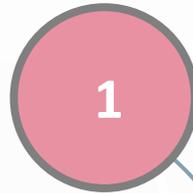


# VISCOSITY: A RHEOLOGICAL PROPERTY

Maja Bjelošević Žiberna  
Prof. ssa. Beatrice Perissutti



**DEFINITION OF TERMS**



**RHEOLOGICAL  
CLASSIFICATION OF FLUIDS**



**PURPOSE OF VISCOSITY  
MEASUREMENT**



**METHODS OF VISCOSITY  
MEASUREMENT**



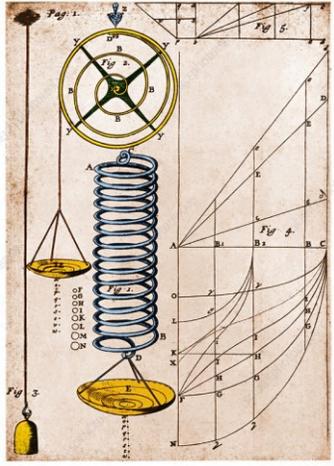
**CONCLUSION**



**QUESTIONS**

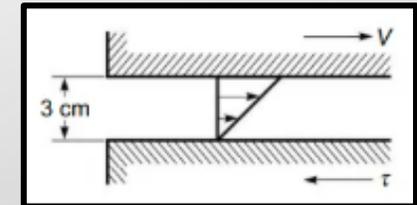
# HISTORY

- **1678: Hook's Law (of Elasticity)**



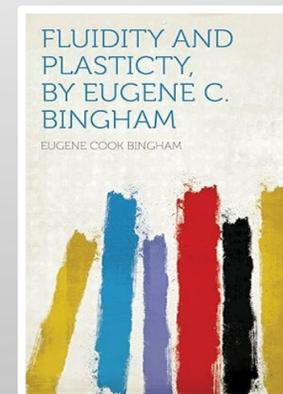
*„The power of any spring is in the same proportion with the tension thereof.“*

- **1687: Newton's Law of Viscosity**



- **1929: E. C. Bingham**

*„Rheology is the study of the deformation and flow of matter.“*



a **science of deformation and flow of matter**;

how materials behave under applied forces?

**including but not limited to viscosity**;

materials: wide range → **solidlike** (elastic), **liquidlike** (viscous), and **intermediate** (viscoelastic)

## VISCOSITY vs. RHEOLOGY?

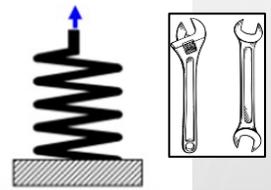
a **property**;

**resistance of a fluid to flow**;

material: **liquidlike** (viscous)

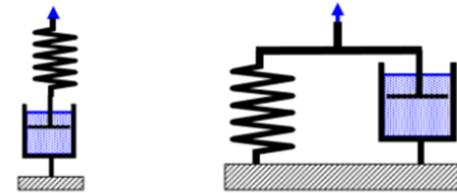


Deformation

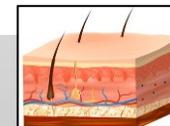


Elastic Solids

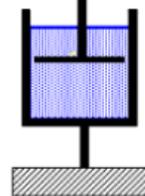
Flow & Deformation



Viscoelastic



Flow



Viscous Liquids

# DEFINITION OF VISCOSITY - MATHEMATICAL



vs.

