Rheology a rheometry
in pharmaceutical practice

Seminar 9/10/2023

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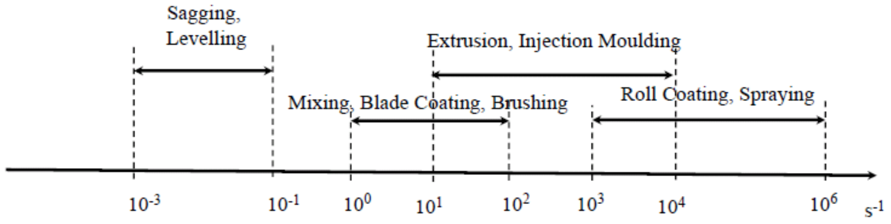
Kinematic

$\nu = \eta/\rho \quad [m^2 \cdot s^{-1}]$

Dynamic

$\eta = \tau/D \quad [Pa \cdot s]$

Typical Shear Rate Ranges



Rotational-Rheometer

Sample: Water up to solids
Results: Shear-Viscosity, Yield Stesses, Visco-Elasticity, Relaxation...

High Pressure Capillary-Rheometer

Sample: Water up to high viscous
Results: Shear-Viscosity, Elongational-Viscosity, Wall Slip...

Match shear rate to processes…

SAMPLE STORAGE
Very low shear rates: ~ $0.001s^{-1}$
How stable is it, sample quality…

SAMPLE DELIVERY
Medium shear rates: ~$10s^{-1}$
Pumpability? Scoopability?

SAMPLE APPLICATION 1
Low shear rates: ~$1s^{-1}$
Flows away? Flows off hand?

SAMPLE APPLICATION - 2
Higher shear rates: ~$100s^{-1}$
Too thick to spread? Nice feel?

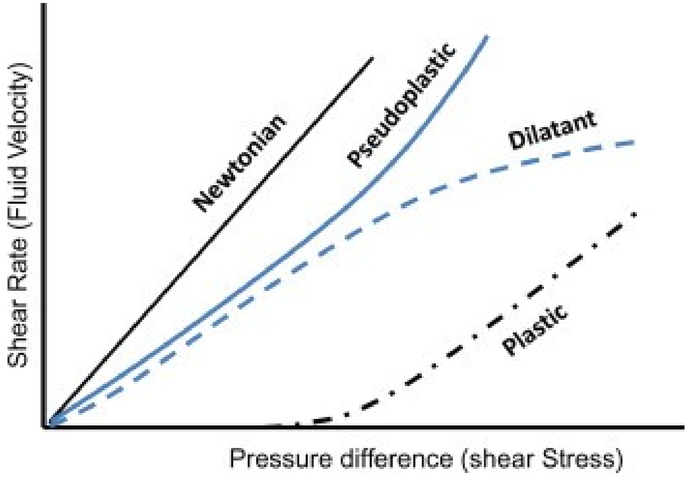
TYPES OF FLOW BEHAVIOR

Newtonian flow

Non-Newtonian flow

Time dependent
- Tixothropy
- Rheopexy

Time independent
- Pseudoplastic = shear thinning
- Plastic = shear thinning with yield
- Dilatant = shear thickenning



Ideal viscosity

- material constant
- changes with temperature, concentration

Newton's law

$$\tau = \eta \cdot D$$

$$\eta = \frac{\tau}{D}$$

PhEur: Paraffinum liquidum
BP: Liquid paraffin
JP: Liquid paraffin
USP: Mineral oil

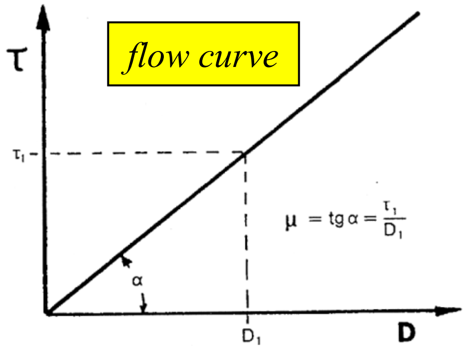
PhEur: Paraffinum perliquidum
BP: Light liquid paraffin
JP: Light liquid paraffin
USPNF: Light mineral oil

