Creation and evaluation of measured values in rheology

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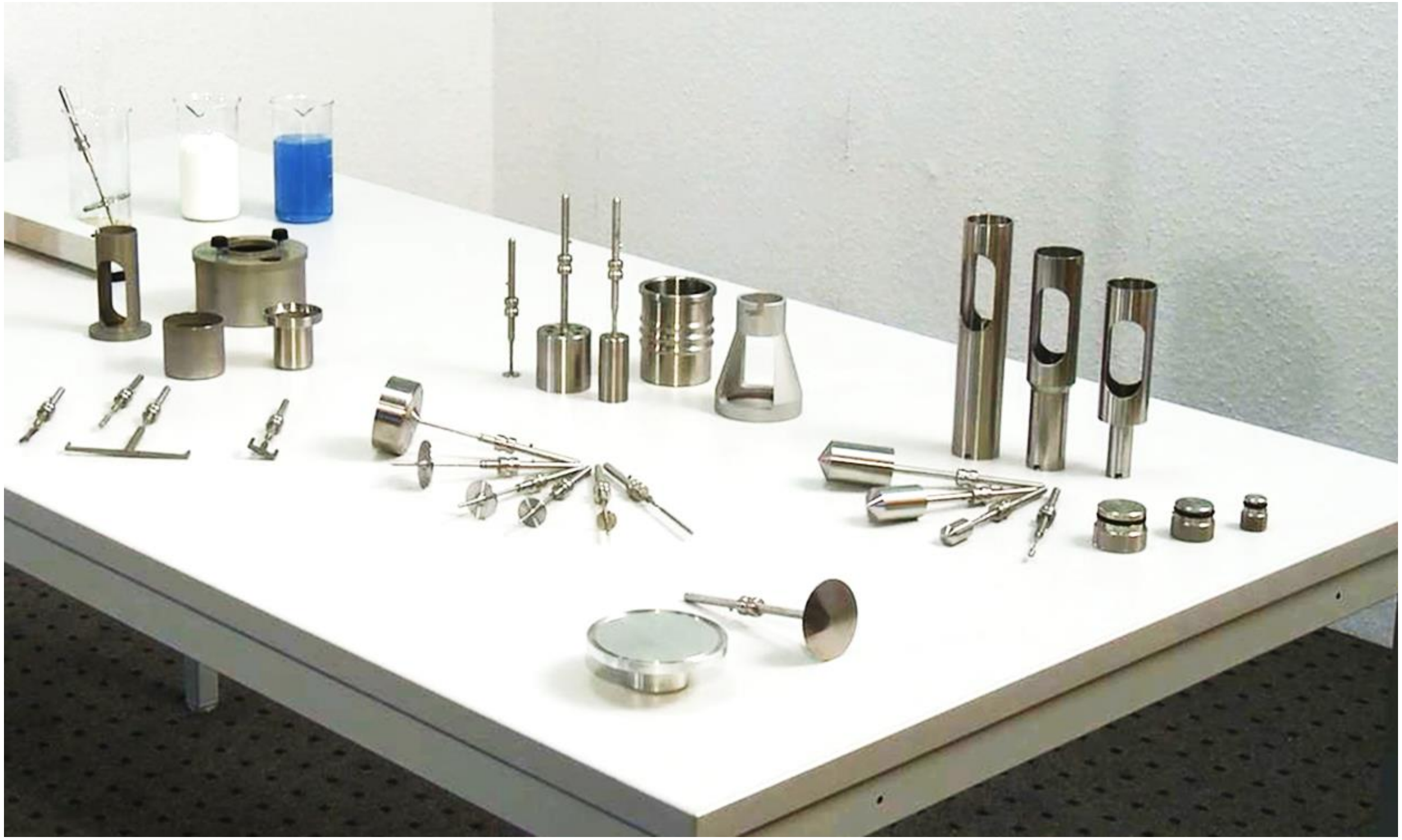
Creation of measured values in rheology

$$\eta = \frac{\tau}{\dot{\gamma}} = \frac{M}{n}\,\frac{K_\tau}{K_{\dot{\gamma}}}$$