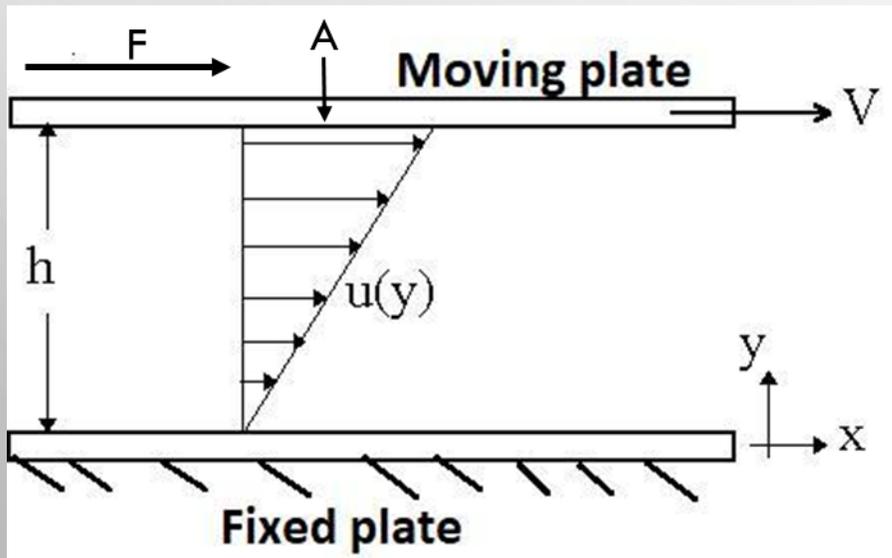


**MOTION:** YES  
**FLOW:** NO

**FLOW:** YES

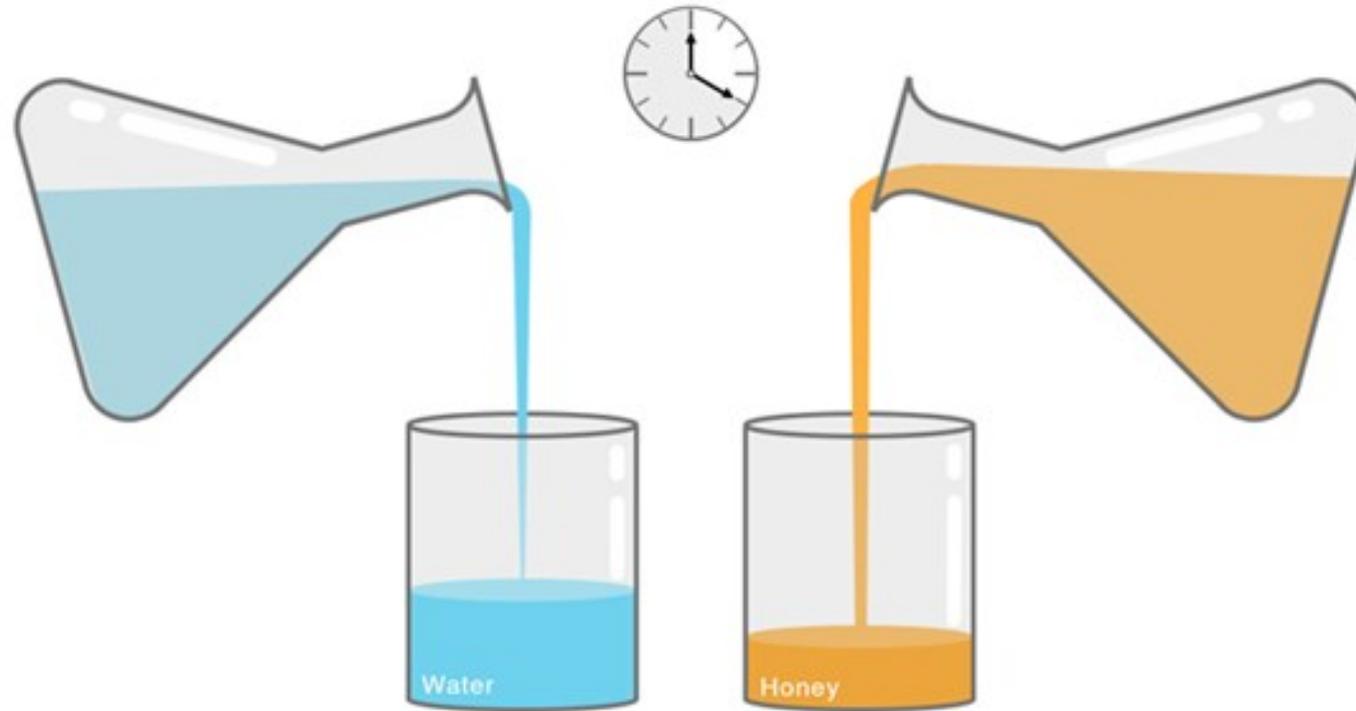
$$dv/dh = \dot{\gamma} \rightarrow \text{SHEAR RATE [s}^{-1}\text{]}$$

$$F/A = \tau \rightarrow \text{SHEAR STRESS [N/m}^2 = \text{Pa]}$$



$$\tau/\dot{\gamma} = \eta \rightarrow \text{VISCOSITY [Pa}\cdot\text{s]}$$

# DEFINITION OF VISCOSITY - SCHEMATIC



# RHEOLOGICAL CLASSIFICATION OF FLUIDS

IDEAL/  
REAL  
FLUIDS?



