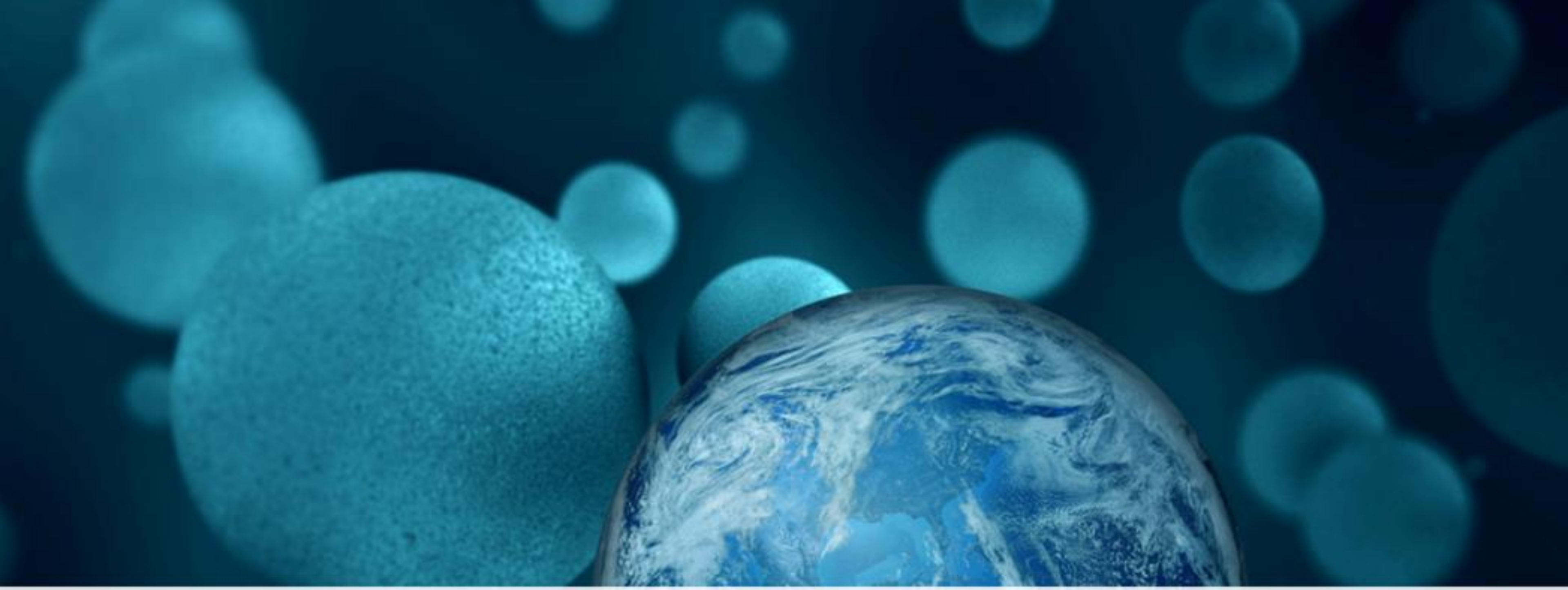

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Rotational Experiement

Mr. Prompong Tansawet / Sales Manager
(089) 923-2804 prompong@lmsinstr.com
LMS Instruments Co., Ltd.
02-612-9091 to 2

The basics of rheology and rotational rheometry

Content

- Definition of basic rheological parameters
  - Viscosity and elasticity
  - Deformation, shear stress and shear rate
- Parameters and factors affecting the viscosity
  - Temperature
  - Shear rate (Newtonian and non-Newtonian behavior)
  - Time and shear time (thixotropic behavior)

Definition of basic rheological parameters

Rheology and viscosity

Rheology

Rheology is the study of deformation and flow of matter

Viscosity

Viscosity is a measure for the resistance of a material against deformation and flow

Definition of basic rheological parameters

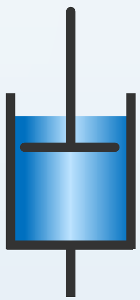
Viscosity and elasticity

Viscous behavior

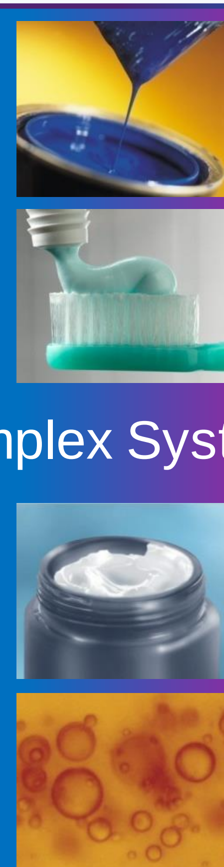
irreversible flow:

all applied energy dissipates completely

Dashpot:



Investigated mainly with tests performed in rotation



Complex Systems

Elastic behavior

reversible deformation:

all applied energy is stored in the system

Spring:

Investigated mainly with tests performed in oscillation

Definition of basic rheological parameters

Calculation of the dynamic viscosity

Viscosity cannot be measured directly!

$$\text{Viscosity } \eta = \frac{\text{Shear stress } \tau}{\text{Shear rate } \dot{\gamma}}$$

Units

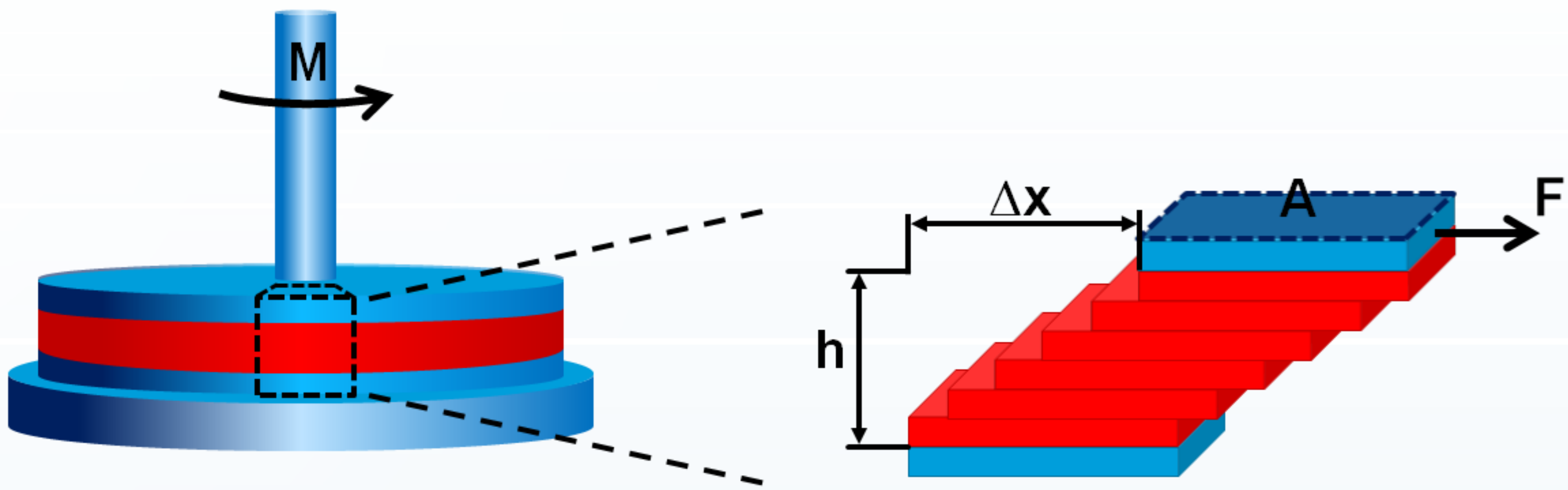
Shear stress τ: Pascal (Pa)

