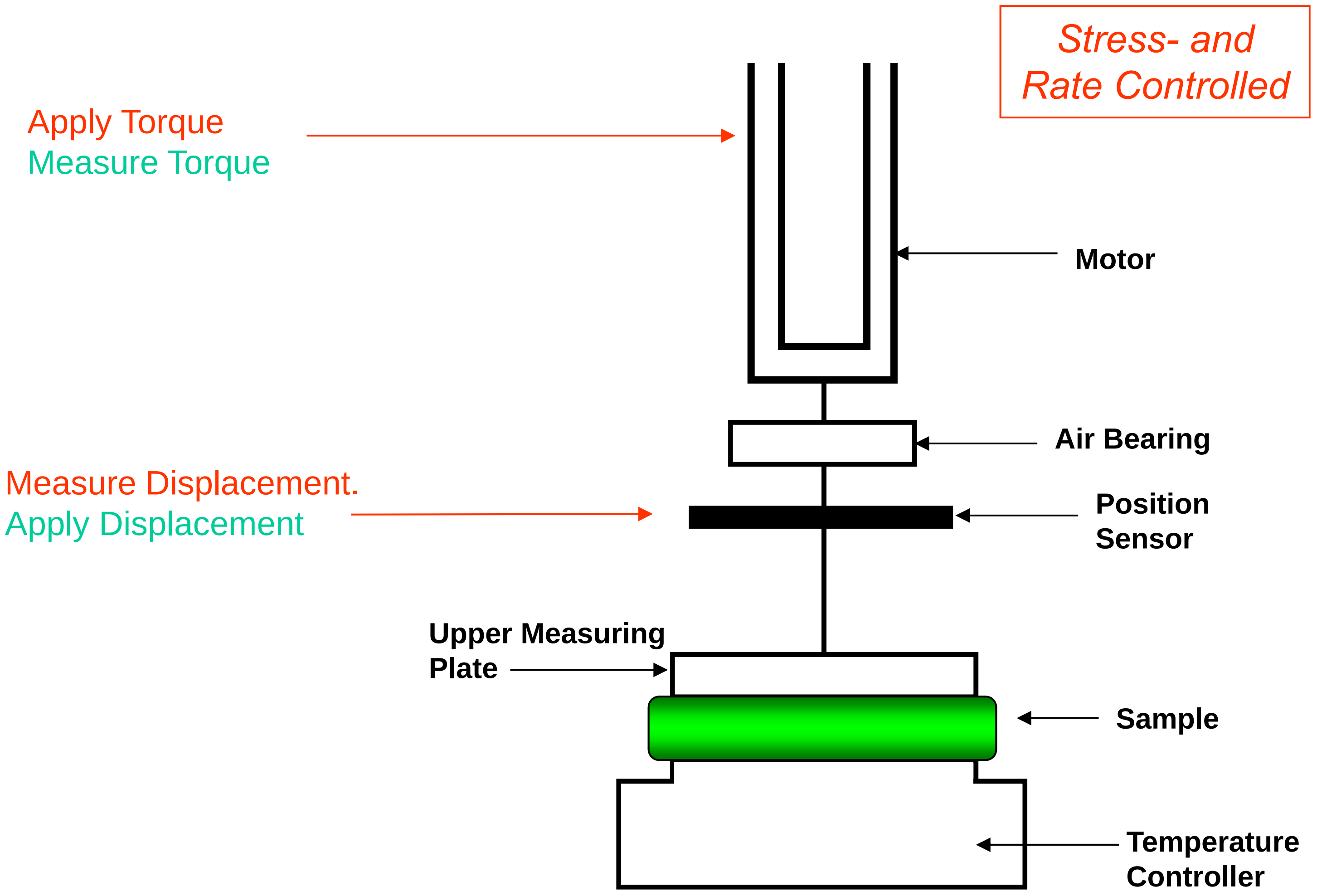
Spraying



$$\dot{\gamma}_{app} = \frac{4 \cdot Q}{\pi R^3}$$

Q = Volume Flux, R= Die Radius, L= Die Length, b= Slot Width
h=Slot Height, v=Velocity, h= Wet Layer Thickness