**FLUIDS**

**Newtonian**

**non-Newtonian**

**time independent**

**time  
dependent**

**viscoelastic**

**shear thinning  
(pseudoplastic)**

**shear thinning with  
yield point (plastic)**

**shear thickening  
(dilatant)**

**rheopectic**

**thixotropic**

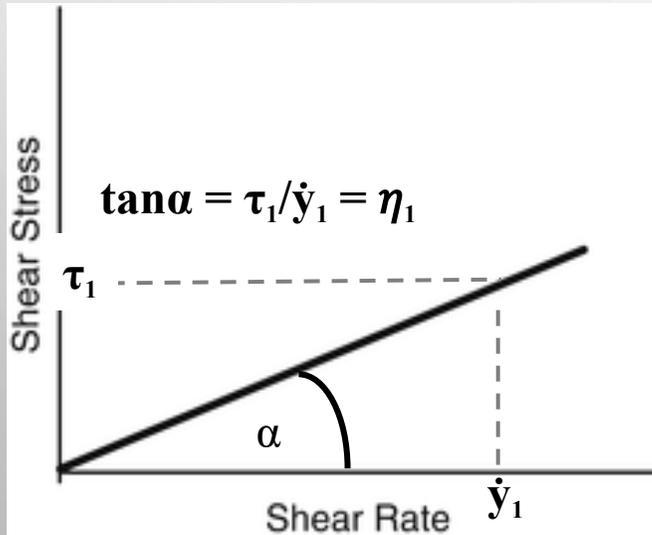
# 1. NEWTONIAN FLUIDS

**VISCOSITY IS  
CONSTANT**



- A PROPERTY OF FLUID;  $\eta = f(T, p) \rightarrow$
- **INDEPENDENT OF DIRECTION,  
MAGNITUDE AND DURATION OF SHEAR**

**RHEOGRAM** (FLOW CURVE)



**VISCOSITY CURVE**



**EXAMPLES:**

- WATER,
- GASES,
- SOLUTIONS OF LOW-MOLECULAR-WEIGHT SOLUTES,
- MINERAL OILS.

## 2. NON-NEWTONIAN FLUIDS

### A) TIME INDEPENDENT

- exhibit a viscosity change with shear rate and shear stress

increases  
with increasing  
shear rate:  
fluid is **shear thickening**

**DILATANT BEHAVIOR**

decreasing  
with increasing  
shear rate:  
fluid is **shear thinning**

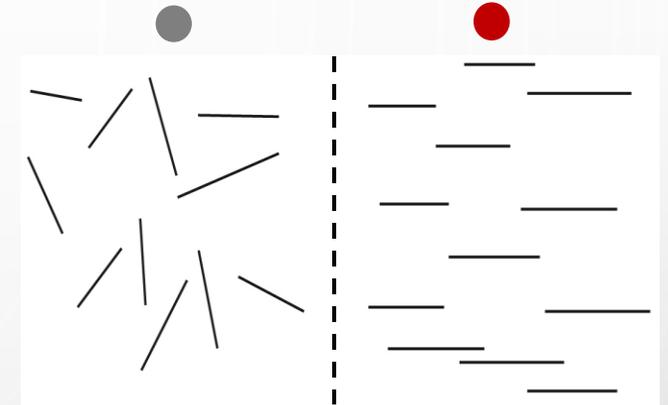
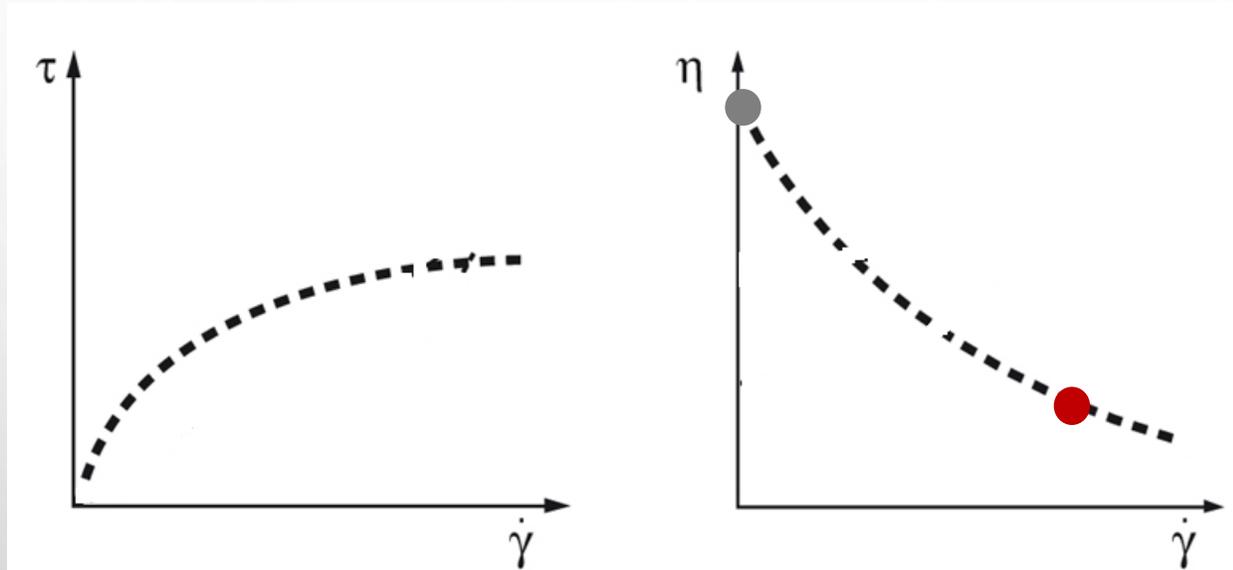
**PSEUDOPLASTIC BEHAVIOR**

decreasing or increasing  
with shear: fluid starts to  
flow at certain shear  
stress - **yield stress**