η	dynamic viscosity
τ	shear stress
$\dot{\gamma}$	shear rate
M	torque
n	rotational speed
K_τ $K_{\dot{\gamma}}$	constants

rheometer types

shear stress controlled CS
shear rate controlled CR

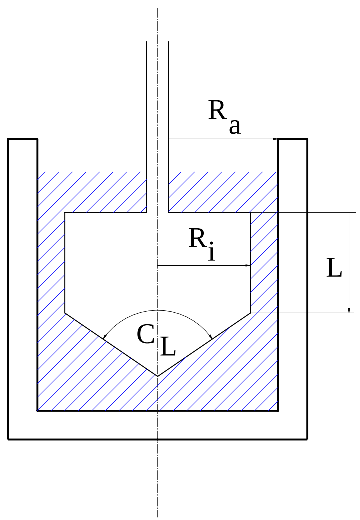


different measurement geometries

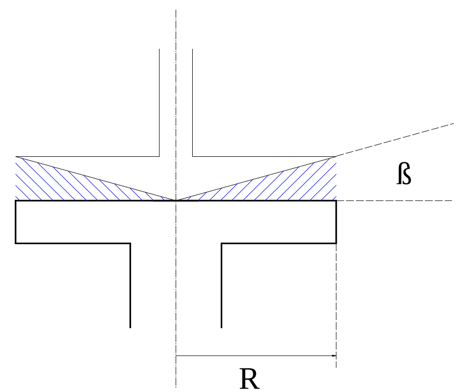
DIN 53 019

$$\eta = \frac{\tau}{\dot{\gamma}} = \frac{M}{n}\,\frac{K_\tau}{K_{\dot{\gamma}}}$$

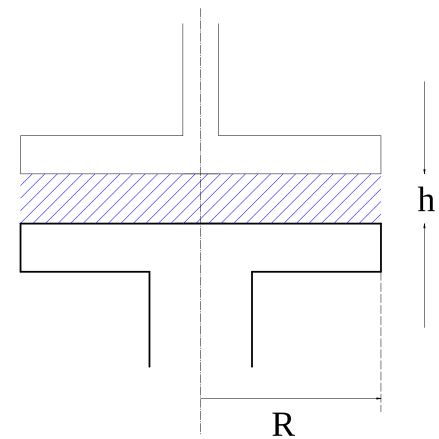
Calculation of the constants



CC System

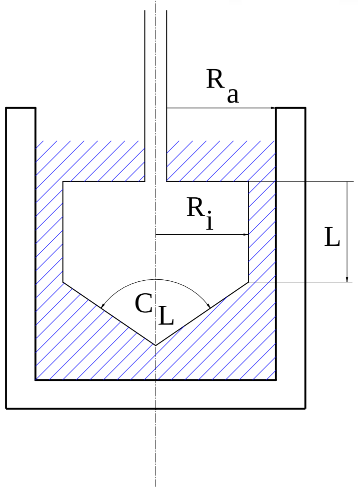


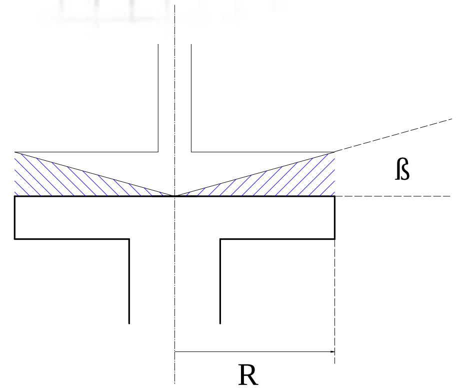
CP System

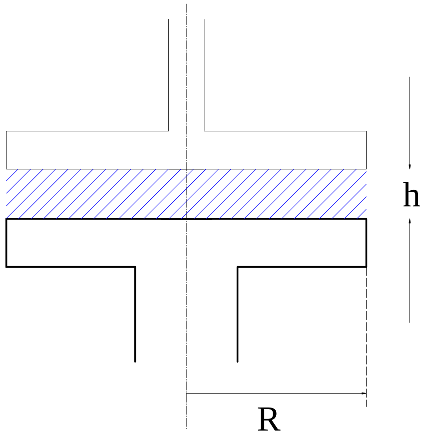


PP System

DIN 53 019







$$\tau_{(rep)} = \left(\frac{1+\delta^2}{2 \cdot \delta^2} \cdot \frac{1}{2\pi \quad L\, R_i^2 \quad C_L} \right) \cdot M$$