Principle of Operation: Rotational Rheometer



Stress- and Rate Controlled

Apply Torque
Measure Torque

Motor

Air Bearing

Measure Displacement.
Apply Displacement

Position Sensor

Upper Measuring Plate

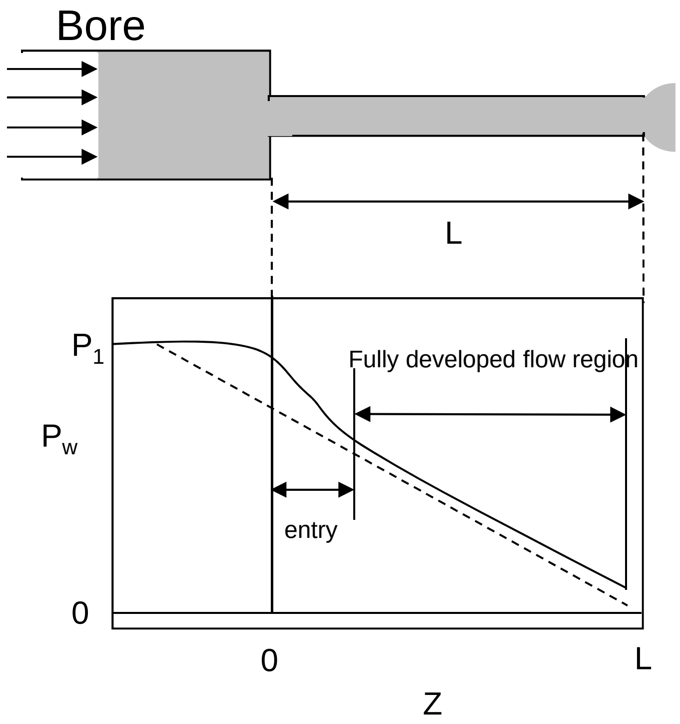
Sample

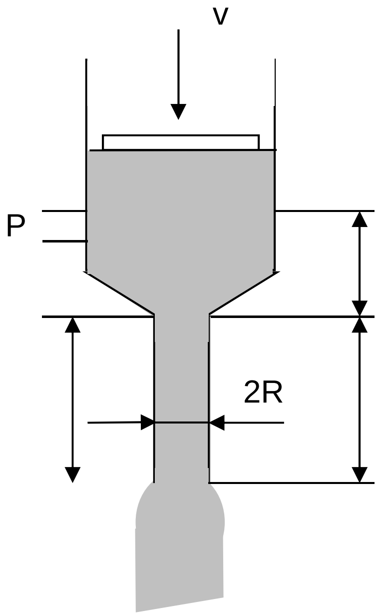
Temperature Controller

kinexus

Principle of Operation: Capillary Rheometer

Given quantity: piston speed $\Rightarrow$ wall shear rate
Measured quantity: pressure drop $\Rightarrow$ wall shear stress





Full pressure drop

=

Entrance pressure drop

+

Shear pressure drop

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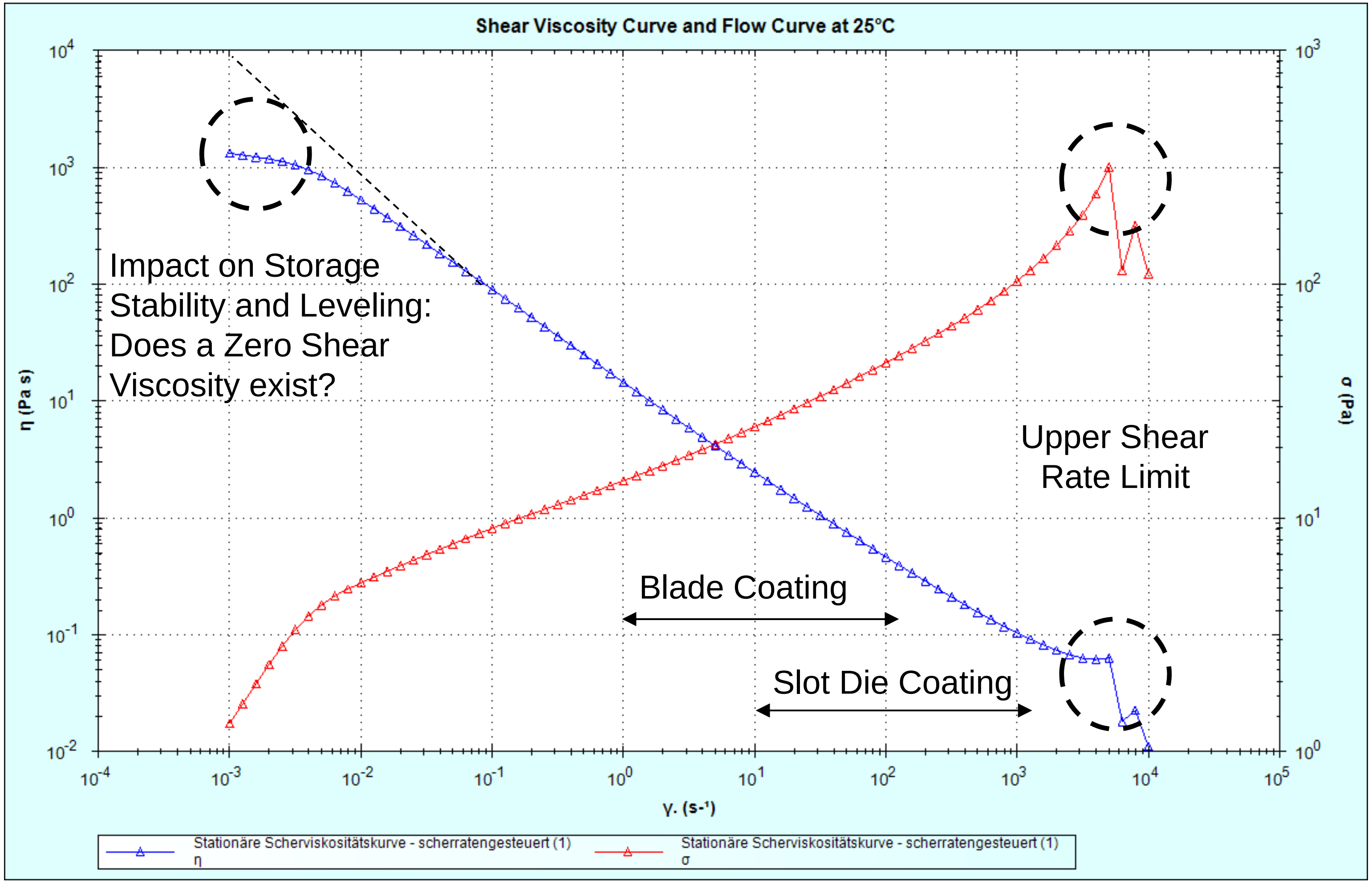
Interpretation of Shear Viscosity Curves of Coatings