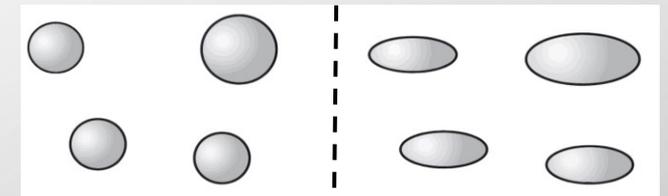
**PLASTIC BEHAVIOR**

$\eta = f(\text{shear}) \rightarrow$  shear conditions have to be given;  
Example:  $\eta_1(\dot{\gamma}_1) = 0.5 \text{ Pas}$  (at  $10 \text{ s}^{-1}$ )

# PSEUDOPLASTIC FLUIDS



*Needle-shaped particles in a suspension.*



*Droplets in an emulsion.*

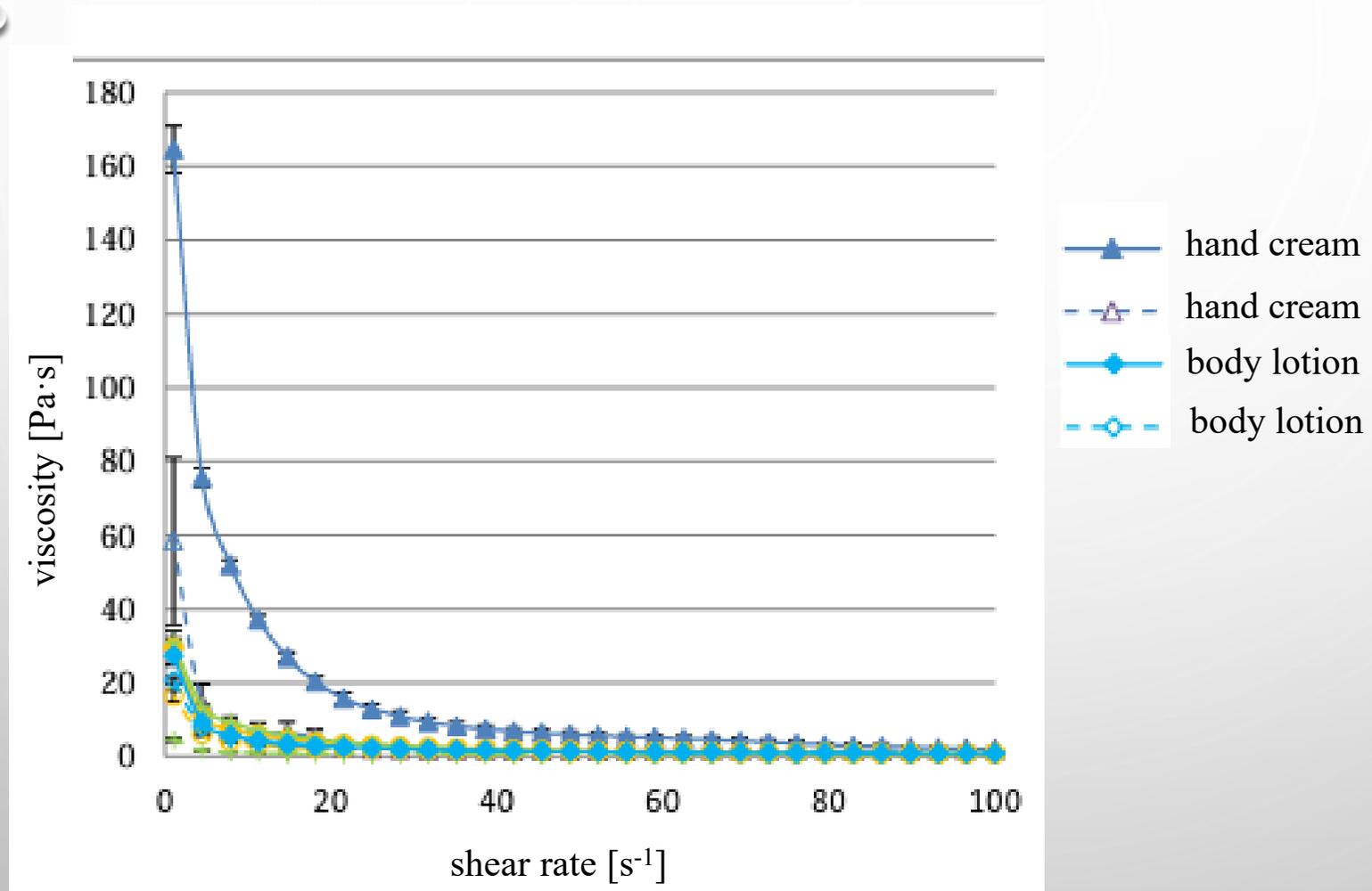
- slope of the curve decreases as the shear rate increases,
- **absence of movement: higher viscosity**