$$\dot{\gamma}_{(rep)} = \frac{1+\delta^2}{\delta^2 - 1} \frac{\pi}{30} n$$

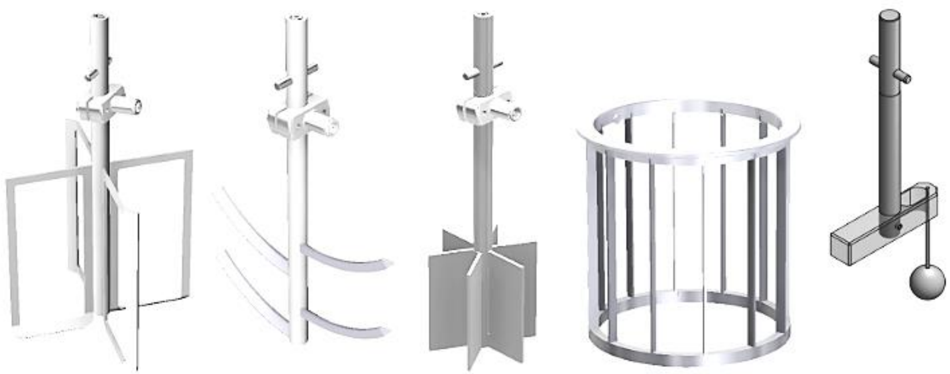
$$\tau_{(r)} = \frac{2}{\pi r^3} \cdot M$$

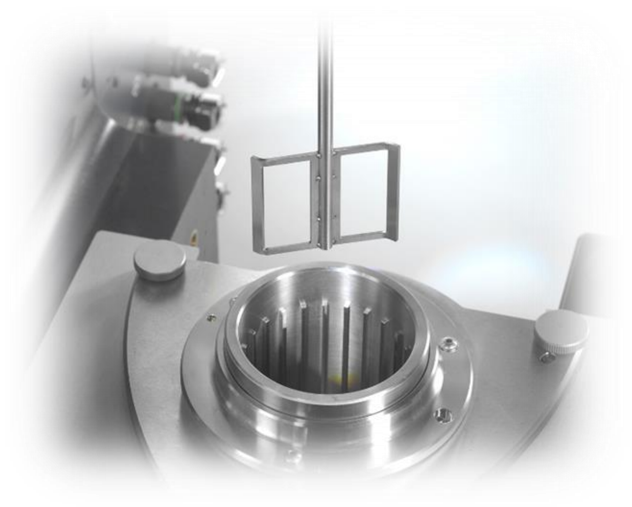
$$\dot{\gamma}_{(r,h)} = \frac{\pi r}{30 h} n$$

$$\tau_{(r)} = \frac{3}{2 \pi r^3} \cdot \mathrm{M}$$

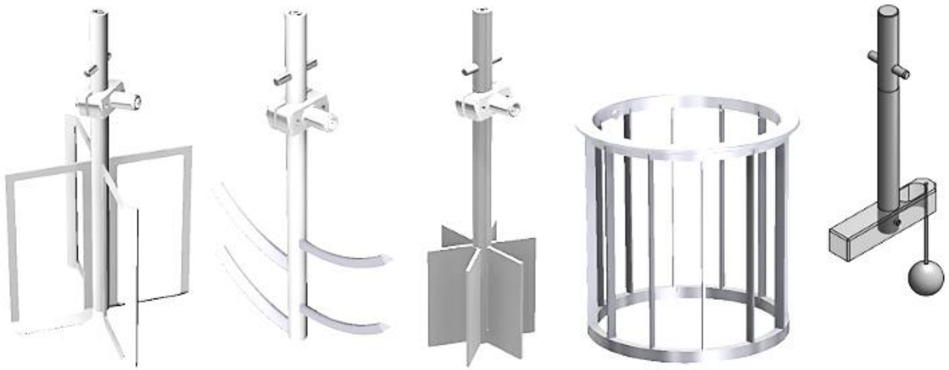
$$\dot{\gamma} = \frac{\pi}{30 \cdot \beta} \cdot n$$