Impact on Storage Stability and Leveling: Does a Zero Shear Viscosity exist?

Upper Shear Rate Limit

Blade Coating

Slot Die Coating

⇒ Low Shear Data needed for Stability Analysis
⇒ High Shear Limit: Stress must not drop with increasing Shear Rate

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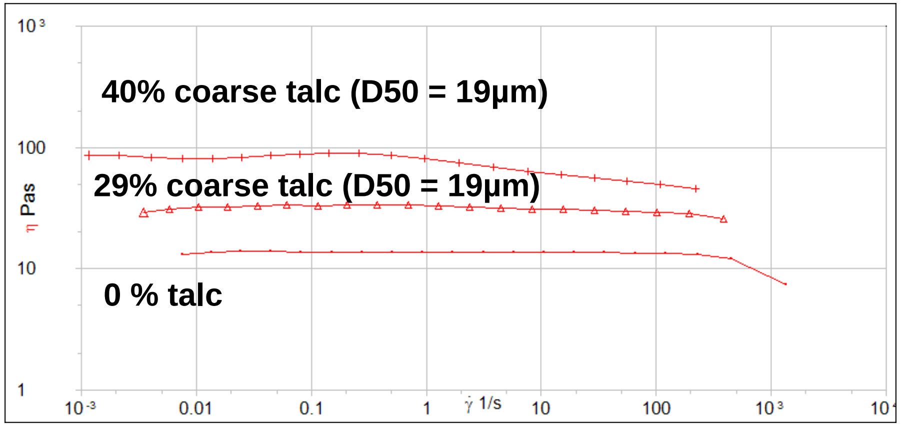
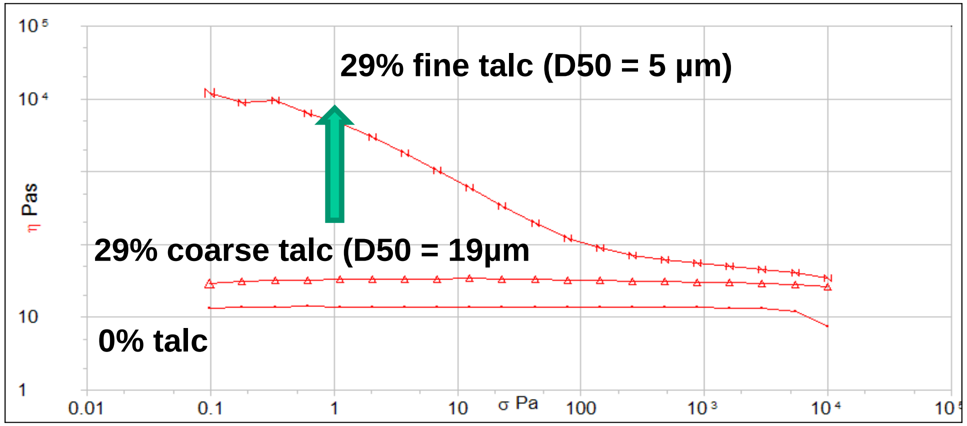
Optimizing Rheology of Coatings:
1. Impact of Adding Coarse or Fine Particles





- Small particles increase the low shear viscosity, as they have more surface area which gives more electrostatic and inter-particle forces.
- Note that the viscosity is almost independent of particle size at higher shear rates, as here hydrodynamic forces dominate

Optimizing Rheology for Coatings:
2. Impact of Particle Loading

- Changing the volume fraction of the particles….