WHY?

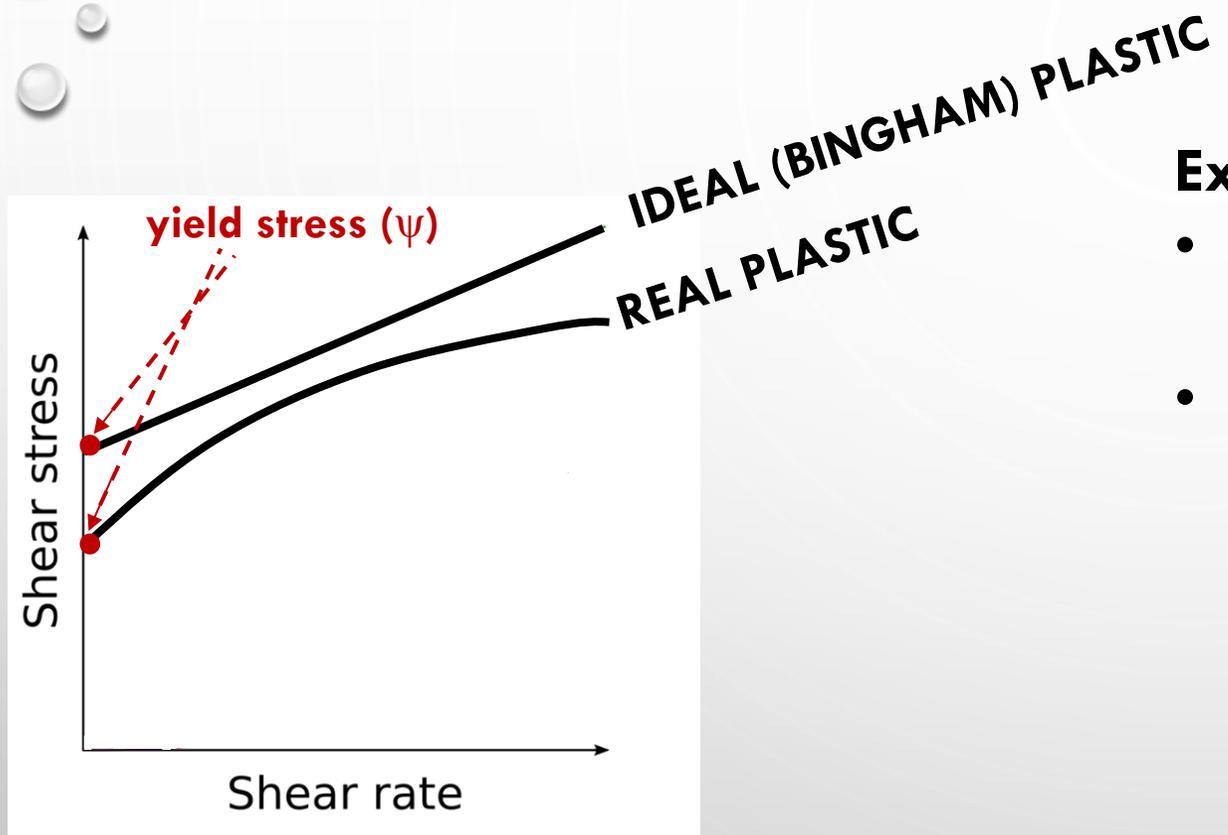
IMPORTANCE?