relative measurement geometry





relative geometry

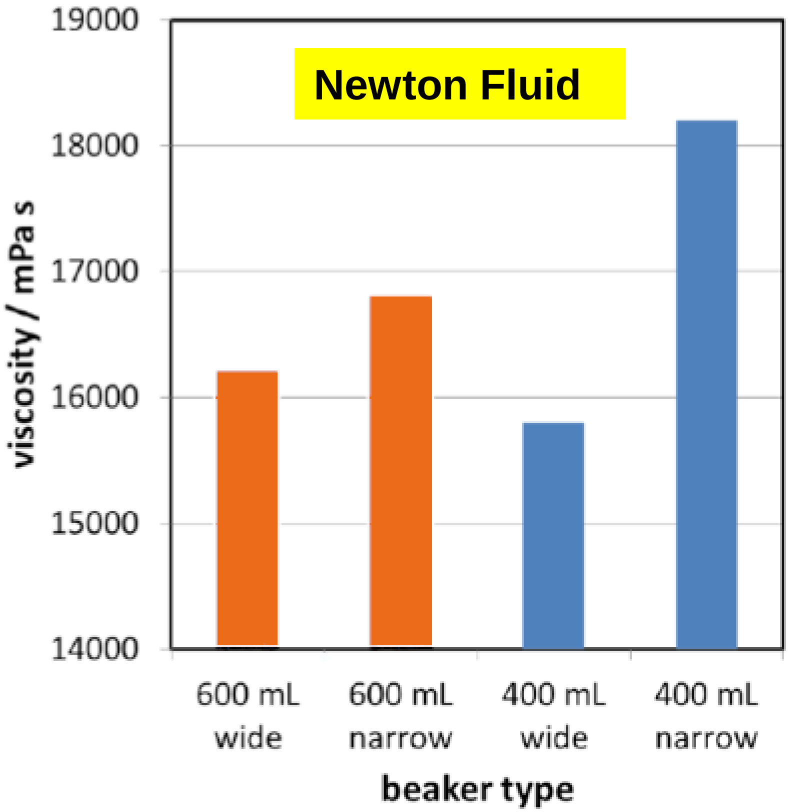


τ = ? ⟷ M

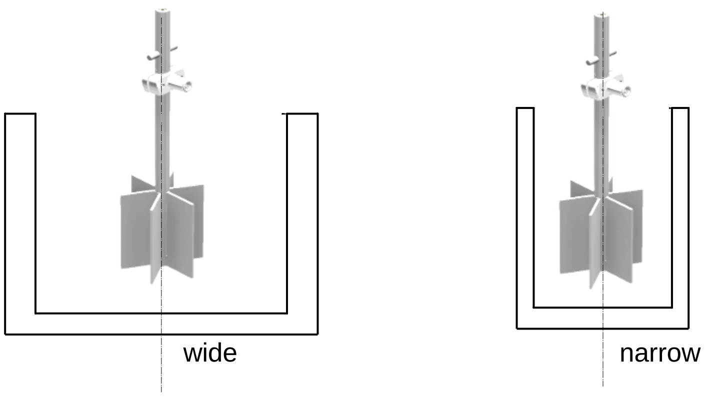
$\dot{\gamma}$ = ? ⟷ n

it is not possible to calculate the constants !

relative geometry



Versuche B. Klotz, Düsseldorf

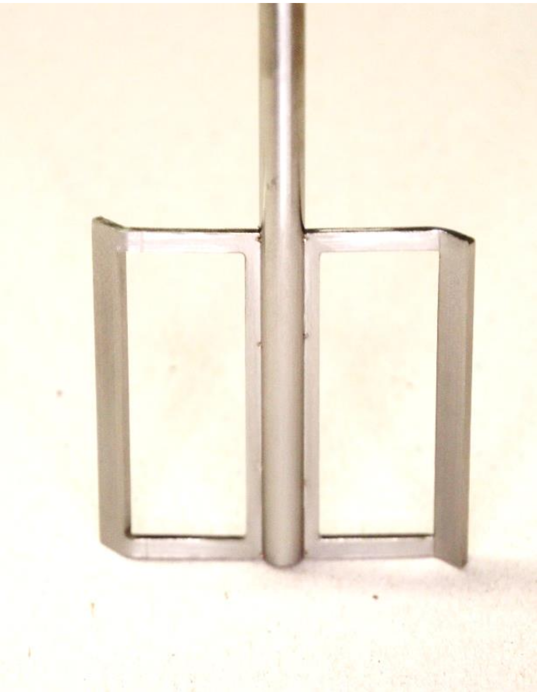


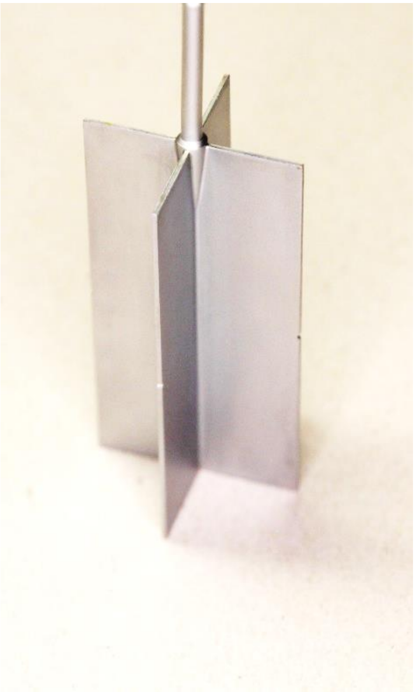
Viscosity is a function of the measurement system - spindle and beaker

