

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

Related concepts

Shear stress, velocity gradient, internal friction, viscosity, plasticity.

Principle

The viscosity of liquids is to be determined with a rotary viscometer, in which a variable-speed motor drives a cylinder immersed in the liquid to be investigated via 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.

Tasks

Determine the gradient of the rotational velocity as a function of the torsional shearing stress for two Newtonian liquids (glycerine, liquid paraffin).

Determine the flow curve for a non-Newtonian liquid (chocolate). Investigate the temperature dependence of the viscosity of Castor oil and glycerine.

Equipment

Rotary viscometer	18221.93	1
Support base -PASS-	02005.55	1
Support rod, stainless steel, $l = 500$ mm	02032.00	1
Right angle clamp	37697.00	1
Magnetic heating stirrer	35720.93	1
Electronic temperature controller	35721.00	1
Magnetic stirrer bar, $l = 30$ mm	46299.02	1
Separator for magnetic bars	35680.03	1
Glass beaker, 600 ml, short	36015.00	3

Glass beaker, 250 ml, tall	36004.00	2
Glass rod, $l = 200$ mm, $d = 5$ mm	40485.03	2
Glycerol, 250 ml	30084.25	2
Liquid paraffin, 250 ml	30180.25	1
Castor oil, 250 ml	31799.27	2
Acetone, chem. pure, 250 ml	30004.25	3
Chocolate		

Set-up and procedure

Set up the experiment as shown in Fig. 1.

The rotary viscometer must be adjusted until it is exactly vertical. To do this, use the adjustment screws of the support base and control the adjustment with the help of the spirit level on the viscometer.

Lower the viscometer until the surface of the liquid exactly reaches the calibration mark of the rotary body. Connect the contact thermometer to the magnetic stirrer and adjust it to the respective experimental temperature (25°C for the first measurement). Place the magnetic stirrer bar in the glass beaker and, under continuous stirring, wait for the temperature to remain constant for several minutes. When thermal equilibrium has been reached, switch off the magnetic stirrer and measure the viscosity of the liquid as described in the operating instructions supplied with the rotary viscometer.

For glycerol 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. In a second experiment, determine the temperature dependence of the viscosity of glycerol and castor oil in steps of 5 degrees between 25 and 70°C. Finally measure the dependence of the moment of rotation on the frequency in the range of 0.1 Hz to 1.0 Hz at a temperature of 30°C.

After each measurement series, clean the viscometer carefully with water or acetone.

Other substances which are appropriate for investigation are oils or ethylene glycol as Newtonian substances, and paints, syrup or lubricants as non-Newtonian liquids.

Theory and evaluation

When a thin film of a liquid is held between two glass plates, moving the plates relative to each other requires the application of force. The liquid layers that are directly adjacent to each the plate surfaces are held to them by forces of adhesion, and forces of cohesion act between the molecules of the liquid. On movement, a linear velocity gradient is formed within the liquid between the two plates.

When the distance between the two plates is dx and the difference in velocity is dv , then acc. to Isaac Newton, a force F is required to move the liquid layers.

$$F = \eta A \frac{dv}{dx} \quad (1)$$

This force is proportional to the area A and the velocity gradient dv/dx . The factor η given here is the dynamic viscosity. The quotient F/A gives the shearing stress τ .

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

A	Area of contact between the plate and the liquid
η	Viscosity of the liquid
dv/dx	Velocity gradient

The dynamic viscosity is therefore equal to the ratio of the shearing stress and the velocity gradient.

Fig. 1. Experimental set-up.



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The gauge in this experiment is a rotary viscometer. It 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 $T(r)$ which is exerted on a cylindrical layer of liquid with a radius r and a height h conforms to the following relationship as a result of the rotation of the outer or inner cylinder:

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

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

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

Fig. 2: Velocity gradient and shearing stress

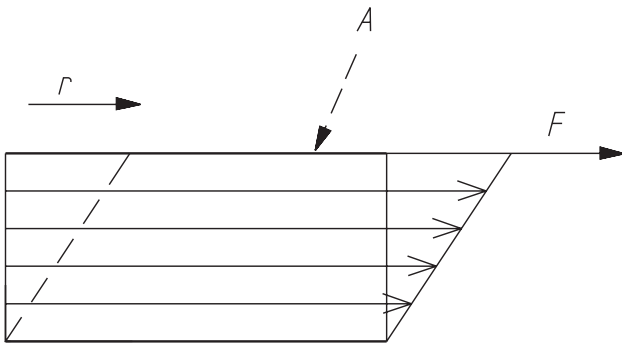
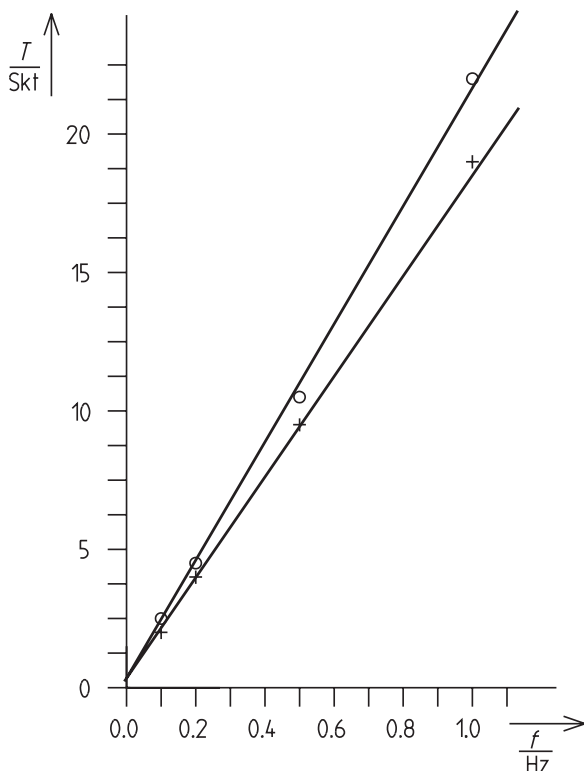


Fig. 3: Moment of rotation as a function of the frequency for a Newtonian liquid.