Shear rate $\dot{\gamma}$: 1/s

Viscosity η: 1 Pa·s = 1000 mPa·s = 1000 centi Poise (cP)

Definition of basic rheological parameters

Calculation of the dynamic viscosity



Shear stress:

$$\tau = \frac{\text{Force } F}{\text{Area } A}$$

Unit: Pascal (Pa)

Deformation:

$$\gamma = \frac{\text{Displacement } \Delta x}{\text{Gap } h}$$

Unit: - or %

Shear rate:

$$\dot{\gamma} = \frac{\text{Change in deformation } d\gamma}{\text{Time } t}$$

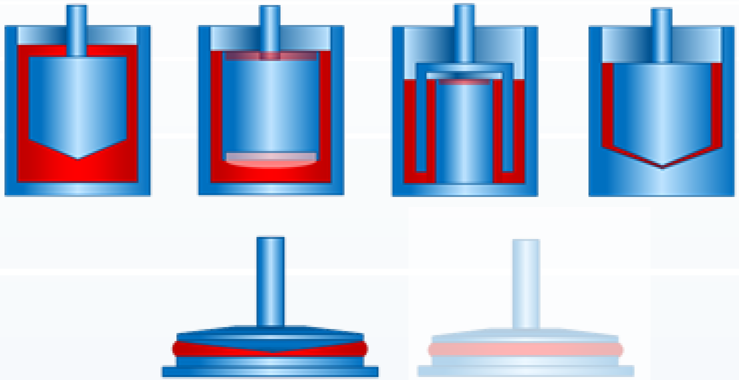
Unit: 1/s

Definition of basic rheological parameters

Experimental determination of the viscosity

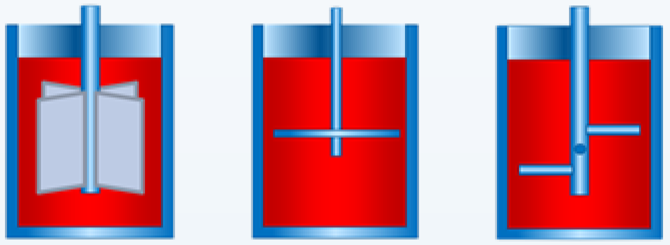
Absolute Measurement

The geometry factors A and M can be calculated for the measuring geometry



Relative Measurements

The geometry factors A und M can not (entirely) be calculated for the measuring geometry



Parameters and factors affecting viscosity

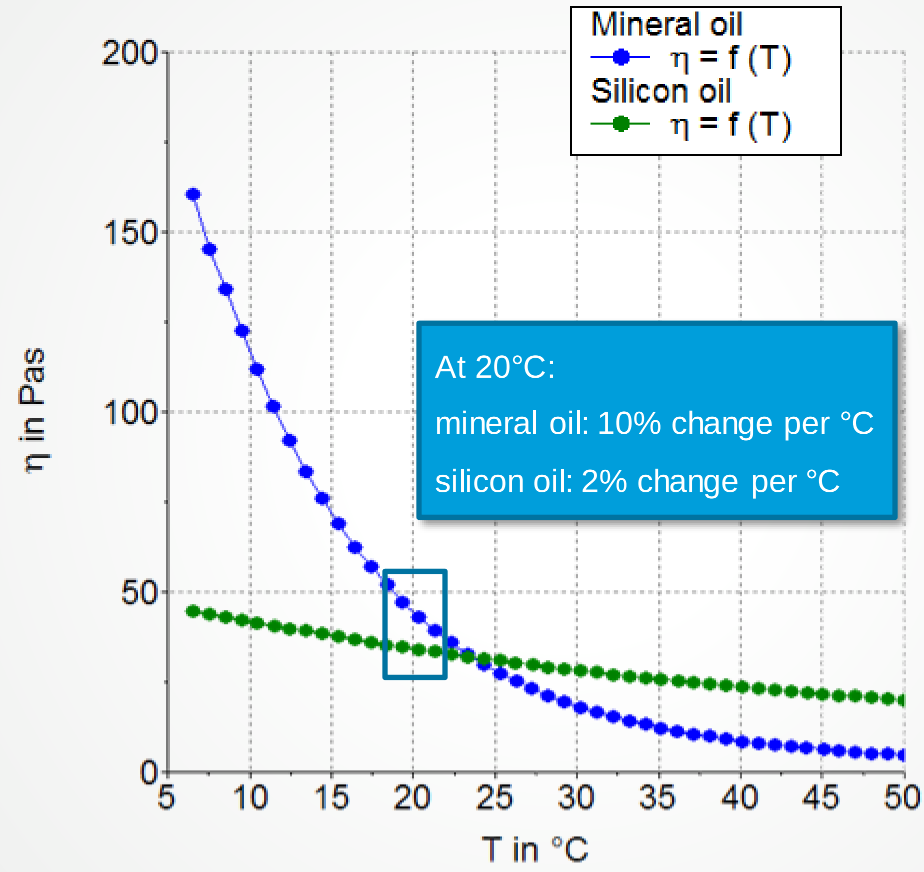
Viscosity is not a constant term

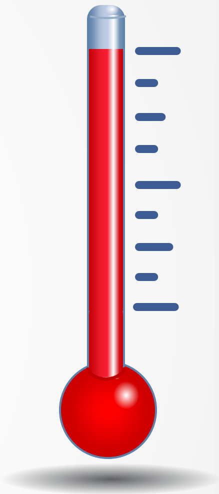
Parameters and factors affecting viscosity

Temperature depending flow behavior

Temperature depending viscosity of two standard fluids

- The higher the absolute value of the viscosity, the higher the temperature dependency
- Different fluids show different temperature dependency





Parameters and factors affecting viscosity

Viscosity is not a constant term

Parameters and factors affecting viscosity

Shear rate depending flow behavior

- Fluids whose viscosity is independent of the applied shear rate are called Newtonian fluids