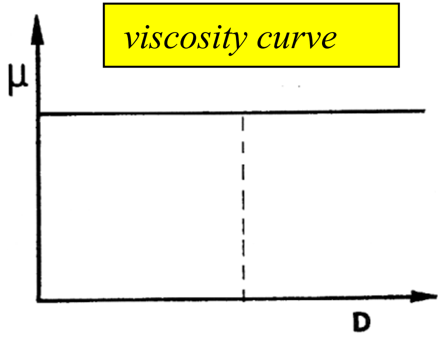
dynamic viscosity at 20°C

110–230 mPa s

25–80 mPa s

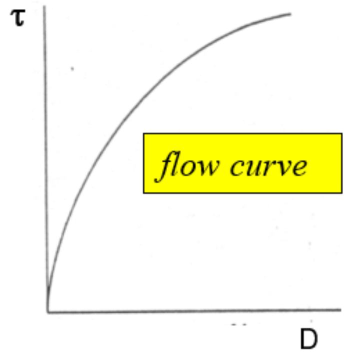
Newtonian flow

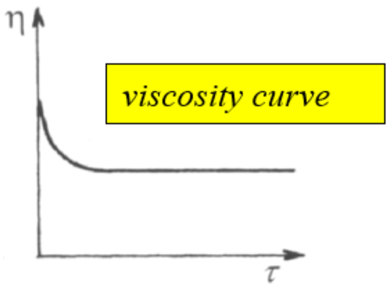




- Direct proportionality between shear stress and shear rate
- Viscosity curve is straight line parallel to *x*-axis (ordinate)
- Viscosity is constant
- Low molecular weight liquids
  water, alcohols, liquid paraffin, glycerin, and thrue solutions

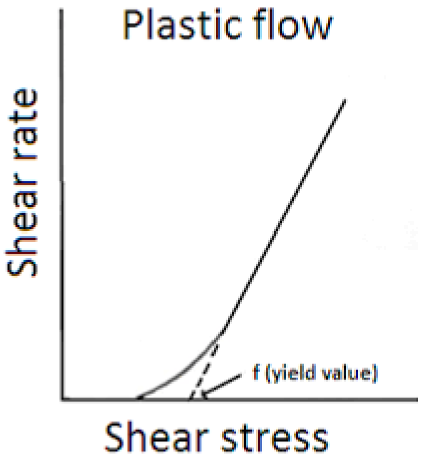
Shear-thinning = Pseudoplastic flow





- Rheogram passes throught the origin
- Flow curve is concave towards the shear-rate axis
- Apparent viscosity decreases with increasing shear rate
- Shear rate thinning
- *Low concentration solutions of polymers*

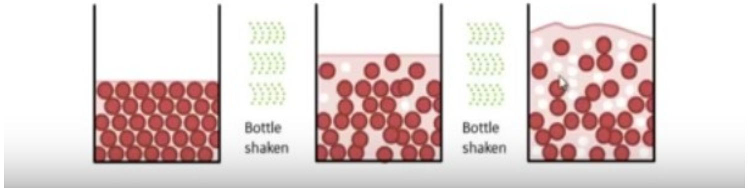
Plastic flow = shear thinning with yield point



- Rheogram (flow curve) doesn´t lead from the origin
- Yield point - the intercept on the shear stress axis
- Apparent viscosity decreases with increasing shear rate
- hight concentration solutions of polymers, gels,

  creams, ointments, pastes… semisolid preparations

Dilatant flow



The viscosity of a shear thickening fluid, or dilatant fluid, appears to increase when the shear rate increases.

An example of a non-Newtonian fluid is a suspension of starch (e.g. cornstarch) in water, sometimes called "oobleck" or "ooze„ (1 part of water to 1.5 - 2 parts of corn starch).