+ Glycerol
o Liquid paraffin



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

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

ω Angular velocity

Substitution of the equations (2), (4) and (5) and integration with the limiting conditions $\omega = 0$ for $r = R_1$ and $\omega = f$ for $r = R_2$ ($R_1, R_2 =$ radii of the two cylinders) gives the following relationship between the measured moment of rotation and the angular velocity:

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

where C is a device constant.

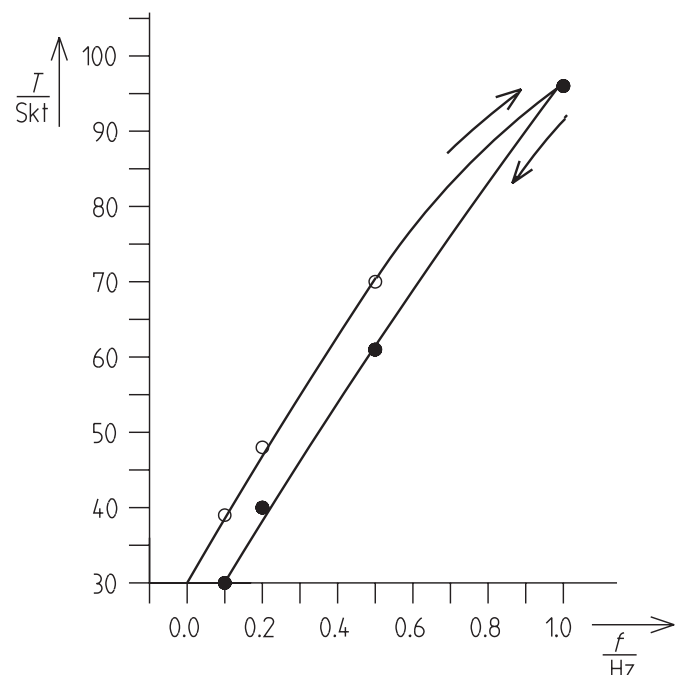
The above expression must be further corrected due to edge effects so that C becomes an empirical constant.

Liquids whose viscosity is independent of the shearing stress and the velocity gradient are called Newtonian liquids. These include liquids of low molecular weight, dilute suspensions of spherical particles and pure, thinly liquid lubricating oils.

With colloidal solutions, suspensions of higher concentration, crystalline liquids and melts, the viscosity is no longer a constant at a given temperature. Such non-Newtonian liquids show a complex correlation between τ and the integral velocity gradient D .

A colloidal solution is one which contains dissolved particles of size between 10^{-5} and 10^{-7} cm. The viscosity of colloidal solutions is dependent not only on the concentration but also on the molecular shape.

Fig. 4: Moment of rotation as a function of the frequency for a non-Newtonian liquid (chocolate at 302 K)



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Spheroid colloids (glycogens, various proteins) have an approximately spherical particle shape. The viscosity of solutions of these is given by the equation

$$\frac{\eta}{c} = K \quad (7)$$

c Concentration

K Constant that has the same value for homologous polymeric substances

Linear colloids (paraffins, rubber, cellulose, polystyrene) have rod-like or sheet-like particle shapes. The viscosity of solutions of the same concentration of a homologous series of polymers is dependent on the molecular length, and increases with increasing degree of polymerisation. In such cases, the viscosity is dependent on the molecular mass.

$$\frac{\eta}{c} = KM \quad (8)$$

Viscosity is a temperature dependent dimension. Liquids exhibit a decrease in viscosity with increase in temperature. When energy is supplied, the average energy of the molecules increases and the mutual forces of attraction between the molecules becomes less noticeable. For most liquids, the following equation is valid:

$$\ln \eta = \frac{E}{RT} + \ln C \quad (9)$$

C Material constant

E Energy required to overcome intermolecular forces

An increase in temperature of 1 K causes the viscosity to be reduced by about 2 %.

Fig. 5: Temperature dependence of the viscosity of glycerol

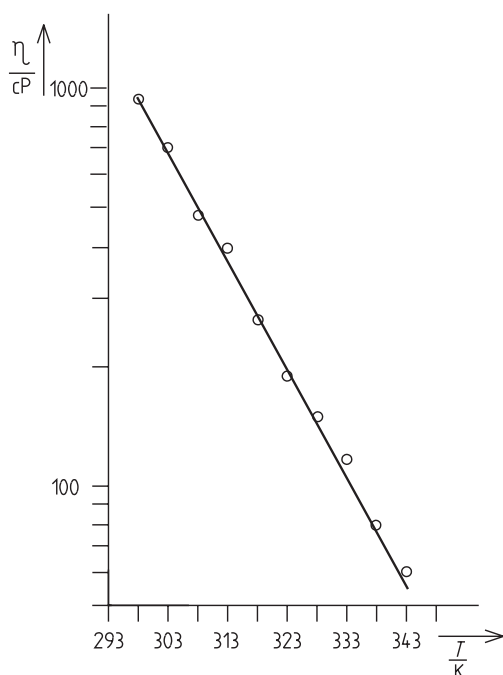


Fig. 6: Temperature dependence of the viscosity of castor oil