- Most complex fluids as well as semi solid materials usually show a non-Newtonian behavior

- There are several different types of non-Newtonian behavior

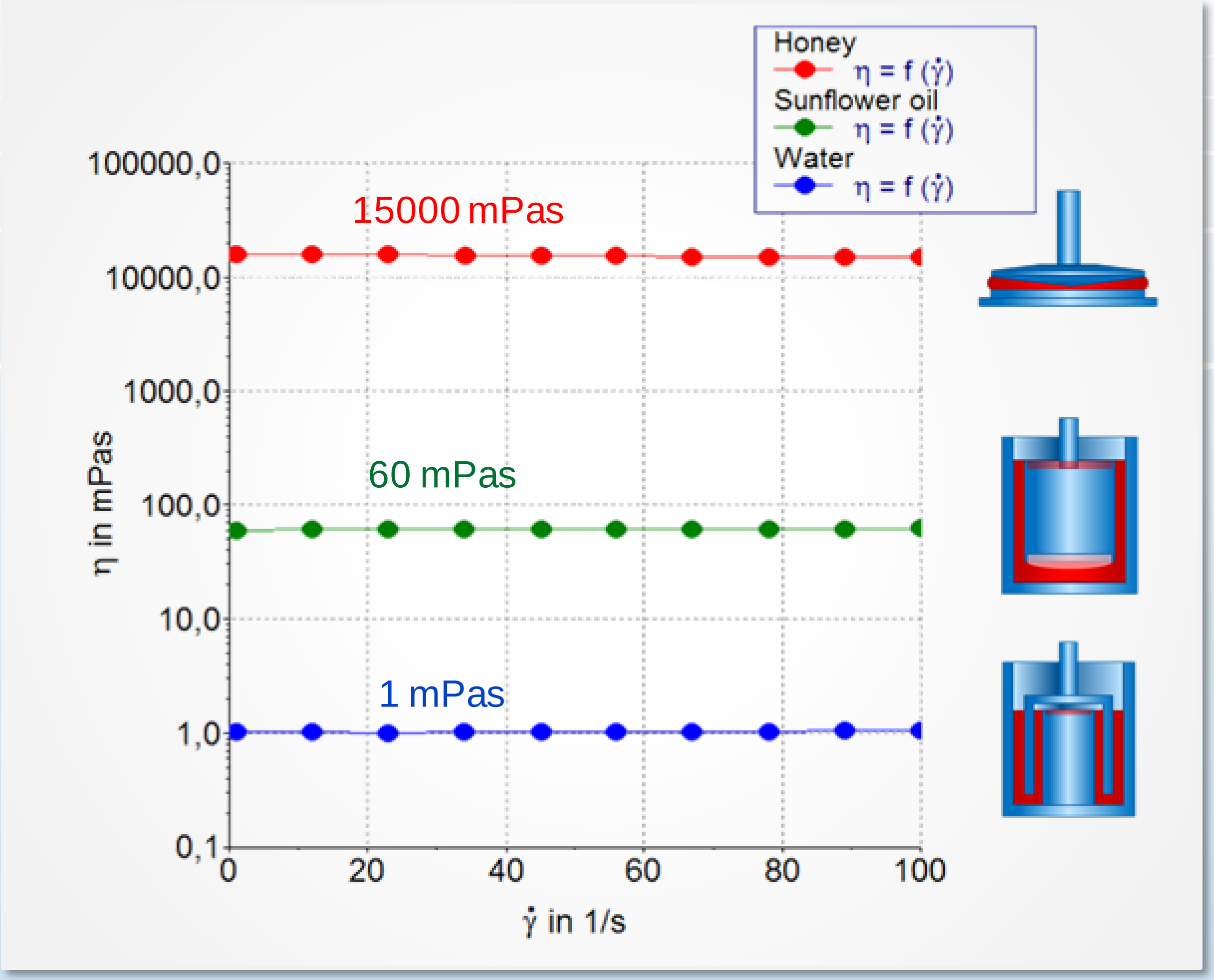
Parameters and factors affecting viscosity

Shear rate depending flow behavior

Newtonian flow behavior

$\eta \neq f(\dot{\gamma})$

- The viscosity is independent of the applied shear rate
- Only 'simple' fluids show a completely Newtonian behavior
- More complex fluids have a shear rate depending viscosity



Parameters and factors affecting viscosity

Shear rate depending flow behavior

Application	Shear rate in s^{-1}	
Sedimentation	10^{-6} - 10^{-4}	Storage, shelf life and post application
Phase separation	10^{-6} - 10^{-4}	
Leveling, running	10^{-1} - 10^{1}	**Slow Processes**
Extrusion	10^{0} - 10^{2}	Processing and application
Dip coating	10^{1} - 10^{2}	
Chewing	10^{1} - 10^{2}	
Pumping, stirring	10^{1} - 10^{3}	
Brushing	10^{1} - 10^{4}	
Spraying	10^{3} - 10^{4}	***Fast Processes***

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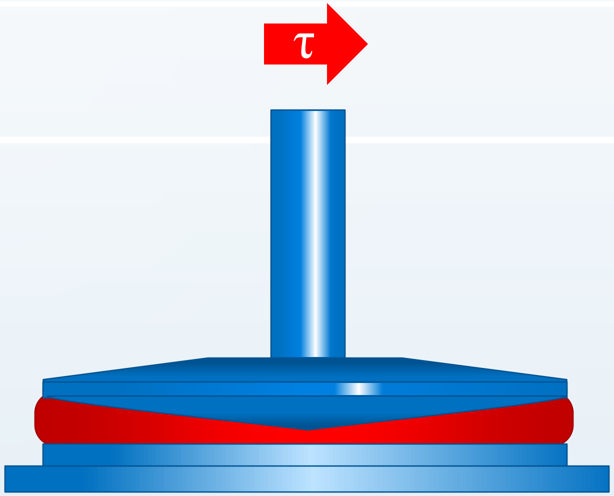
Parameters and factors affecting viscosity