Newtonian

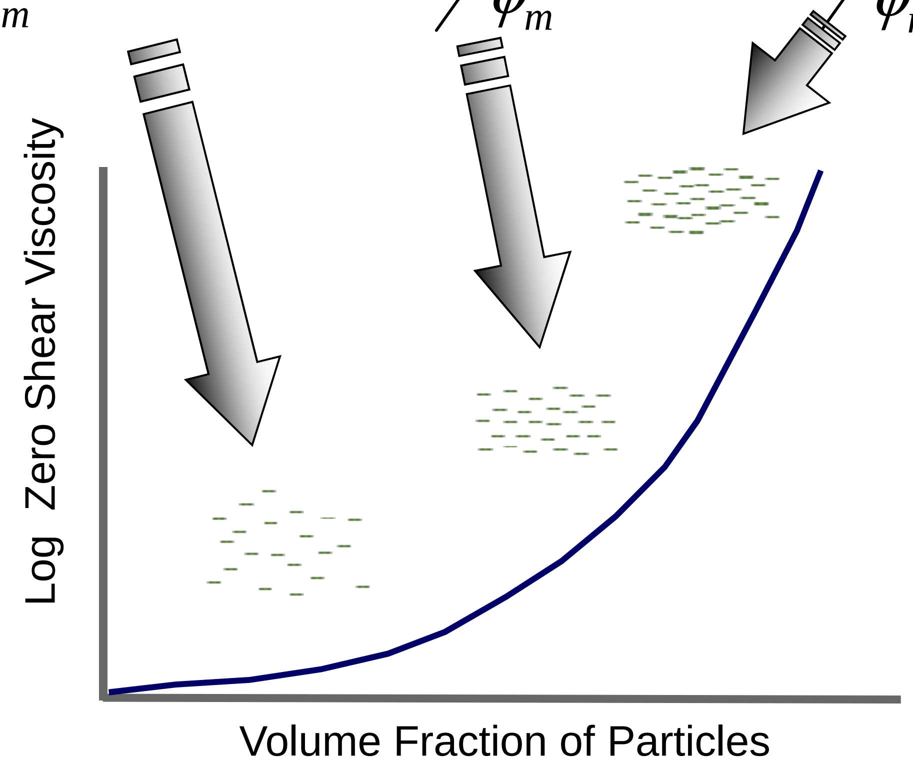
$$\phi/\phi_m < 0.1$$

Shear Thinning

$$0.1 < \phi/\phi_m < 0.5$$

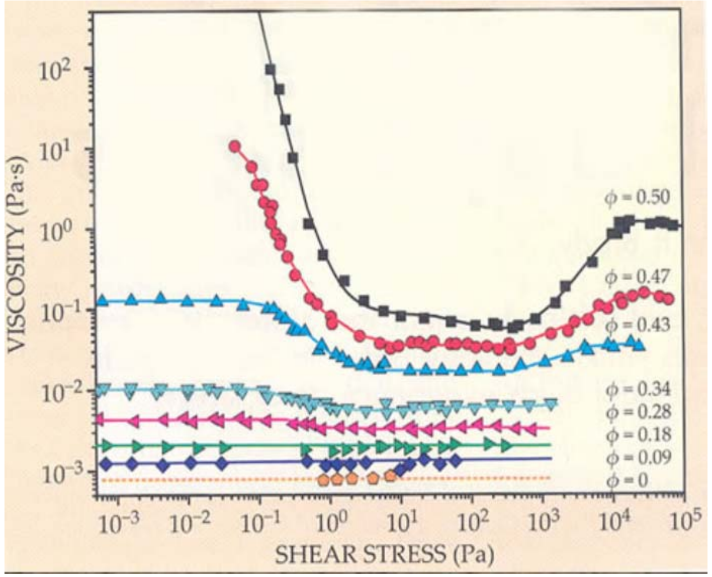
Shear Thickening

$$\phi/\phi_m > 0.5$$



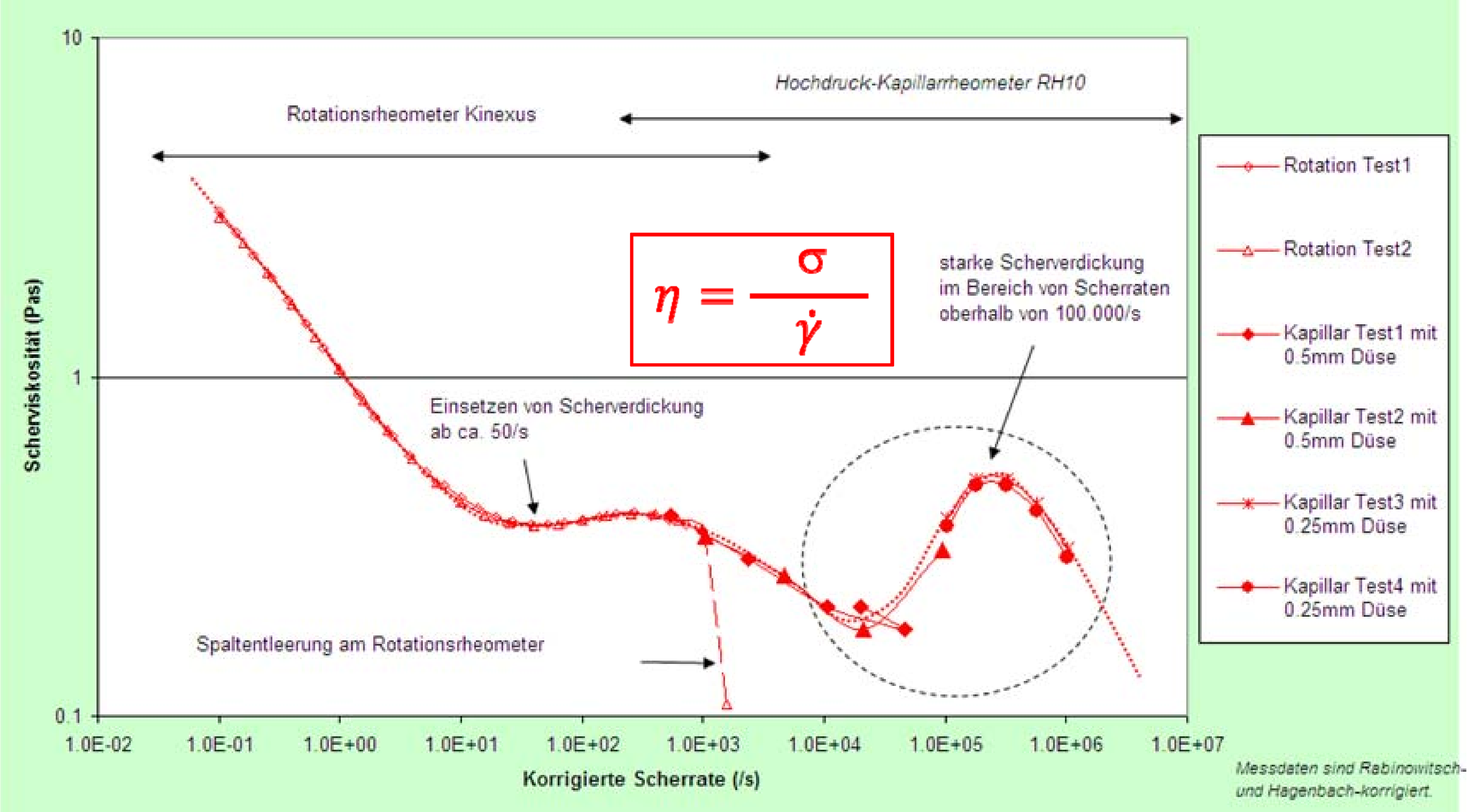
Krieger-Dougherty:

$$\frac{\eta}{\eta_{medium}} = \left(1-\frac{\phi}{\phi_m}\right)^{-[\eta]\phi_m}$$



Norman J. Wagner, J. B. (2009). Shear thickening in colloidal dispersions. *Physics Today* , 27-32.