Viscosity measurement **absolute** ./. **relative**

$$\eta = \frac{\tau}{\dot{\gamma}}$$

$$\eta = \frac{M}{n}$$





absolute

DIN 53019

relative

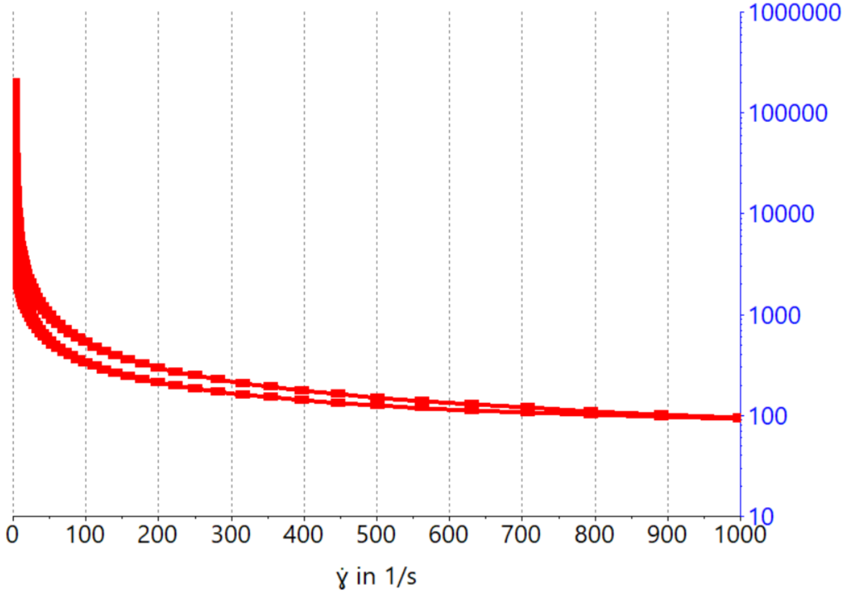
PADDLE

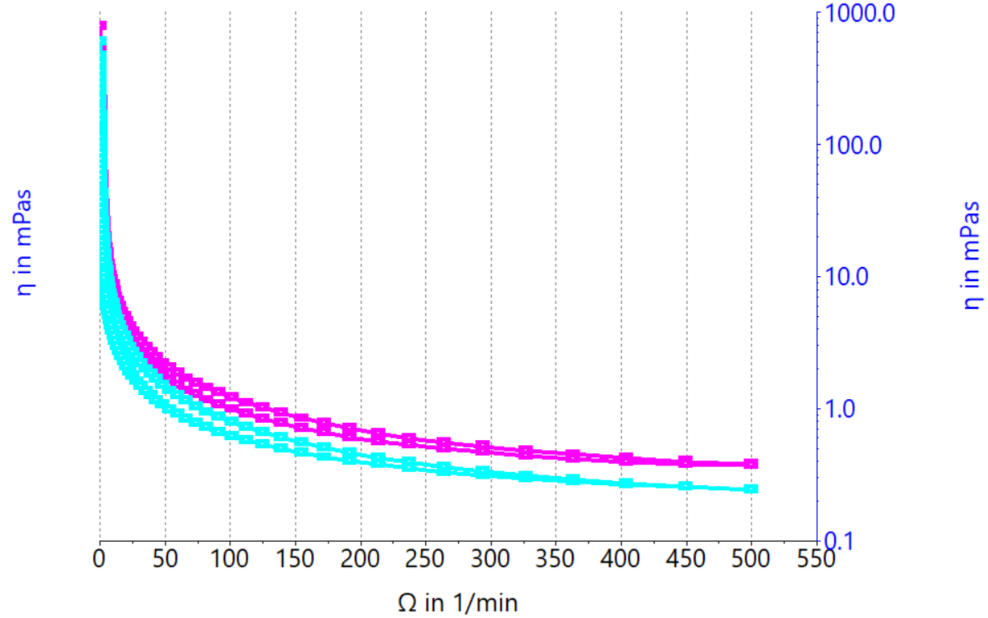
VANE

Viscosity measurement **absolute ./. relative** viscosity curve

$$\eta = \frac{\tau}{\dot{\gamma}}$$

$$\eta = \frac{M}{n}$$





absolute

DIN 53019