Shear rate depending flow behavior

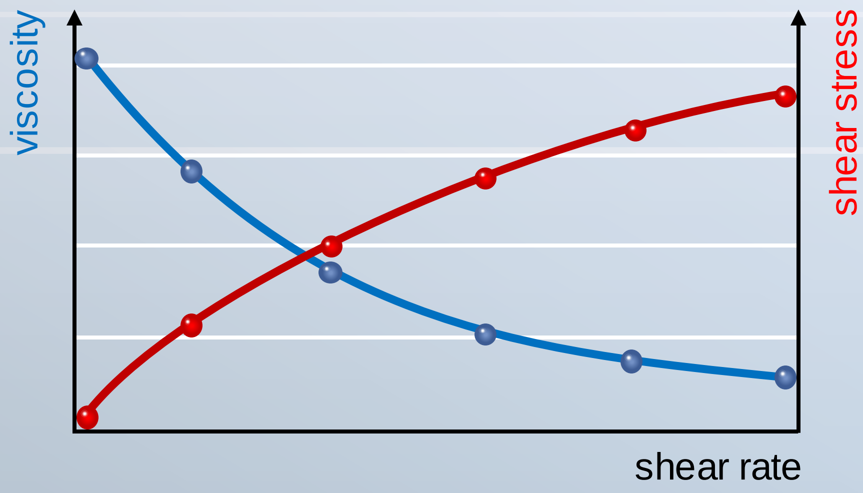
Non-Newtonian flow behavior

$$\eta = f(\dot{\gamma})$$



- Most complex fluids like solutions, emulsions or suspensions

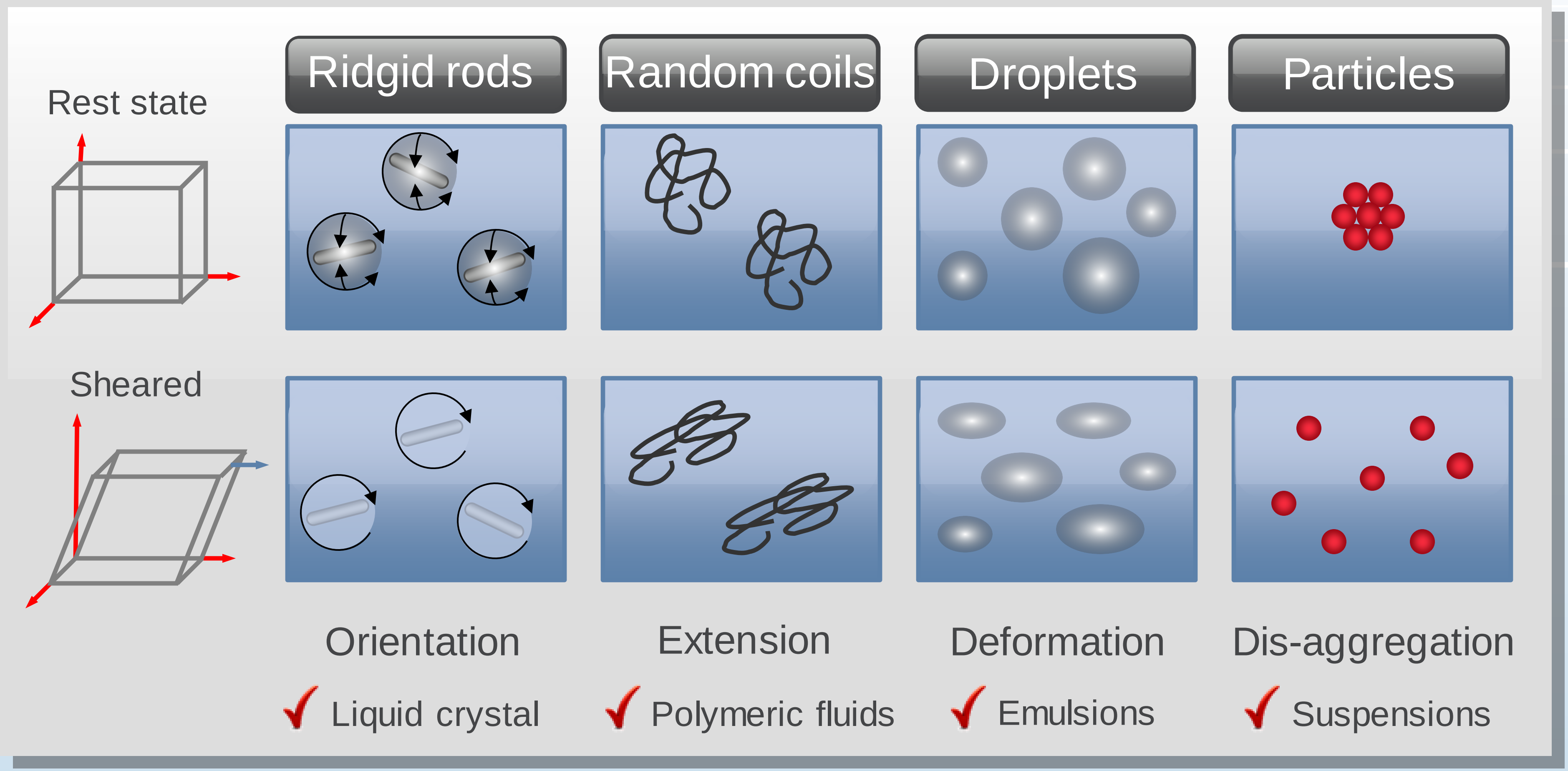
Shear thinning



The viscosity decreases with increasing shear rate

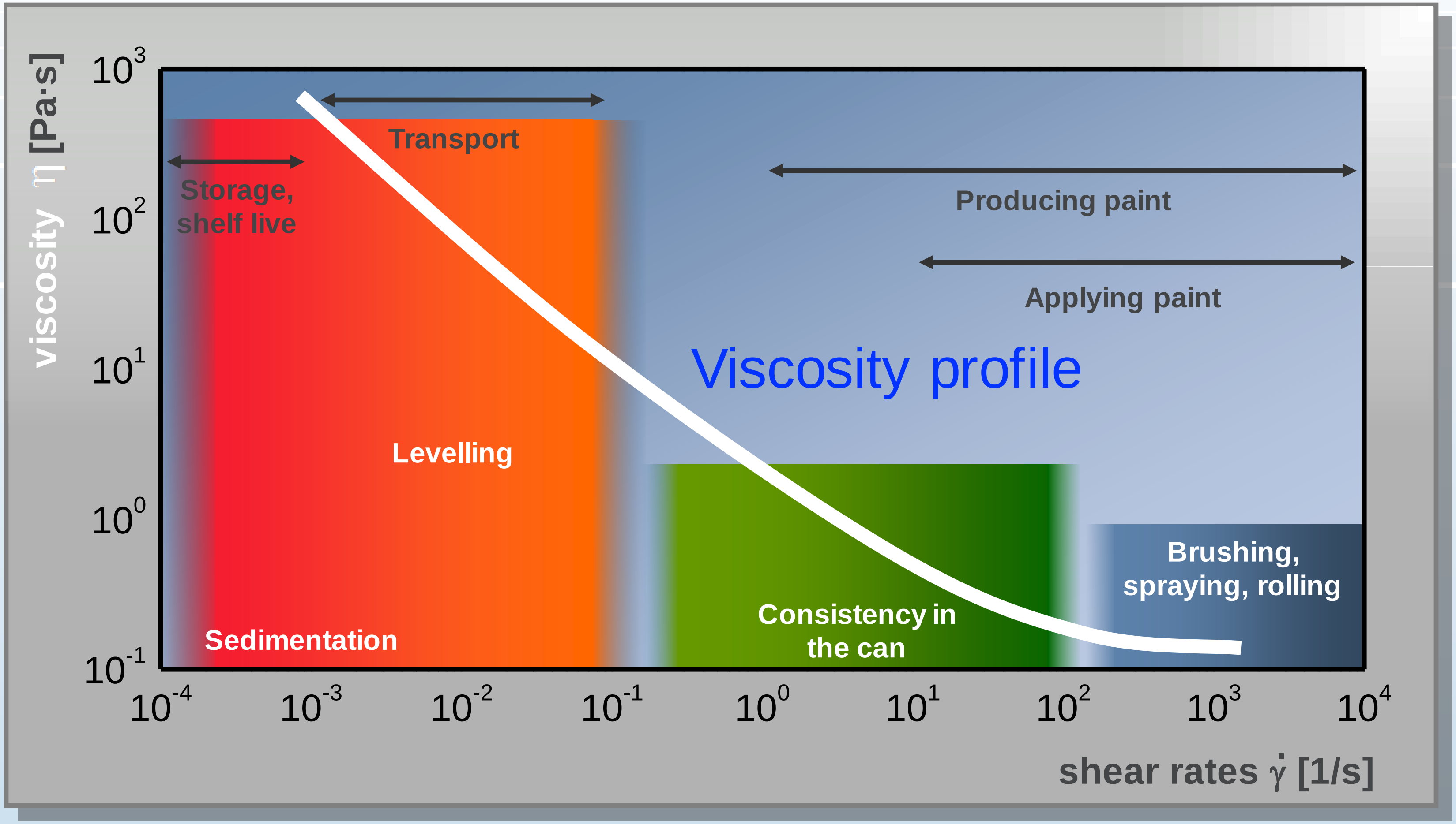