Example: Shear Thickening of a Spray Coating

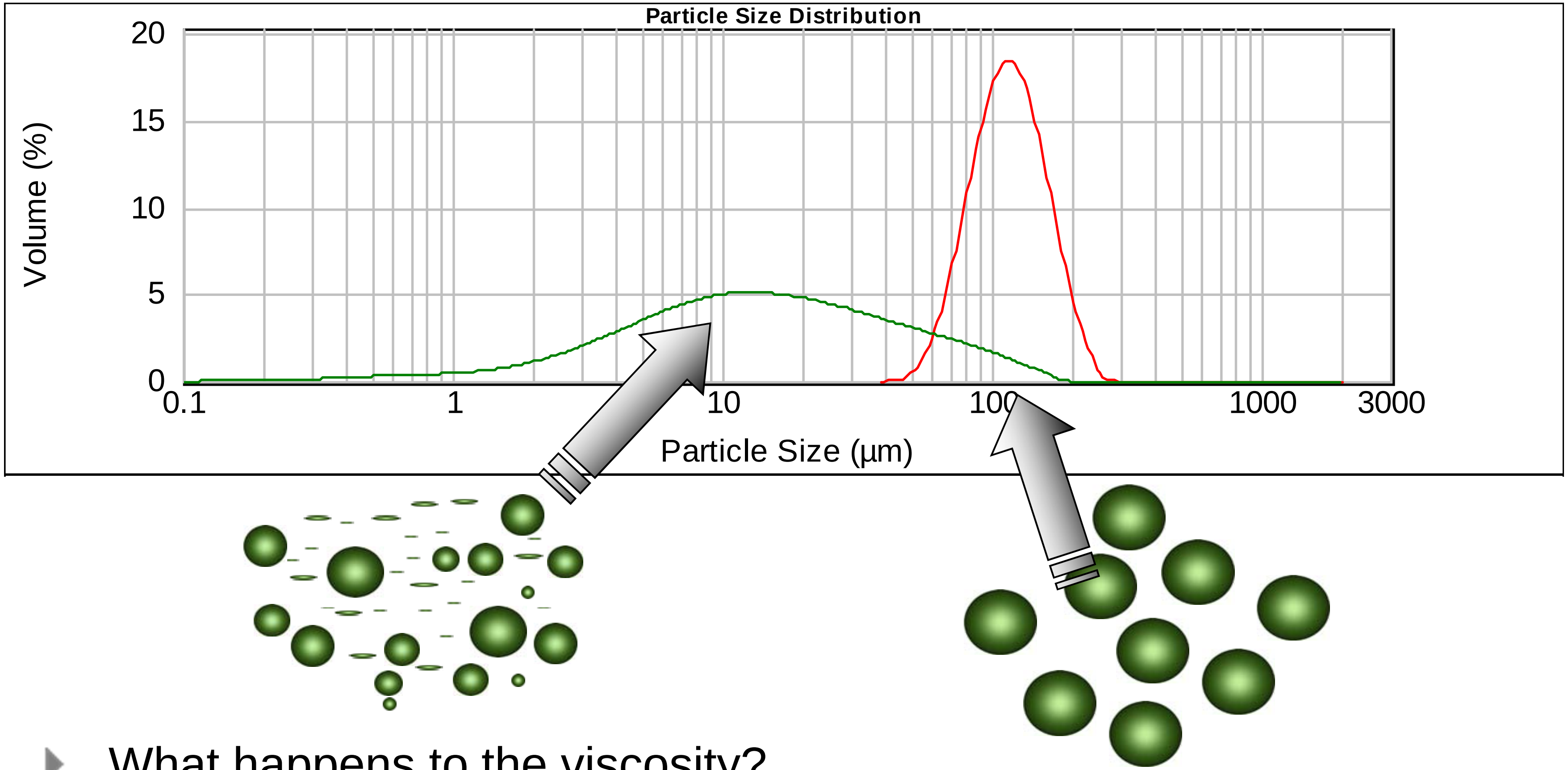


⇒ Shear Thickening at High Shear Rates: Critical for Spray Process

⇒ Strong Shear Thinning at Low Shear Rates: Defines the Structure Build-Up after Spraying

