Viscosity of Newtonian and non-Newtonian liquids (rotary viscometer) (Item No.: P2140300)

Curricular Relevance

Area of Expertise: Physics

Education Level: University

Topic: Mechanics

Subtopic: Mechanics of Fluids and Gases

Experiment: Viscosity of Newtonian and non-Newtonian liquids (rotary viscometer)

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Intermediate	1 Hour	1 Hour	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

shear stress, velocity gradient, internal friction, viscosity, plasticity

Overview

Short description

Principle

The viscosity of liquids can be determined with a rotation viscometer, in which a motor with variable rotation speed drives a cylinder immersed in the liquid to be investigated with a spiral spring. The viscosity of the liquid generates a moment of rotation at the cylinder which can be measured with the aid of the torsion of the spiral spring and read on a scale.

Fig. 1: Experimental set up: Viscosity of Newtonian and non- Newtonian liquids (rotary viscometer).

Equipment

Position	Material	Bestellnr.	Menge
1	Rotary viscometer, 15 - 2,000,000 mPas	18223-99	1
2	Magnetic stirrer with heater MRHei-Tec	35750-95	1
3	Supp.rod stainl.st.,50cm,M10-thr.	02022-20	1
4	Support rod with hole, stainless steel, 10 cm	02036-01	1
5	Right angle clamp	37697-00	2
6	Spring balance holder	03065-20	1
7	Glass beaker DURAN®, short form, 600 ml	36015-00	3
8	Glass beaker DURAN®, tall, 250 ml	36004-00	2
9	Magnetic stirring bar 30 mm, cylindrical	46299-02	1
10	Separator for magnetic bars	35680-03	1
11	Glass rod,boro 3.3,l=200mm, d=5mm	40485-03	1
12	Acetone, chem.pure 250 ml	30004-25	3
13	Glycerol, 250 ml	30084-25	2
14	Liquid paraffin 250 ml	30180-25	1
15	Castor oil 250 ml	31799-27	2

Tasks

1. Determine the gradient of the rotational velocity as a function of the torsional shearing stress for two Newtonian liquids (glycerine, liquid paraffin).
2. Investigate the temperature dependence of the viscosity of Castor oil and glycerine.
3. Determine the flow curve for a non-Newtonian liquid (chocolate).

Set-up and procedure

The experimental set-up is presented in Fig. 1. The rotary viscometer must be adjusted until it is exactly vertical. Use the adjustment screws to do this: they are located on the base of the support stand. There is a box level on the viscometer which allows one to check the exactness of the set-up's adjustment.

Screw the rotary cylinder on carefully (left-handed threads). Subsequently, lower the viscometer until the surface of the liquid exactly reaches the calibration mark on the rotary body in each case. Stir low viscosity fluids while heating to the desired measuring temperature with the aid of a magnetic stirrer and a magnetic stirring rod to rapidly achieve a uniform heat distribution. The temperature should always be measured in the immediate vicinity of the immersion cylinders. After the experimental temperature has been reached, turn off the heater. The temperature should remain constant for several minutes before measurements are begun, as the immersion cylinder must be in thermal equilibrium with the liquid. When thermal equilibrium has been reached, switch off the magnetic stirrer and determine the viscosity of the liquid. Since the moments of rotation which are measured in this experiment are very small, it is necessary to study the operating instructions of the rotary viscosimeter carefully and to follow them exactly.

After the measurement has been made, always clean the bar of the viscometer and the rotary cylinder carefully with water or acetone.

For glycerine and liquid paraffin, determine the dependence of the moment of rotation on the frequency in the range between 0.1 Hz and 1.0 Hz.

For glycerine and castor oil, determine the dependence of the viscosity on the frequency in the temperature range between approximately 290 K and 350 K. For chocolate, determine the dependence of the moment of rotation of the frequency in the range between 0.1 Hz and 1.0 Hz at a temperature of approximately 303 K.

Other substances which are appropriate for investigation are: Newtonian substances: oils, ethylene glycol, etc.

Non-Newtonian liquids: paints (structural colour, hammer effect enamel), syrup, lubricants, chocolate spread, etc.

Theory and evaluation

If a liquid is between two plates and a force F acts along the plate in the direction of the x axis, the plate moves with velocity v . For Newtonian liquids the corresponding component of the shearing stress τ

$\tau = \frac{F}{A}$ (1)

is linked with the velocity gradient $\frac{dv}{dx}$

as follows:

$\tau = \eta \frac{dv}{dx}$ (2)

(η is the viscosity of the liquid and A the area of contact between the plate and the liquid.)