Newtonian and Non-Newtonian flow behavior

Shear thinning flow behavior



Newtonian and Non-Newtonian Flow (viscosity) curve

Shear rates for different paint applications



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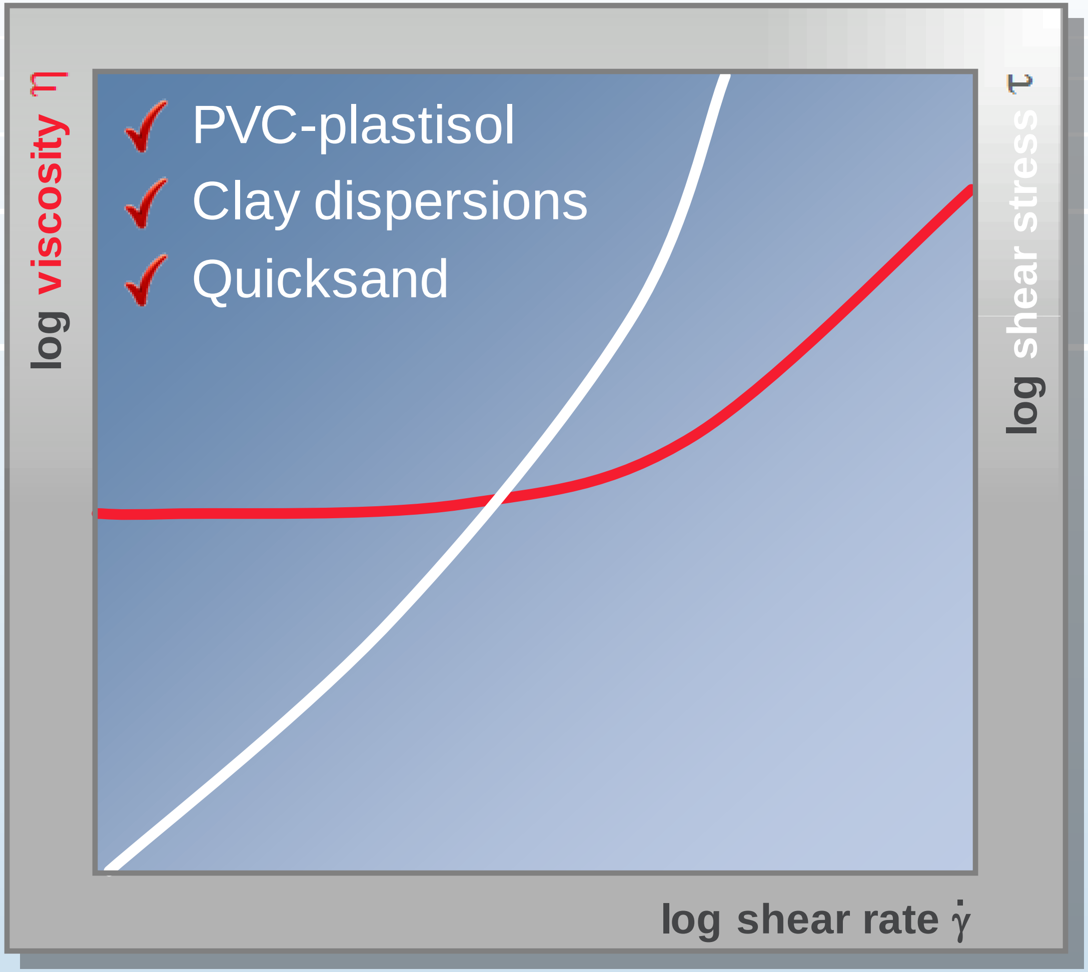
Newtonian and Non-Newtonian flow behavior