- when stirred slowly it looks liquid
- when stirred vigorously it feels like a solid

Fun with Non-Newtonian Fluid - Lamar University

„Walking on water“

Look at this web pages and watch the video:

https://www.youtube.com/watch?v=RIUEZ3AhrVE

Viscometers/rheometers



- ✓ Capillary viscometers
- ✓ Falling balls viscometers
- ✓ Rotating viscometers/rheometers
  - Relative (spindle)
  - Absolute (CR/CS)


2.2.9 Capillary viscometer method

PRINCIPLE

The determination of viscosity is carried out using a suspended-level (Ubbelohde-type) capillary viscometer of appropriate size at a temperature of 20.0 ± 0.1 °C

The time required for the level of the liquid to drop from one mark to the other is measured.

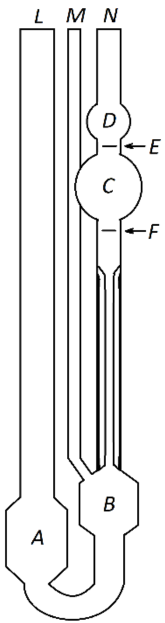
Kinematic viscosity ν (mm^2s^{-1}): $$\nu = k\,t$$

Dynamic viscosity η (mPa.s): $$\eta = k\rho\,t$$

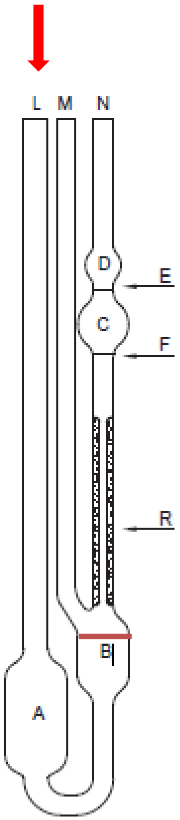
k…constant of the viscometer ($mm^2.s^{-2}$)
ρ…density of the liquid ($g\cdot cm^{-3}$)
t….flow time (s)

The choice of the viscometer size

Size number	Constant of viscometer ($mm^2.s^{-2}$)	Kinematic viscosity range ($mm^2.s^{-1}$)
1	0.01	3.5 to 10
1a	0.03	6 to 30
2	0.1	20 to 100
2a	0.3	60 to 300
3	1.0	200 to 1000
3a	3.0	600 to 3000
4	10	2000 to 10 000
4a	30	6000 to 30 000
5	100	20 000 to 1000 000



Select a capillary viscometer of appropriate size to obtain a minimum flow time of 200 s.



Method

- Charge the viscometer through tube L with a sufficient quantity of the liquid to be examined to fill bulb A while ensuring that the level of liquid in bulb B is below the exit to ventilation tube M.

- Close tube M and draw the level of the liquid in tube N up to a level about 8 mm above mark E. Keep the liquid at this level by closing tube N and opening tube M.

- Open tube N and, using a stopwatch, measure the time required, to at least the nearest 1/5 of a second, for the level of the liquid to drop from mark E to mark F.

- The flow time of the liquid to be examined is the mean of 3 consecutive measurements.

CALCULATION

Calculate the *kinematic viscosity* v in square millimetres per second [$mm^2\ s^{-1}$] using the following expression:

$$v = k\,t$$

Calculate the *dynamic viscosity* η in millipascal seconds [mPa·s] using the following expression:

$$\eta = k \times \rho \times t$$

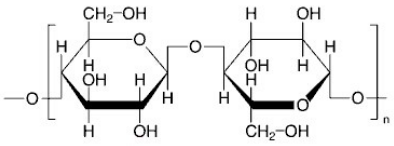
Sample name:			
Time (min:s)			
Average (s)			
Viscometer constant ($mm^2\ s^{-2}$)			
Kinematic viscosity ($mm^2 \cdot s^{-1}$)			
Density ($g \cdot cm^{-3}$)			
Dynamic viscosity [mPa·s]			

Assay of apparent viscosity - *Methylcellulosum*

Nominal value of viscosity: 447 mPa·s

CHARACTERS

A white, yellowish-white or greyish-white powder or granules, hygroscopic after drying, practically insoluble in hot water, in acetone, in ethanol and in toluene. It dissolves in cold water giving a colloidal solution.