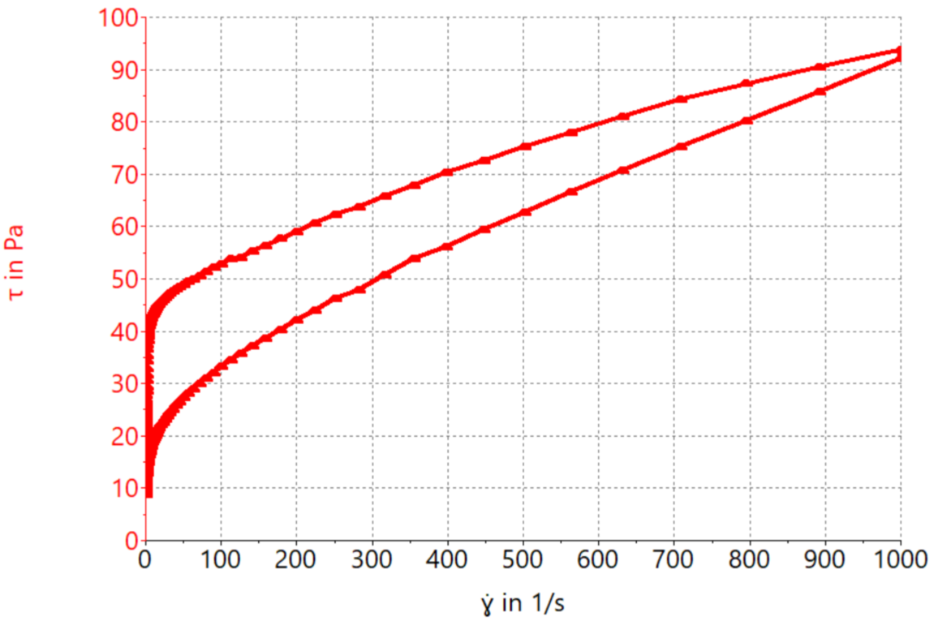
relative

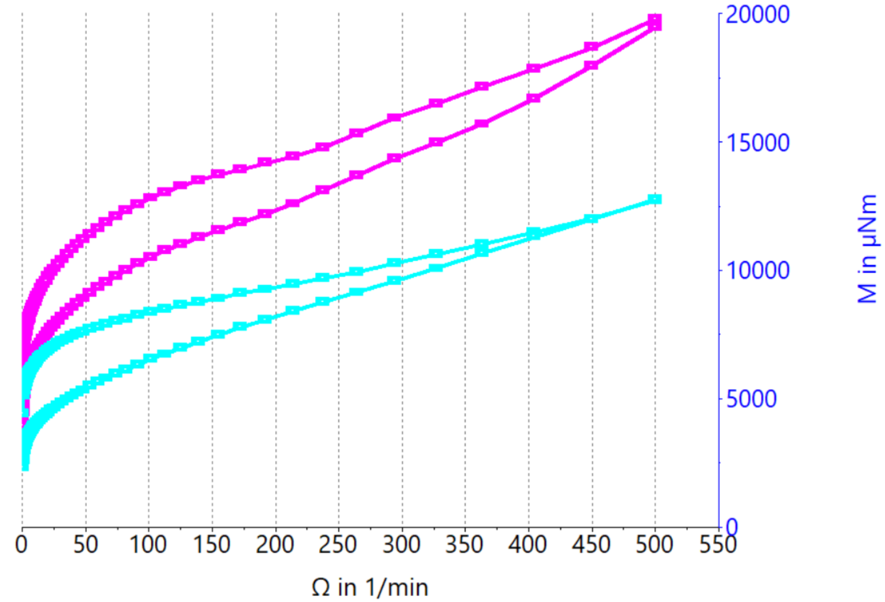
PADDLE VANE

Viscosity measurement **absolute ./. relative** flow curve

$$\eta = \frac{\tau}{\dot{\gamma}}$$

$$\eta \sim \frac{M}{n}$$





absolute

DIN 53019

relative

PADDLE VANE

example

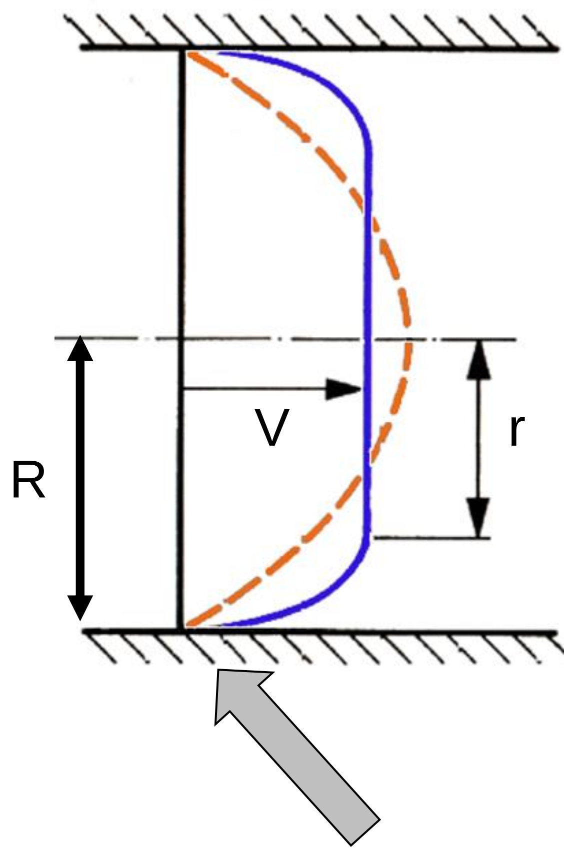
What is the effect of an incorrect interpretation of the shear stress and/or shear rate?