Dilatant flow behavior



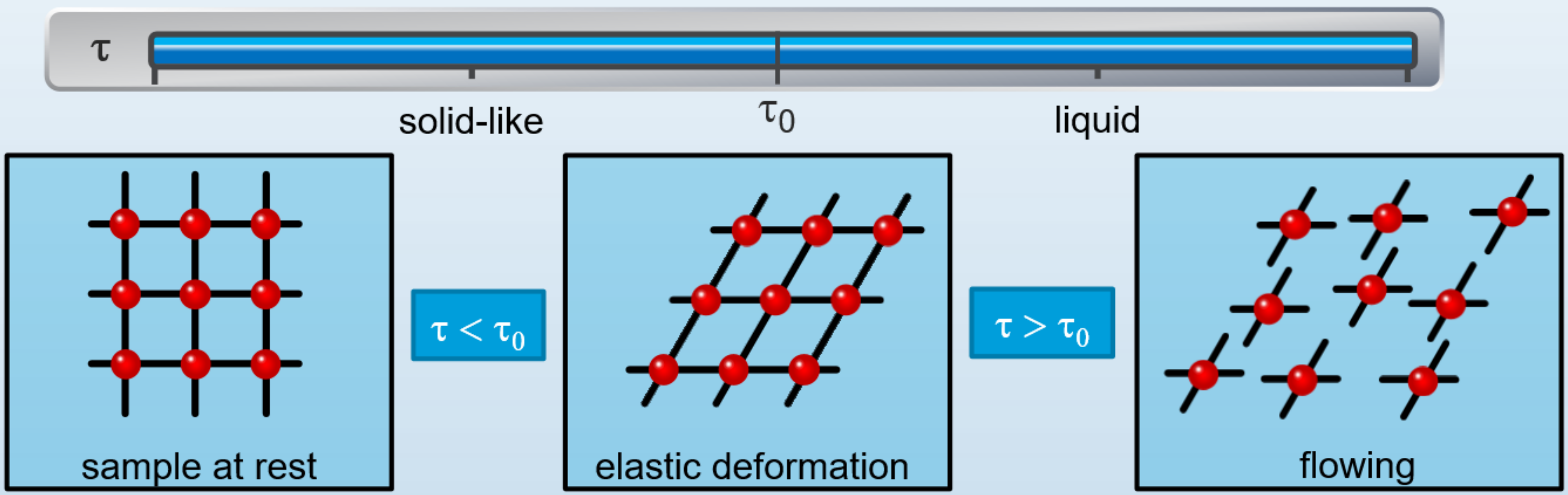
Parameters and factors affecting viscosity

Shear rate depending flow behavior

Yield stress

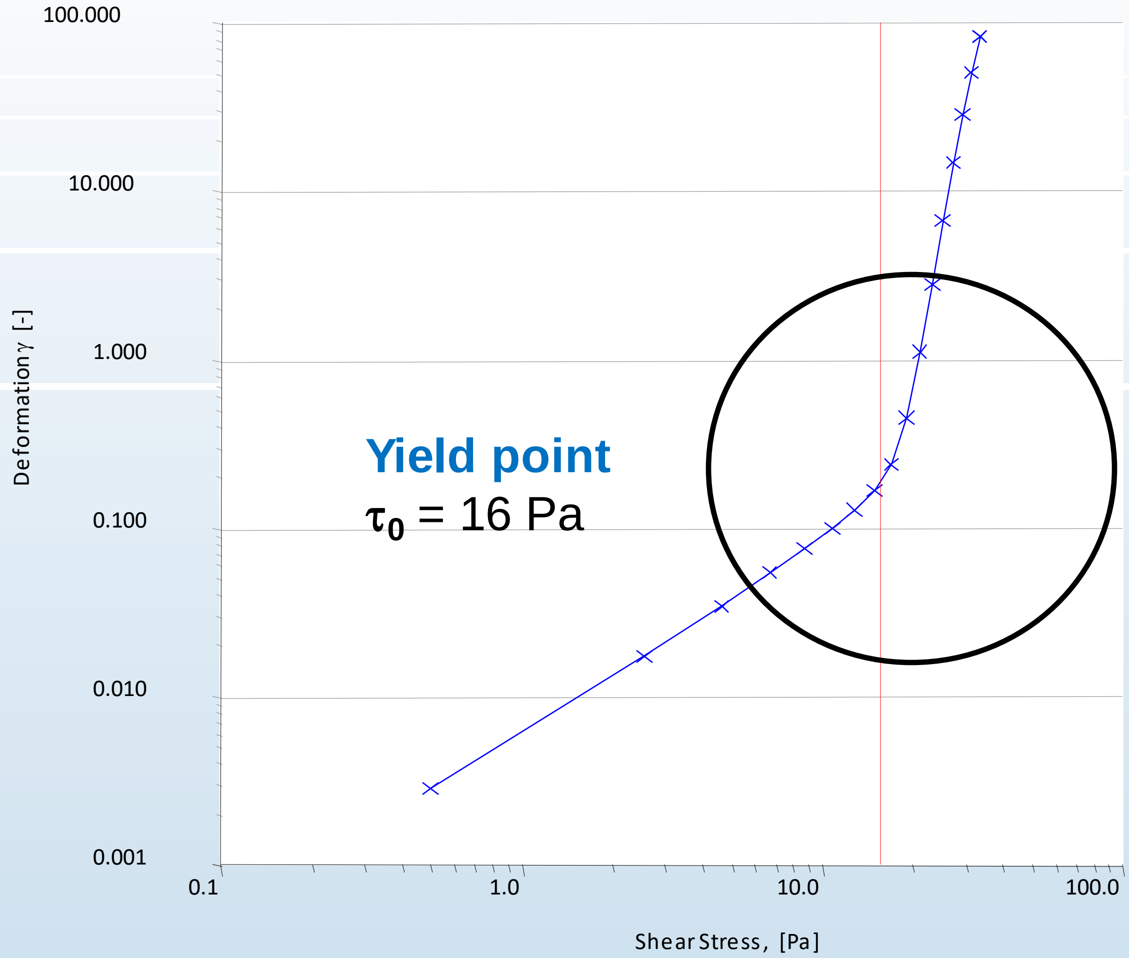
The yield stress τ_0 is the minimum shear stress τ required, to

- overcome elastic behavior and
- obtain stationary flow behavior



Yield stress τ_0: Determination in CS-mode

- **Input**:
  shear stress τ
  (increase logarithmic)
- **Measurement**:
  deformation γ
- **Result:**
  log deformation γ =
  f(log shear stress τ)
- **Evaluation** :
  Transition between the linear regimes
  (= yield stress τ_0)