# AN EXAMPLE

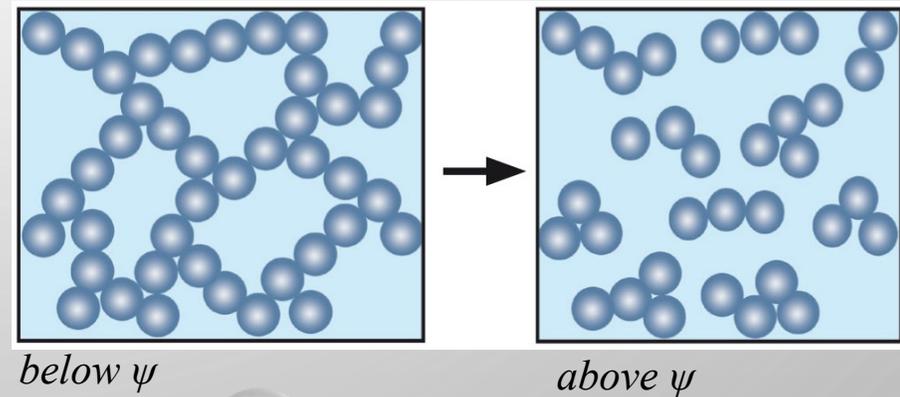


# PLASTIC FLUIDS

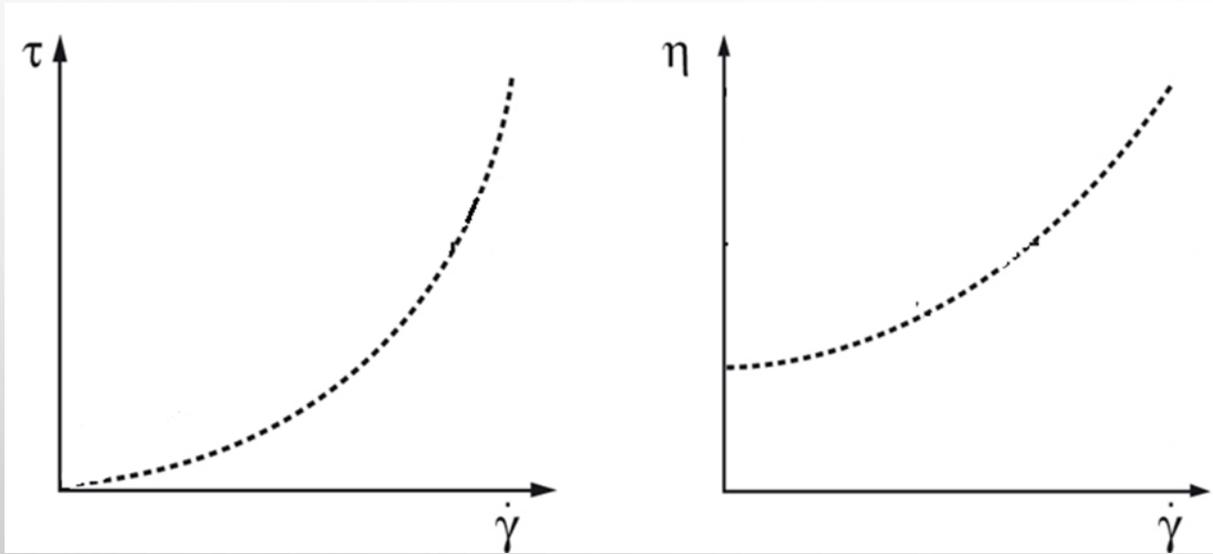


## Examples:

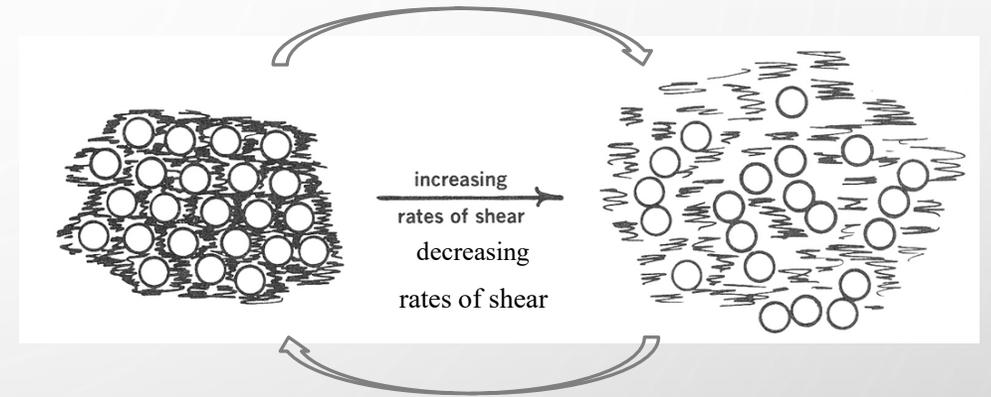
- stabilization of suspensions:  
high  $\psi \rightarrow$  reduction of sedimentation.
- emulsions with high concentrations of dispersed phase: force  $\rightarrow$  spreading on the skin (some semisolids)



# DILATANT FLUIDS



- **agitation: viscosity increases,**
- **absence of movement: lower viscosity.**



## NOTE!

- dilatant fluids exhibit an increase in volume and may solidify when subjected to high shear.