Pumping a non-Newtonian sample through a pipe

$$\eta_C = \frac{1}{\dot{\gamma}} \left(\sqrt{\tau} + \sqrt{\tau_{FG}}\right)^2$$

η_C	Casson viscosity [Pa s]
$\dot{\gamma}$	Shear rate [s^{-1}]
τ	Shear stress [Pa]
τ_{FG}	Casson yield point [Pa]

flow profile



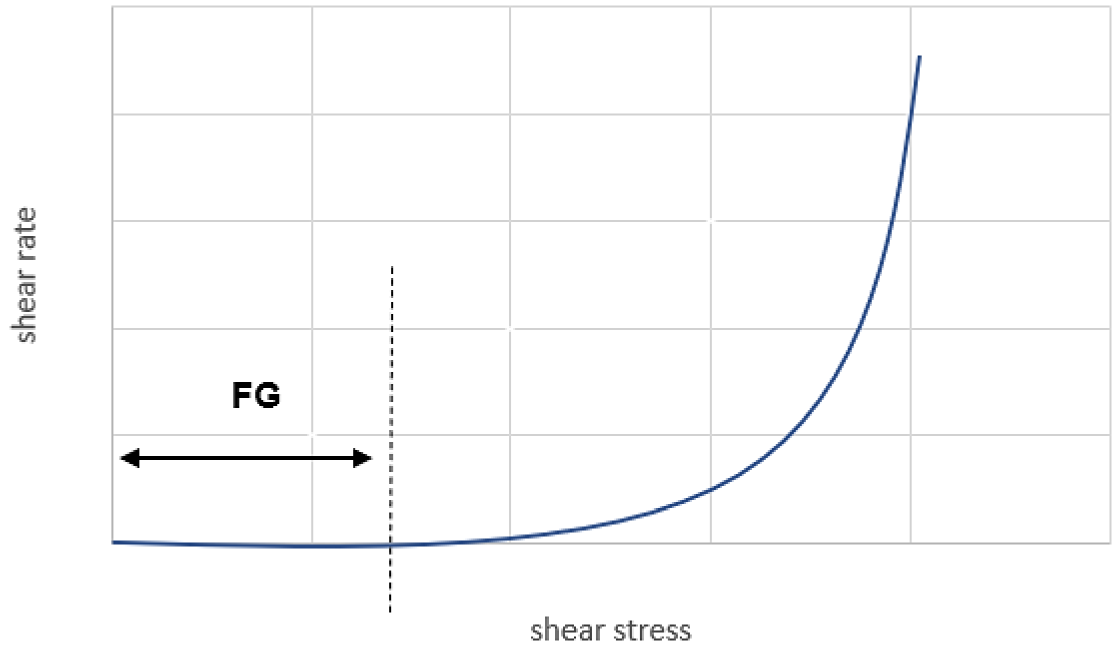
non-Newtonian sample

newtonian sample

wall adhesion and wall slip

v velocity
R radius tube

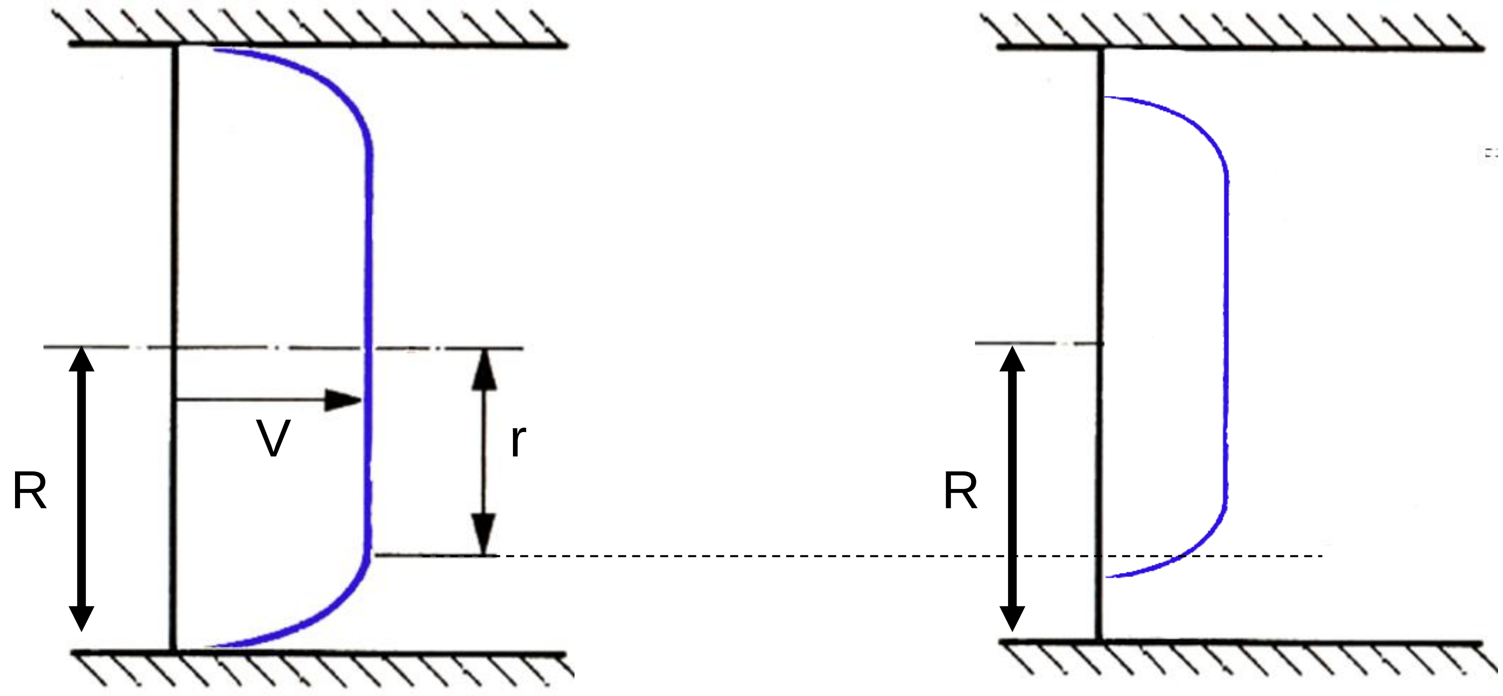
r radius plug



FG yield point

sample
without yield point

sample
with yield point

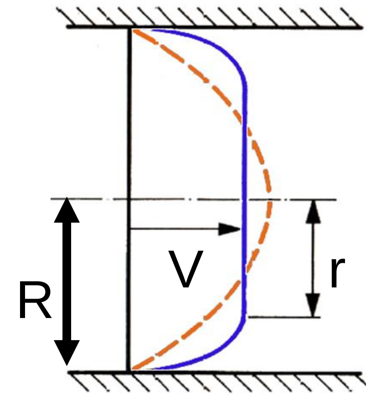


an incorrect shear stress and/or shear rate

Fouling / Contamination caused by yield point

Calculation of shear stress and shear rate

$$\eta_C = \frac{1}{\dot{\gamma}} \left(\sqrt{\tau} + \sqrt{\tau_{FG}}\right)^2$$



$$\tau = \frac{\Delta p}{2L}\, r$$ shear stress

$$\dot{\gamma} = \frac{1}{\eta_C} \left(\tau + \tau_{FG} - 2\sqrt{\tau}\sqrt{\tau_{FG}}\right)$$ shear rate

Approach for the flow rate Q

$$\frac{Q}{\pi R^3} = \frac{1}{\tau_W^3} \int_0^{\tau_w} r^2\, \tau\, d\tau$$

Approach for the flow rate Q

$$\frac{Q}{\pi R^3} = \frac{1}{\tau_W^3} \int_0^{\tau_W} r^2 \, \tau \, d\tau$$

$$\frac{\boldsymbol{Q}\,\eta_C}{\pi\,\tau_W\,R^3} = \frac{1}{4} - \frac{4}{7}\sqrt{Z} + \frac{Z}{3} - \frac{z^2}{84}$$

$$Z = \frac{FG}{\tau_W}$$

Z=0 corresponds to Newtonian flow,
Z=1 means pure plug flow

comparative measurements with pressure measurements on the pipe

The transfer of factors found through measured with a standard liquid is not sufficient for the interpretation of shear rate and shear stress.

The viscosity cannot be determined with relative measuring systems - vane, paddle, ... - in this way.

The determination of the effectively acting shear stresses and shear rates at the application site requires sufficient experience in the interpretation of the flow curves obtained.

Approximate shear rate and shear stress can only be calculated with additional information from the system itself.

Thanks for your attention

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