Parameters and factors affecting viscosity

Viscosity is not a constant term

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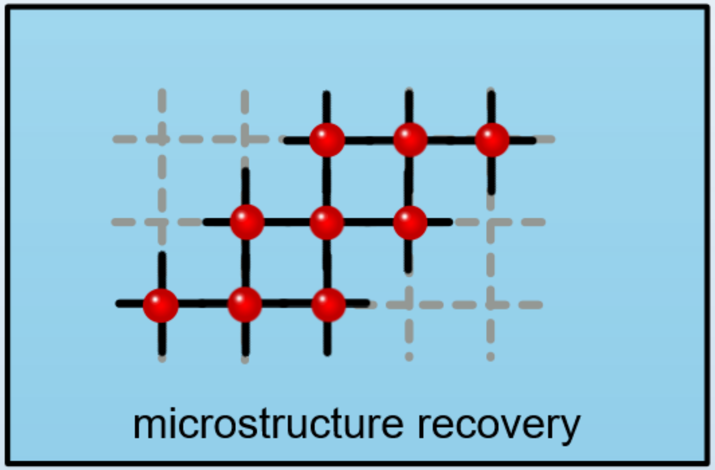
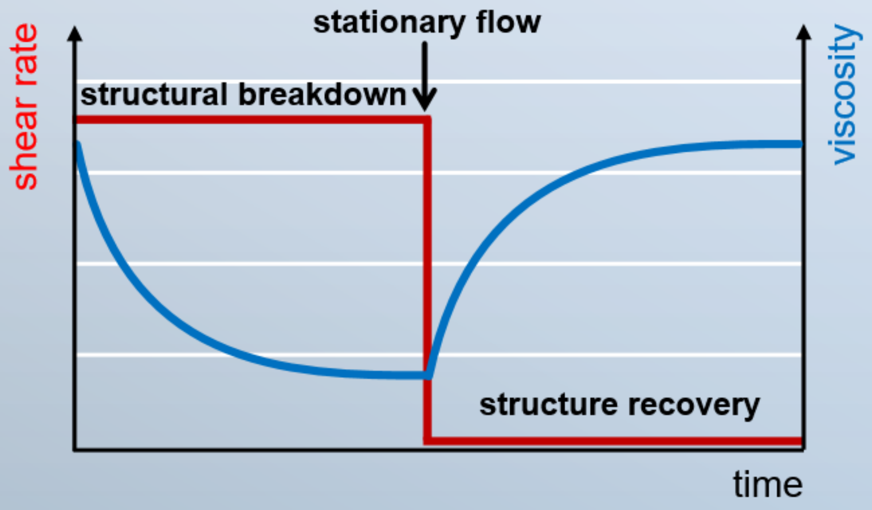
Parameters and factors affecting viscosity

Shear time depending flow behavior

Thixotropy

- Thixotropy is a time delayed structural breakdown of a materials microstructure under shear
- When shear forces are removed microstructure will recover entirely





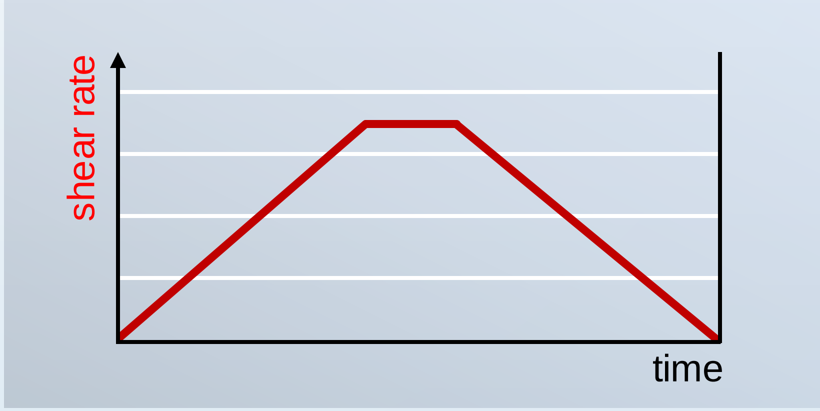
Parameters and factors affecting viscosity

Shear time depending flow behavior

Measuring thixotropic behavior

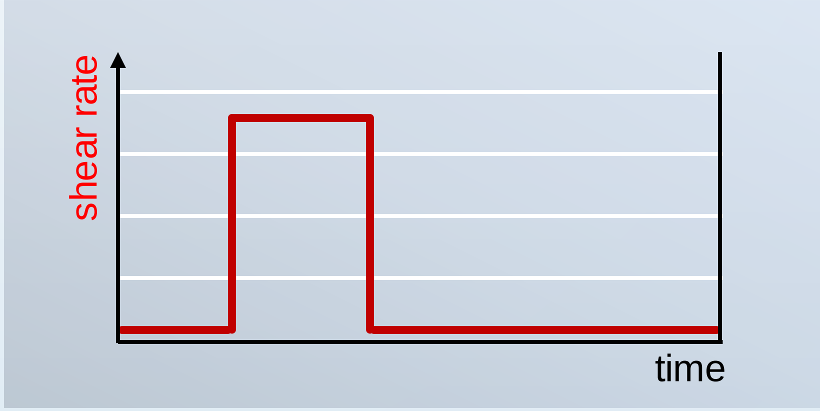
Thixotropy loop:

- Shear rate ramp up, peak hold and ramp down
- Shear stress signal is monitored
- Hysteresis area as a measure for thixotropy



3-Interval Test:

- Recording of initial state at low shear stress, shear rate or oscillation
- Disaggregation at constant shear rate
- Re-aggregation at low shear stress, shear rate or oscillation