Viscosity: 80 per cent to 120 per cent of the nominal value for samples with a viscosity less than 600 mPa·s (Method 1); 75 per cent to 140 per cent of the nominal value for samples with a viscosity of 600 mPa·s or higher (Method 2).

Method 1, to be applied to samples with a viscosity of less than 600 mPa·s. Weigh a quantity of the substance to be examined equivalent to 4.000 g of the dried substance. Transfer into a wide-mouthed bottle, and adjust the total mass of the sample and the water to 200.0 g with hot *water* R. Capping the bottle, stir by mechanical means at 400 ± 50 r/min for 10-20 min until the particles are thoroughly dispersed and wetted. Scrape down the insides of the bottle with a spatula if necessary, to ensure that there is no undissolved material on the sides of the bottle, and continue the stirring in a cooling water-bath maintained at a temperature below 10 °C for another 20-40 min. Adjust the solution mass if necessary to 200.0 g using cold *water* R. Centrifuge the solution if necessary to expel any entrapped air bubbles. Using a spatula, remove any foam. Determine the kinematic viscosity (ν) of this solution using the capillary viscometer method (2.2.9). Separately determine the density (ρ) (2.2.5) of the solution and calculate the dynamic viscosity (η), as $\eta = \rho\nu$.

Protocol of procedure

Concentration of MC dispersion: 2 %
Temperature: 20 ± 0,1 °C

Nominal value of viscosity: 447 mPa·s
Tolerance: 80 % - 120 %

Time* [min:s]	Average	Constant of viscometer [$mm^2 \cdot s^{-2}$]	Kinematic viscosity [$mm^2 \cdot s^{-1}$]	Density [$g \cdot cm^{-3}$]	Dynamic viscosity [mPa·s]
6:55.8		1.0		1.035	
6:52.6					
6:53.2					

* Time in min and sec convert to sec

Rotational rheometers/viscometers

Viscometry: shear rate range from 10^{-1} to 10^{1} s^{-1}
Rheometry: shear rate range from 10^{-3} to 10^{3} s^{-1}

Viscosity of Newtonian (shear-independent viscosity)
or non-Newtonian liquids (shear dependent viscosity or appatent viscosity)

Absolute rotational rheometers

- The flow in the measuring geometry is well defined
- The measurements result in absolute viscosity values, which can be compared with any other abolute values

Relative spindle viscometers

- The flow in the measuring geometry is not defined
- The measurements result in relative viscosity values, which cannot be compared with abolute values or other relative values if not determined by the same relative viscometer method

2.2.10. ROTATING VISCOMETER METHOD

(relative viscometer)

The viscosity of non-Newtonian liquids has a relative character, which depends on:

- the type of spindle and the angular velocity
- the dimensions of the sample container (Ø = minimum 80 mm)
- the depth of immersion of the spindle

The values obtained are comparable only if the method is carried out under experimental conditions that are rigorously the same.

- Speed of the spindle from 0.3 to 100 RPM
- Set of the standard spindles (disc, cylinder, rod)

Assay of viscosity - Hypromellose

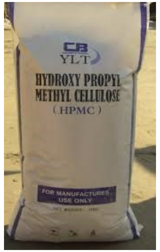
DEFINITION

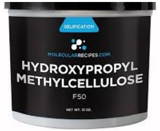
Hydroxypropylmethylcellulose. Cellulose, 2-hydroxypropyl-methyl ether.

Partly *O*-methylated and *O*-(2-hydroxypropylated) cellulose.

Appearance: white, yellowish-white or greyish-white powder or granules, hygroscopic after drying.

Solubility: practically insoluble in hot water, in acetone, in anhydrous ethanol and in toluene. It dissolves in cold water giving a colloidal solution.♦





Viscosity: 80 per cent to 120 per cent of the nominal value for samples with a viscosity less than 600 mPa·s (Method 1); 75 per cent to 140 per cent of the nominal value for samples with a viscosity of 600 mPa·s or higher (Method 2).