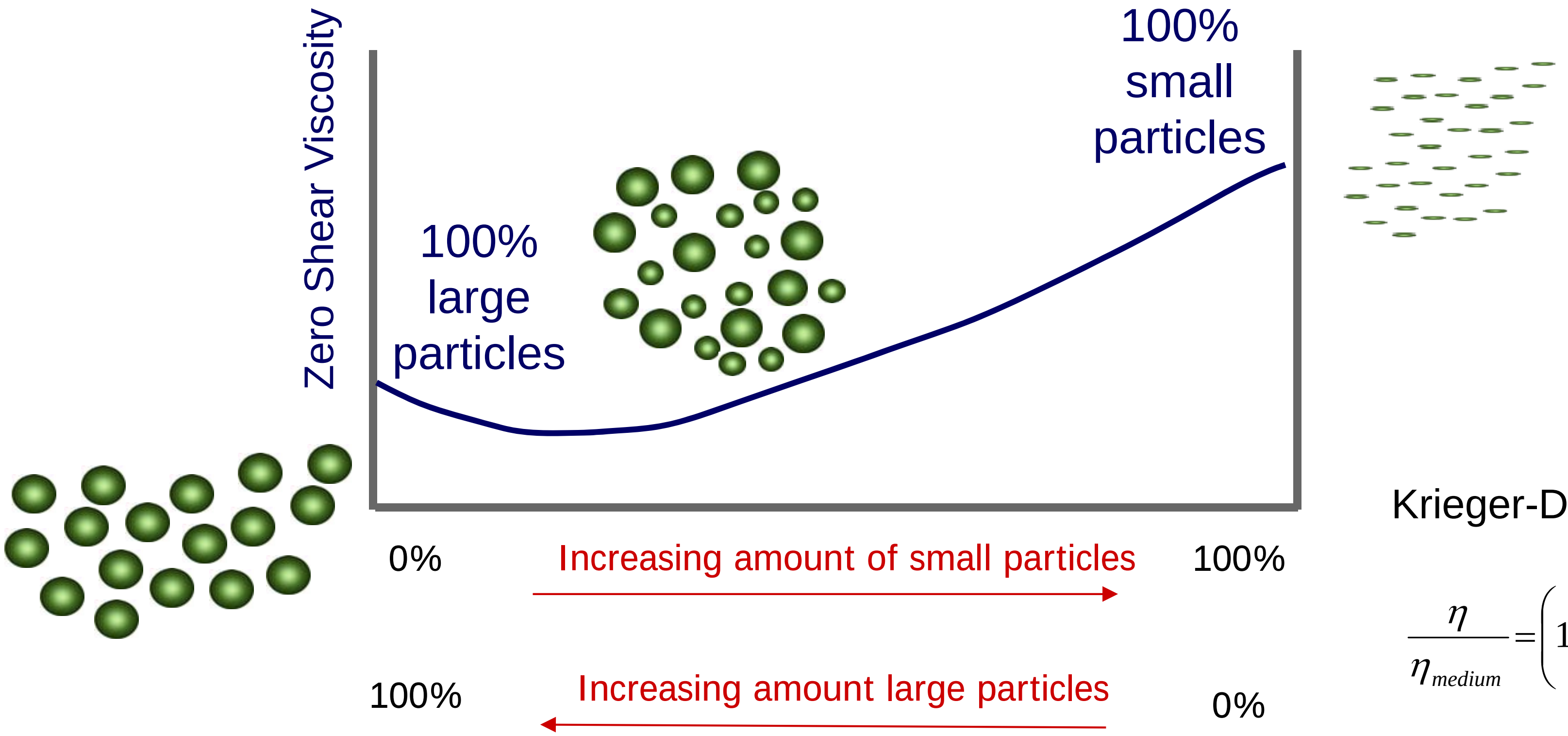
Optimizing Rheology for Coatings:
3. Impact of Polydispersity

- We keep the volume fraction (ϕ) constant
- But changing polydispersity…



- What happens to the viscosity?

Impact of Polydispersity on Flow Behaviour



Krieger-Dougherty

$$\frac{\eta}{\eta_{medium}} = \left(1 - \frac{\phi}{\phi_m}\right)^{-[\eta]\phi_m}$$

- If you want to increase the solid content of the sample but keep the viscosity the same, increase the particle size distribution (polydispersity) as well.
- Conversely, narrow the particle size distribution to increase the viscosity.