# FLUIDS

Newtonian

non-Newtonian

time independent

time dependent

viscoelastic

shear thinning  
(pseudoplastic)

shear thinning with  
yield point (plastic)

shear thickening  
(dilatant)

rheopectic

thixotropic

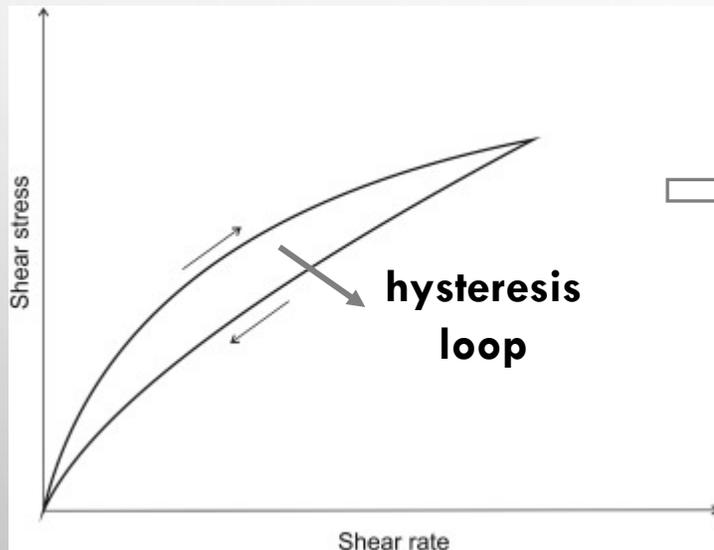
# 2. NON-NEWTONIAN FLUIDS

## B) TIME DEPENDENT

- viscosity depends on **duration** of shear and **shear „history“**

### I.) THIXOTROPIC FLUID

- i. **phase:** increase of shear rate → higher shear stress is obtained
- ii. **phase:** transition from higher to lower shear rates: shear stress is lower due to shear „history“ on the internal structure of the fluid.



### GEL-SOL TRANSFORMATION

- viscosity decreases with duration of shear ●●● →

# 2. NON-NEWTONIAN FLUIDS

## B) TIME DEPENDENT

### REVERSIBLE THIXOTROPY:

constant shear rate  $\rightarrow$  viscosity **decreases**

increased shear rate  $\rightarrow$  viscosity **decreases** until **equilibrium**

reduced shear rate  $\rightarrow$  viscosity **increases** with **time** under shear

shear **stops**  $\rightarrow$  viscosity **returns** to (almost) initial value.

### IRREVERSIBLE TIME-DEPENDENT BEHAVIOR:

time under shear  $\rightarrow$  viscosity **decreases**

shear **stops**  $\rightarrow$  viscosity does not **return** to initial value.

### II.) RHEOPECTIC FLUIDS:

- **viscosity increases with duration of shear,**
- less common.