Nominal value of viscosity: 122 534 mPa·s

Method 2, to be applied to samples with a viscosity of 600 mPa·s or higher. Weigh a quantity of the substance to be examined equivalent to 10.00 g of the dried substance. Transfer into a wide-mouthed bottle, and adjust the total mass of the sample and the water to 500.0 g with hot *water R*. Capping the bottle, stir by mechanical means at 400 ± 50 r/min for 10-20 min until the particles are thoroughly dispersed and wetted. Scrape down the insides of the bottle with a spatula if necessary, to ensure that there is no undissolved material on the sides of the bottle, and continue the stirring in a cooling water-bath maintained at a temperature below 10 °C for another 20-40 min. Adjust the solution mass if necessary to 500.0 g using cold *water R*. Centrifuge the solution if necessary to expel any entrapped air bubbles. Using a spatula, remove any foam. Determine the viscosity (*2.2.10*) of this solution at 20 ± 0.1 °C using a rotating viscometer.

Apparatus: single-cylinder type spindle viscometer.

Rotor number, revolution and calculation multiplier: apply the conditions specified in Table 0348.-1.

Table 0348.-1.

Nominal viscosity* (mPa·s)	Rotor number	Revolution (r/min)
600 to less than 1400	3	60
1400 to less than 3500	3	12
3500 to less than 9500	4	60
9500 to less than 99 500	4	6
99 500 or more	4	3

Allow the spindle to rotate for 2 min before taking the measurement. Allow a rest period of at least 2 min between subsequent measurements. Repeat the measurement twice and determine the mean of the 3 readings.

Protocol of procedure:

Sample name:

Temperature:

Spindle number:

RPM:

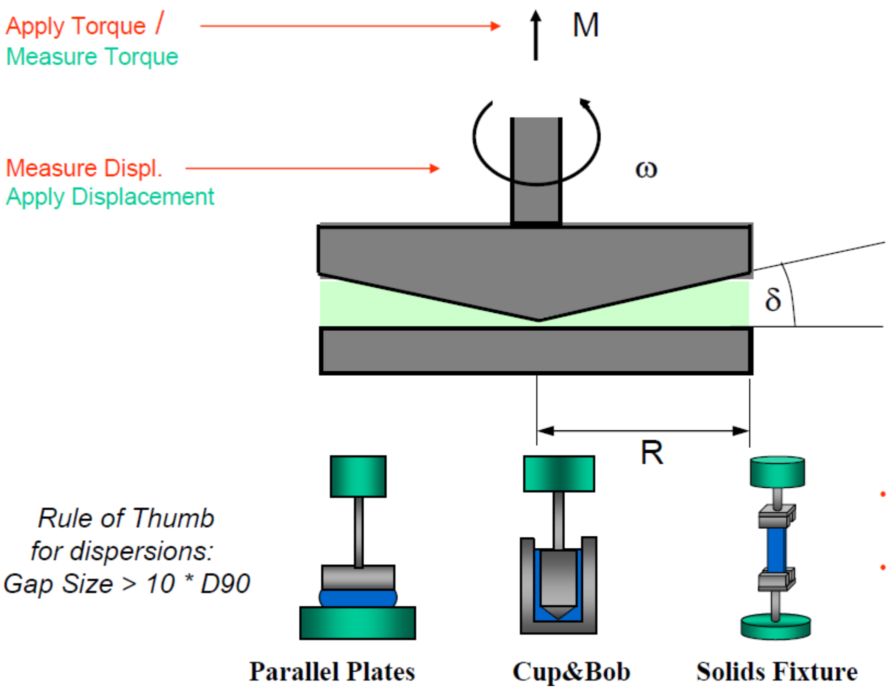
Nominal value of viscosity: 122 534 mPa·s

Tolerance:

Dynamic viscosity [mPa·s]	Average [mPa·s]	% of specified value	Result
108 800			
103 200			*Comply/Do not comply*
101 700			

Absolute rotational rheometers

Choice of Geometry: From Fluids to Solids



Rule of Thumb
for dispersions:
*Gap Size > 10 * D90*

- the higher the viscosity, the smaller the geometry
- the higher the shear rate, the smaller the gap.