Further Factors affecting Coating Rheology

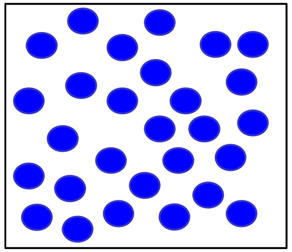
Laser Diffraction

Spray Particle Analyzer

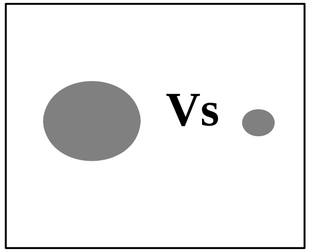
Light Scattering

Size and Zeta

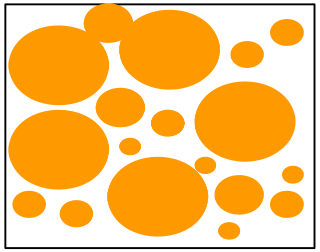
Volume fraction ϕ



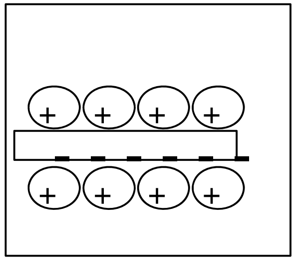
Particle size



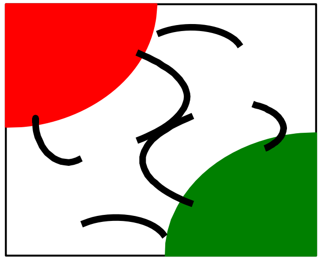
Particle size distribution



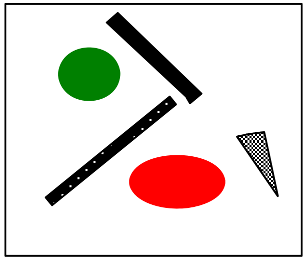
Electrostatic interactions



Steric Hindrance



Particle shape



Digital Microscopy

Dry

Wet

Storage Stability: Importance of Zero Shear Viscosity

Shear Stress by Gravity:

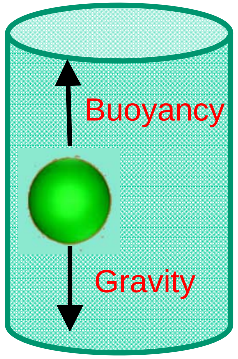
$$\sigma = \frac{F}{A} = \frac{m \cdot g}{A} = \frac{(\rho_1 - \rho_2) \cdot V \cdot g}{A}$$

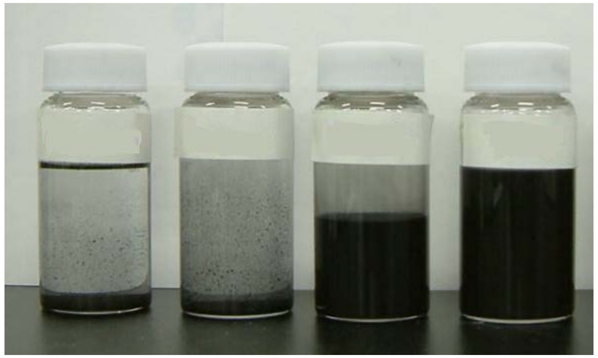
$$= \frac{(\rho_1 - \rho_2) \cdot \frac{4}{3} \cdot \pi \cdot r^3 \cdot g}{4 \cdot \pi \cdot r^2}$$

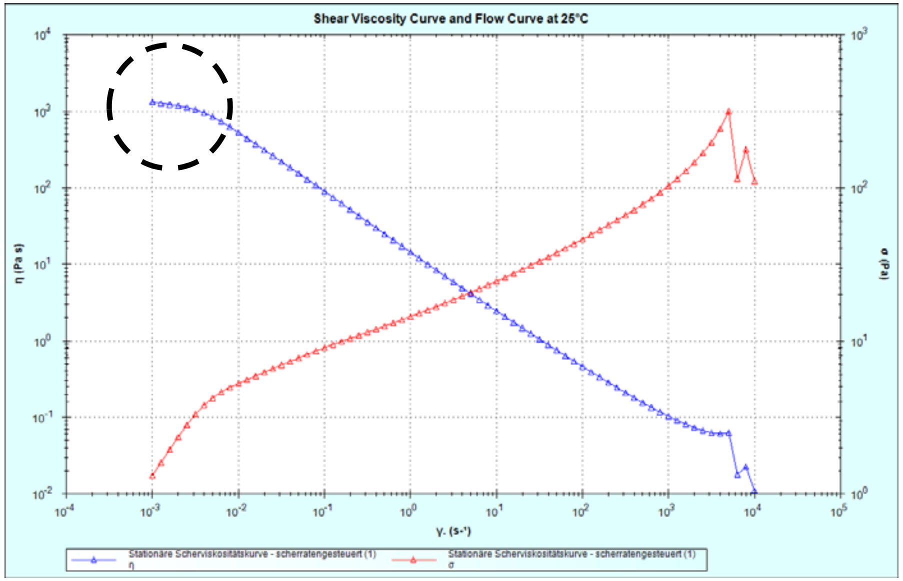
$$= \frac{(\rho_1 - \rho_2) \cdot r \cdot g}{3}$$

Settling Speed:

$$v = \frac{2}{9} \cdot \frac{(\rho 1 - \rho 2) \cdot r^2 g}{\eta}$$







v = *settling speed, r= particle radius,* ρ_1 = density of the particle
ρ_2 = *density of the fluid, g = gravitational acceleration*
η = *dynamic shear viscosity*

Summary

- Rotational and Capillary Rheometry cover the typical Processing Conditions for Paints and Coatings

- Shear Viscosity Function related to Particle Properties (Size, Polydispersity, Volume)

- Storage Stability: Importance of Zero Shear Viscosity

Any Questions?

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