# 3. NON-NEWTONIAN FLUIDS

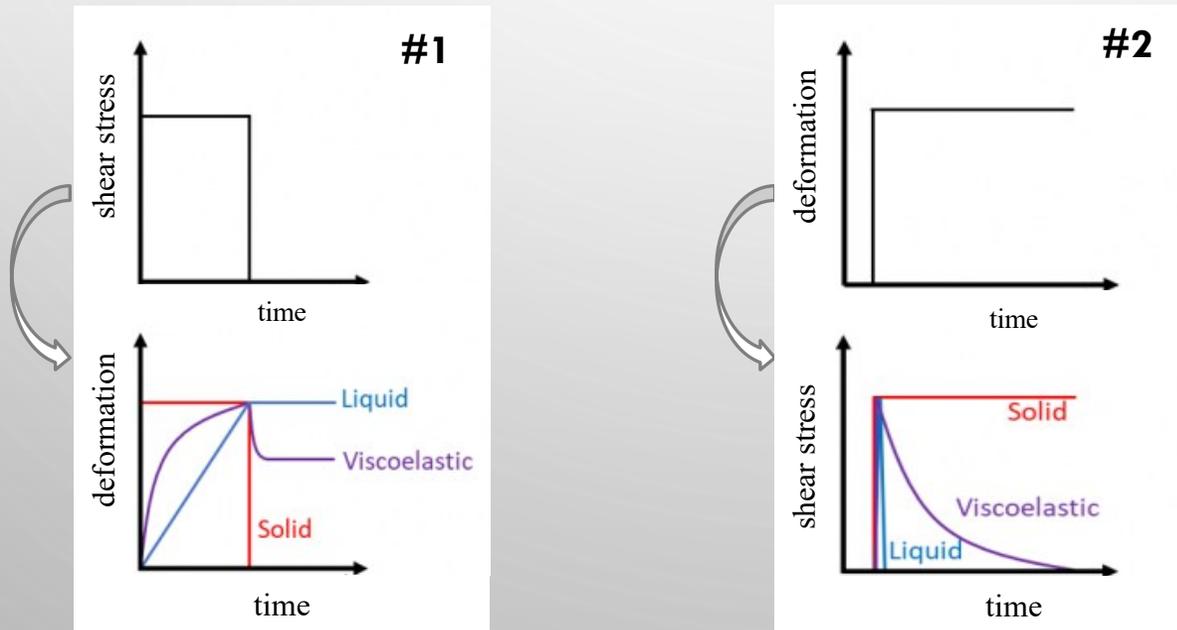
## C) VISCOELASTIC PROPERTIES

- **viscosity** & **elasticity**: properties of materials → response to applied forces (shear),
- most real fluids: both viscous and elastic properties → **VISCOELASTIC BEHAVIOR**



↑  
at small deformation

depending on material, shear & duration of shear



# 3. NON-NEWTONIAN FLUIDS

## C) VISCOELASTIC PROPERTIES

understanding the mechanical behavior of materials

insight into the microstructure → degree of polymer chain entanglement or crosslinking → drug release

viscoelastic response of cells, tissues, organs → physiological or disease state

**IMPORTANCE?**

stability and resistance to deformation of pharmaceutical and cosmetic products → ensuring consistency

processability during extrusion, molding, coating

tablet compression and granulation → powder deformability and mechanical strength

suspensions and emulsions: maintain homogeneous particle distribution and prevents phase separation

semisolids: spreadability, ability to remain on the skin

# PURPOSE AND METHODS OF VISCOSITY MEASUREMENT

## WHY?

- provides very useful information about the formulation and process:
  - ease of withdrawal, extrusion, spreading on the skin, passage through a syringe needle,
  - understand the effect of adding the granulating liquid on the powder properties,
  - stability,
  - process optimization,
  - quality control of raw materials and final drug,
  - ...

## HOW?

- several instruments are available → selection depends on type of fluid and purpose of measurement

# RHEOMETERS AND VISCOMETERS

- **ABSOLUTE INSTRUMENTS:**

- rotational and capillary rheometers and viscometers,
- values of shear rates or stresses can be calculated using measurable and adjustable quantities or geometric characteristics of selected sensor system.

- **RELATIVE INSTRUMENTS:**

- falling ball viscometer, penetrometer, viscometer with turbine agitators,
- shear conditions during measurement are not precisely defined → viscosity is determined comparatively with respect to a fluid of known viscosity.

# ROTATIONAL RHEOMETERS

- MEASURING SYSTEM CONSISTS OF TWO PARTS:
  - one stationary, one rotating or
  - both rotating.
- ACCORDING TO THE MEASUREMENT METHOD:
  - **ROTATIONAL RHEOMETER WITH ADJUSTABLE SHEAR RATE** (controlled rate rheometer):  
shear rate  $\rightarrow$  independent variable; shear stress  $\rightarrow$  measured,
  - **ROTATIONAL RHEOMETER WITH ADJUSTABLE SHEAR STRESS** (controlled stress rheometer):  
shear stress  $\rightarrow$  independent variable; shear rate  $\rightarrow$  measured.



*Brookfield viscometer.*



*Controlled stress rheometer.*

# ROTATIONAL RHEOMETERS: SENSOR SYSTEMS

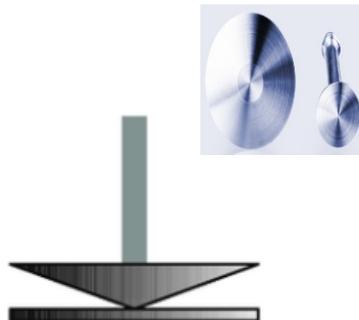
- **SELECTION:**

- TYPE OF FLUID,
- MEASUREMENT CONDITIONS,
- TEMPERATURE RANGE OF MEASUREMENTS,
- ADDITIONAL CONDITIONS (inert atmosphere, elevated pressure...)

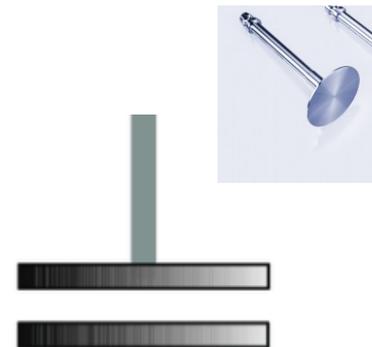
**a) coaxial cylinder sensor system**



**b) cone-and-plate sensor system**



**c) parallel plate sensor system**



# TRENDS

rheometers based on microfluidic technology



a few micro-liters of sample for measurement



development of formulations with biological drug



**THANK YOU FOR  
YOUR ATTENTION!**



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