Viscosity measurement with the falling ball viscometer

P2140400

Physics	Mechanics	Mechanics of liquids & gases	
Chemistry	Physical chemistry	Viscosity	
Applied Science	Engineering	Applied Mechanics	Fluiddynamics & Aerodynamics

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

This content can also be found online at:

http://localhost:1337/c/604415cb56e9a30003dc8bc9

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General information

Application

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Varnish

The viscocity of liquids is an important parameter in some industries, for example in:

- lubricants: a suitable lubricant is selected by its viscosity and how it varies with temperature
- medicine: viscosity of medications introduced into the body and the blood viscocity are critical factors in medicines.
- paints and varnishes: the thickness of liquids varies for different types of walls or furnitures

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Other information (1/2)

Prior knowledge

Viscosity is defined as resistance of a fluid to deformation or flow.

Scientific principle

Due to internal friction among their particles, liquids and gases have different viscosities. The viscosity, a function of the substance's structure and its temperature, can be experimentally determined, for example, by measuring the rate of fall of a ball in a tube filled with the liquid to be investigated.

Other information (1/2)

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Other information (2/2)

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Learning objective

Understanding principles of liquids viscocity and its relation with temperature.

Tasks

Measure the viscosity

1. of methanol-water mixtures of various composition at a constant temperature,
2. of water as a function of the temperature and
3. of methanol as a function of temperature.

From the temperature dependence of the viscosity, calculate the energy barriers for the displaceability of water and methanol.

Safety instructions

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For this experiment the general instructions for safe experimentation in science lessons apply.

For H- and P-phrases please consult the safety data sheet of the respective chemical.

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Theory (1/6)

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The dynamic viscosity η of a liquid (1) is defined by the force F which is required to move two parallel layers of liquid both having the area A and separated by dx with the velocity $d\omega$ with respect to each other.

$$\eta = \frac{F}{A\,\frac{d\omega}{dx}} \qquad (1)$$

By relating the dynamic viscosity to the density ρ of the liquid, one obtains the kinematic viscosity v (2); the reciprocal of the dynamic viscosity is designated as fluidity ϕ (3).

$$v = \frac{\eta}{\rho} \qquad (2)$$

$$\phi = \frac{1}{\eta} \qquad (3)$$

Theory (2/6)

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A spherical particle with a radius r moves in a liquid under the influence of a force F and the viscosity η with a constant velocity ω .

$$\omega = \frac{F}{6\pi\eta r} \qquad (4)$$

For the fall of a sphere in the gravitational field of the earth the motive force F is equal to the product of the acceleration of gravity g and the effective mass m, which can be expressed as the density difference between the sphere (ρ_1) and the liquid (ρ_2).

$$F = m'g = \frac{4}{3}\pi r^3 g(\rho_1 - \rho_2) \qquad (5)$$

The correlation (6) for the calculation of the viscosity, which is derived from (4) and (5), is only considered as the limit law for expanded media (the radius can be neglected with respect to that of the gravity tube); otherwise, the relationship can be approximated by corrections (Ladenburg Correction).

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Theory (3/6)

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$$\eta = \frac{2r^2 \left(\rho_1 - \rho_2\right) g}{g\omega} \qquad (6)$$

For commercial falling ball viscometers with sets of calibrated spheres, the constants in equation (6) are combined with the apparative factors to form the spherical constant K; this makes the calculations much simpler:

$$\eta = Kt \left(\rho_1 \ - \ \rho_2\right) \qquad (7)$$

(t = rate of fall of the sphere for a measuring distance of s = 100 mm)

The density ρ_2 of the liquid at temperature T which is contained in Eq (7), can be calculated using the relationship

Theory (4/6)

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$$\rho_2 = \frac{m}{V} \qquad (8)$$

(m = mass of the liquid; V = volume of the pycnometer)

using the experimentally determined pycnometer data or alternatively that obtained from Tables 1 and 2.

The viscosity is a function of the structure of the system and the temperature. The alteration in the measured viscosity in which the composition of methanol-water mixtures are expressed as the mass fraction ω (9.1) or the mole fraction x (9.2) is an expression of the non-ideal behaviour of the liquids. It correlates to additional mixing phenomena such as mixing volume (volume contraction) and mixing enthaIpy.

$$\omega_1 = \frac{m_1}{m_1 + m_2} \qquad (9.1)$$

(ω_1 = mass fraction, m_1 = mass of the substance 1)

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Theory (5/6)

$$x_1 = \frac{n_1}{n_1 + n_2} = \frac{\frac{m_1}{M_1}}{\frac{m_1}{M_1} + \frac{m_2}{M_2}} \qquad (9.2)$$

(x_1 = mole fraction, n_1 quantity of substance, m_1 = mass of the substance 1, M_1 = molar mass of substance 1)

For many liquids the reduction of the viscosity with temperature is described by an empirically determined exponential function (10).

$$\frac{1}{\eta} = \phi = Ce - \frac{E}{RT} \qquad (10)$$

$R = 8.3144\, J \cdot K^{-1} \cdot mol^{-1}$, universal gas constant.