Parameters and factors affecting viscosity

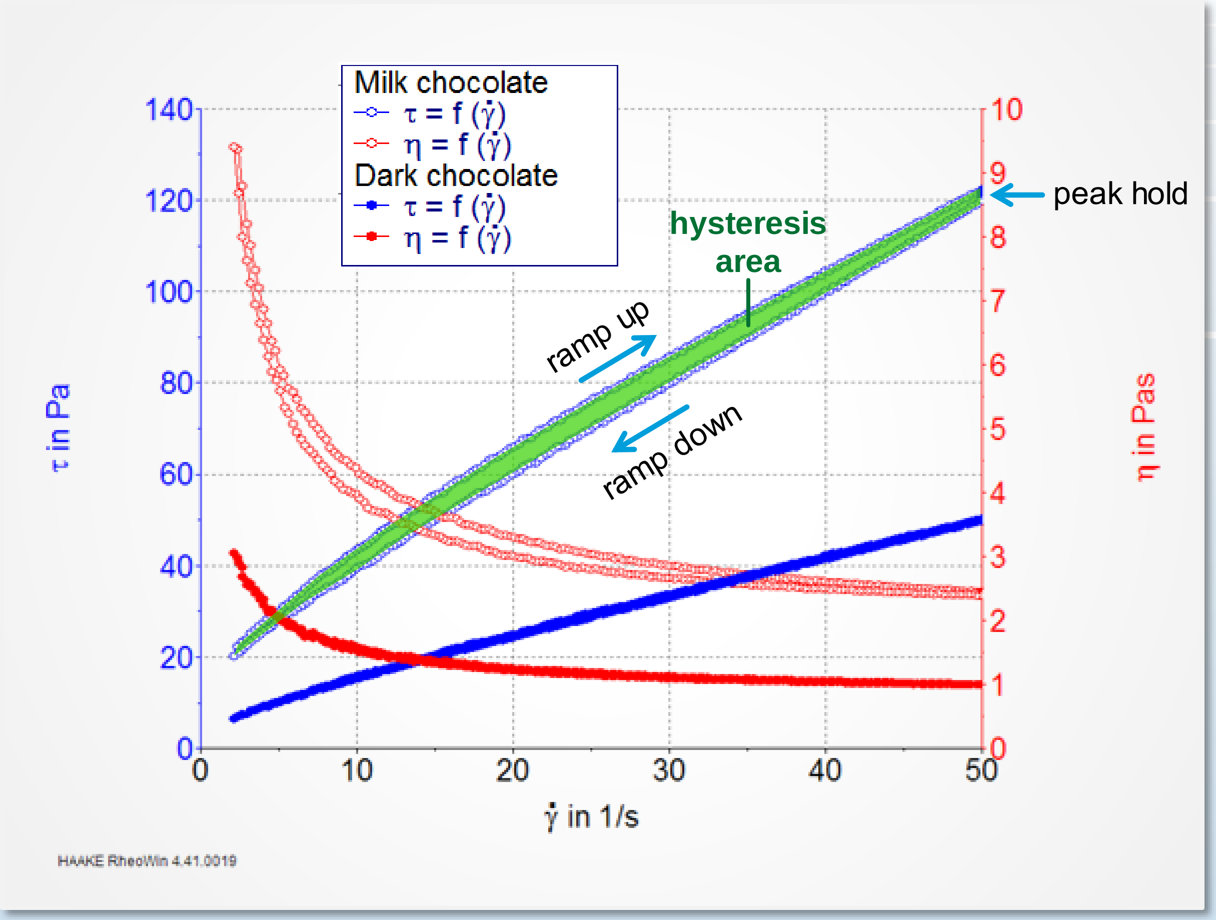
Shear time depending flow behavior

Thixotropic loop

- Comparison of milk and dark chocolate melt
- Thixotropy loop performed at 40°C
- Milk chocolate shows a much stronger thixotropic behavior compared to dark chocolate

  milk chocolate: 203 Pa/s

  dark chocolate: 22 Pa/s

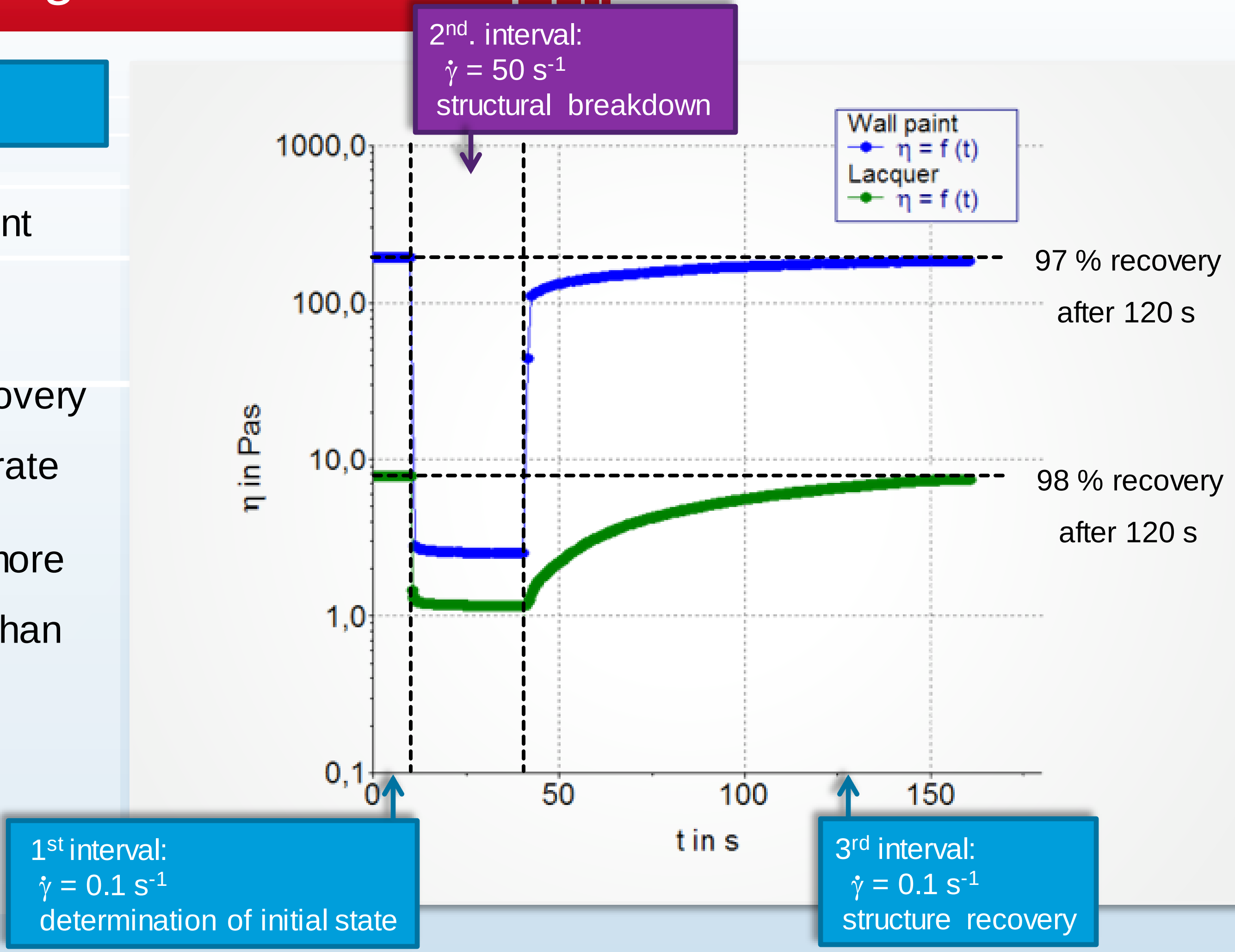


Parameters and factors affecting viscosity

Shear time depending flow behavior

3-Intervall test

- Comparison of a wall paint and a lacquer
- Both show complete recovery after 120 s at low shear rate
- The wall paint shows a more instantaneous recovery than the lacquer



Flow behavior

Conclusions

Newtonian flow behavior: $\eta \neq f(\dot{\gamma})$

Non-Newtonian Flow behavior: $\eta = f(\dot{\gamma})$

- ✓ Bingham (yield stress)
- ✓ Shear thinning (pseudoplastic)
- ✓ Plastic (yield stress)
- ✓ Dilatant (shear thickening)

Time dependant flow behavior: $\eta = f(t, \dot{\gamma})$

- ✓ Thixotropy
- ✓ Rheopexy

The basics of rheology and rotational rheometry

Summary

- Viscosity is a measure for the resistance of a material against deformation and flow
- Viscosity is calculated from the shear stress and the shear rate
- The viscosity of a fluid can be affected by different parameters like temperature and shear rate
- Fluids with a shear rate independent viscosity are called Newtonian fluids
- Most complex fluids show a shear thinning behavior
- Time delayed breakdown and recovery of a material is called thixotropy

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Dr. Fritz Soergel
Senior Application Specialist

Dr. Klaus Oldörp
Senior Application Specialist

Thank you for your attention!

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Any Questions?