Carmellose sodium

is the sodium salt of a partly O-carboxymethylated cellulose.

Characters
A white or almost white, granular powder, hygroscopic after drying, practically insoluble in acetone, in ethanol, in ether and in toluene.

It is easily dispersed in water giving colloidal solutions.

Apparent viscosity
While stirring, introduce a quantity of the substance to be examined equivalent to 2.00 g of the dried substance into 50 ml of water R heated to 90°C. For a product of low viscosity, use if necessary, the quantity required to give the concentration indicated on the label. Allow to cool, dilute to 100.0 ml with water R and stir until dissolution is complete.

Determine the viscosity (2.2.10) using a rotating viscometer at 20 °C and a shear rate of 10 s^{-1}. If it is impossible to obtain a shear rate of exactly 10 s^{-1}, use a shear rate slightly higher and a rate slightly lower and interpolate.

The apparent viscosity is not less than 75 per cent and not more than 140 per cent of the value stated on the label.

Protocol of procedure:

Sample name:

Viscometry_0006 Single shear rate with statistics analysis.rseq

Geometry: CP 1/60

Temperature: 20 °C

Shear rate: 10 s^{-1}

Specified value of viscosity: 2 072 mPa·s

Tolerance: 75 % - 140 %

Shear viscosity [mPa·s]	Average [mPa·s]	% of specified value	Result
1 751			
1 773			
1 816			

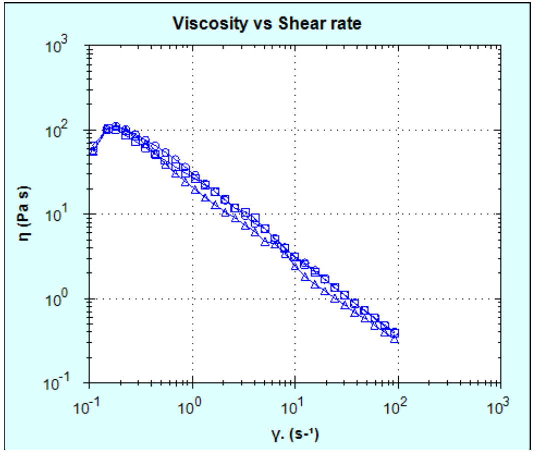
Conclution: *Comply/Do not comply*

Toolkit_V005 Shear Rate Ramp - Alternative Flow Curve.rseq

Power Law model

$\tau = K \cdot D^n$

η_{App}	shear viscosity
D	shear rate
K	index of consistency - viscosity at a shear rate of 1 s^{-1}
n	power law index (flow index)
	= index of the deviation from Newtonian flow
	or measure of non-Newtonian-ness



Measurement	Power law model K (Pa·s^n)	n (-)	corr.
1	29.75	0.0737	0.9095
2	27.71	0.1998	0.9633
3	28.32	0.0183	0.3978
avrg	28.59	0.0973	
SD	1.05	0.0930	

Newtonian flow	n = 1
Pseudoplastic flow (shear-thinning)	$0 < n < 1$
Dilatant flow (shear-thickenning)	$n > 1$

MOODLE

[Course: Pharmaceutical Technology II - Practical Training (cuni.cz)]

THEORETICAL BACKGROUND

SOUBOR
Lecture on rheology_Physical Principles of DF

SOUBOR
Seminar_prezentation

SOUBOR
Basic terms

URL
Types of flow_instruction video

PRACTICAL TRAINING

SLOŽKA
Instructions for measurements

H5P
Measurement on a capillary viscometer_video

H5P
Measurement on a spindle rotational viscometer_video

H5P
Absolute rotational rheometer_introduction video

H5P
Measurement of consistency by penetrometry_video

Thanks for your attention