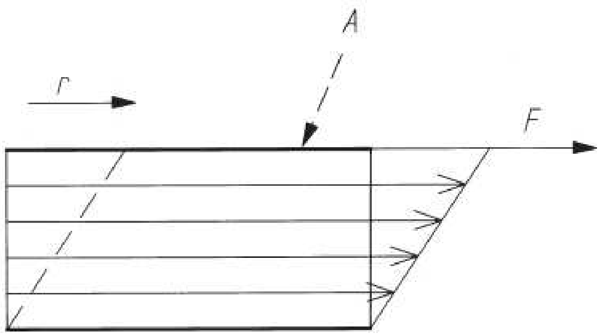


Fig. 2: Velocity gradient and shearing stress.

A number of substances (suspensions, emulsions) show a complex correlation between T and the integral velocity gradient D (non-Newtonian liquids). Hysteresis is also possible.

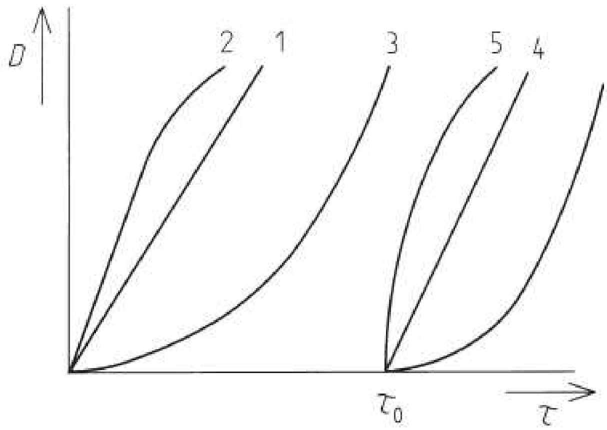


Fig. 3: Viscous and plastic flow of different substances 1. Newtonian (pure viscous) liquid 2. Dilatant liquid 3. Psuedoplastic liquid 4. Bingham (pure plastic) liquid 5./6. Quasiplastic liquid.

Rotary viscometer

A rotary viscometer consists of an inner and an outer cylinder. The liquid to be investigated is located between them. At low rotational velocity the moment of rotation which is exerted on a cylindrical layer of liquid with a radius rand a height h conforms to the following relationship as a result of the rotation of the outer or inner cylinder:

$T(r) = \tau \cdot 2\pi r h \cdot r$ (3)

The shearing stress can be expressed by the measurable moment of rotation:

$\tau(r) = \frac{T}{2\pi r^2 h}$ (4)

In this case, the velocity gradient D is as follows:

$D(r) = r\frac{d\omega}{dr}$ (5)

ω is the angular velocity.

For Newtonian liquids eqn. (2) or eqn. (3) can be substituted in eqn. 1. Integration with the following limiting conditions:

$\omega = 0 \text{ for } r = R_1$

$\omega = f \text{ for } r = R_2$

(R_1 and R_2 are the radii of the two cylinders) gives the following relationship between the measured moment of rotation and the angular velocity:

$T = \frac{4\pi R_1^2 R_2^2 h}{R_2^2 - R_1^2}\eta f = C\eta f$ (6)

where C is a device constant.

The above expression must be further corrected due to edge effects so that C becomes an empirical constant.

It is customary to use the average shearing stress acting on the surface of the two cylinders (2), which is obtained from the geometric or arithmetic mean of the shearing stresses (τ_{mg} or τ_{ma}).

$\tau_{\text{ma}} = T\frac{R_1^2 + R_2^2}{4\pi h R_1^2 - R_2^2}$ (7)

or

$\tau_{\text{ma}} = T\frac{1}{2\pi R_1 R_2 h}$ (8)

Using Expression (4) the following is obtained for D

$D_{\text{ma}} = \frac{R_2^2 + R_1^2}{R_2^2 - R_1^2} \cdot f$ (9)

or

$D_{\mathrm{mg}} = \frac{2R_1+R_2}{R_2^2-R_1^2} \cdot f$ (10)

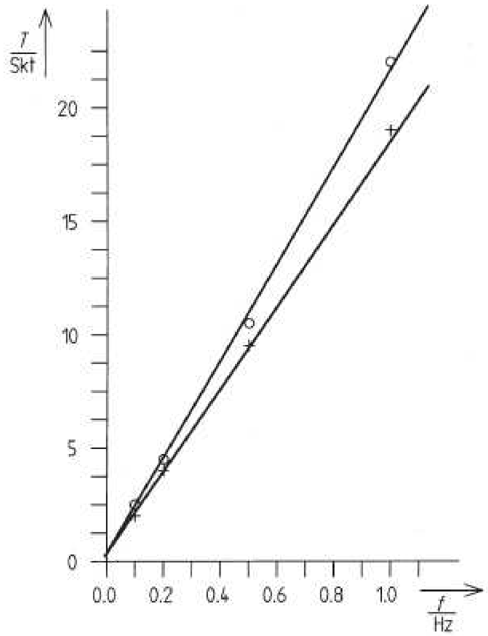


Fig. 4: Moment of rotation as a function of the frequency for a Newtonian liquid + Glycerine o Liquid paraffin

For non-Newtonian liquids T is no longer directly proportional to f nor is τ proportional to D . There is an approximation formula which describes a relationship between T and τ and between D and f .

For many liquids, the viscosity changes exponentially with the temperature T_{abs} :

$\eta = Ae^{b/T_{\mathrm{abs}}}$ (Andrage) (11)

or

$\log\eta = \frac{T_{\mathrm{abs}}+b}{T_{\mathrm{abs}}+c}$ (Vogel) (12)

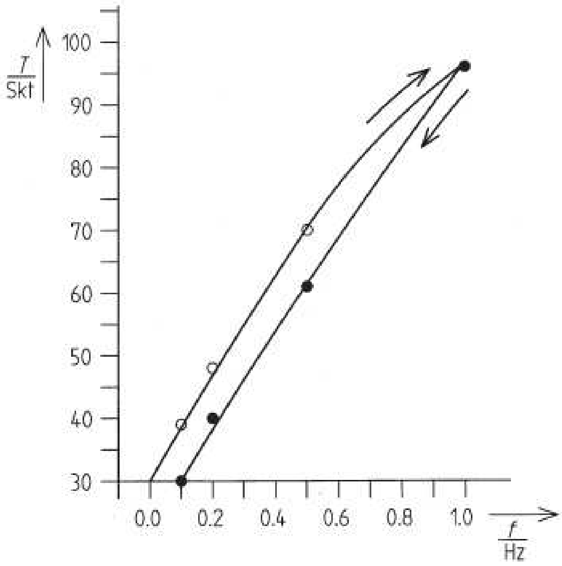
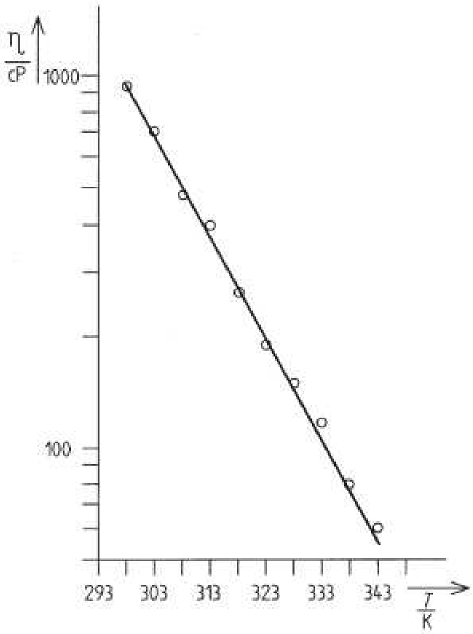


Fig. 7: Moment of rotation as a function of frequency for a non-Newtonian liquid (chocolate at 302 K).

At 303 K the viscosity of glycerine was calculated to be

$\eta = 680\ \mathrm{cP}$



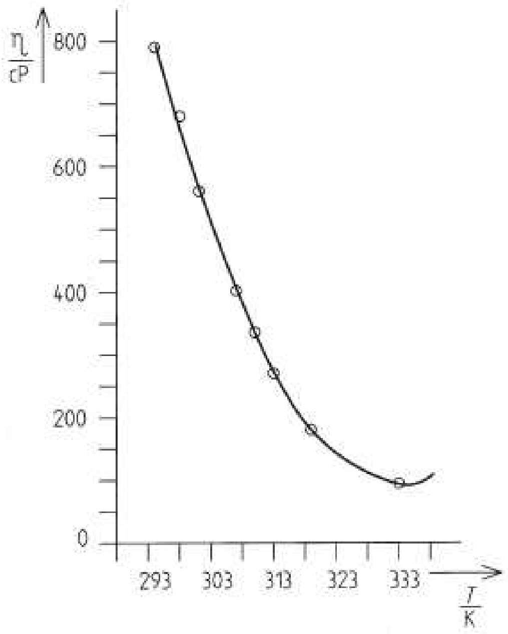


Fig. 5: Temperature dependence of the viscosity of glycerine.

Fig. 6: Temperature dependence of the viscosity of castor oil.

Data

Glycerine

$\eta_{293} = 1499$ cP

$\eta_{303} = 624$ cP