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Equipment

Position	Material	Item No.	Quantity
1	Falling ball viscometer	18220-00	1
2	Thermometer, 24...+ 51 °C, for Falling ball viscometer	18220-02	1
3	Immersion thermostat Alpha A, 230 V	08493-93	1
4	Cooling coil for thermostat Alpha A	08493-01	1
5	External circulation set for thermostat Alpha A	08493-02	1
6	Bath for thermostat, makrolon	08487-02	1
7	Retort stand, h = 750 mm	37694-00	1
8	Right angle boss-head clamp	37697-00	1
9	Universal clamp with joint	37716-00	1
10	Pycnometer, calibrated, 25 ml	03023-00	1
11	Volumetric flask, Borosilicate, 100 ml, IGJ12/21	36548-00	9
12	Beaker, Borosilicate, tall form, 150 ml	46032-00	11
13	Beaker, Borosilicate, low form, 250 ml	46054-00	1
14	Pasteur pipettes, 250 pcs	36590-00	1
15	Rubber caps, 10 pcs	39275-03	1
16	Rubber tubing, i.d. 6 mm	39282-00	6
17	Digital stopwatch, 24 h, 1/100 s and 1 s	24025-00	1
18	Wash bottle, plastic, 500 ml	33931-00	2
19	Methanol 500 ml	30142-50	2
20	Water, distilled 5 l	31246-81	1
21	Hose clamp for 8-12 mm diameter	41000-00	10
22	Rubber tubing, i.d. 10 mm	39290-00	1
23	Tubing connector, ID 6-10mm	47516-01	2

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Setup and procedure

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Setup (1/2)

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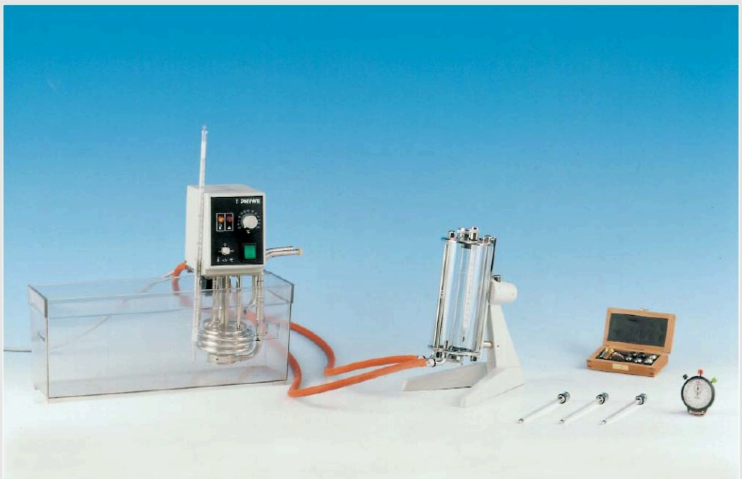

Experimental set-up

Perform the experimental set-up according to the figure. Connect the falling ball viscometer to the pump connection unit of the thermostat with rubber tubing (secure the tubing connections with hose clips!).

Fill the bath of the circulating thermostat with distilled or demineralised water to avoid furring.

Connect the cooling coil of the thermostat to the water supply line with tubing (secure the tubing connections with hose clips!).

Setup (2/2)

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$m(CH_3OH)/g$	$m(H_2O)/g$	$\rho/g\cdot cm^{-3}$	$\eta/mPa\cdot s$
0	100	0.9970	0.897
10	90	0.9804	1.178
20	80	0.9649	1.419
30	70	0.9492	1.581
40	60	09316	1.671
50	50	0.9122	1.577
60	40	0.8910	1.427
70	30	0.8675	1.234
80	20	0.8424	1.025
90	10	0.8158	0.788
100	0	0.7867	0.557

Table 1

Prepare the falling ball viscometer according to its operating instructions; calibrate it; and for each experiment fill it with the liquid to be investigated (water, methanol or methanol-water mixtures according to the table) in such a manner that it is bubble-free.

Table 1: Literature values for the density and the dynamic viscosity of methanol-water mixtures of different compositions at constant temperature (T= 298.15 K)

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Procedure (1/2)

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Ball number 1, which is made of borosilicate glass, is appropriate for investigations in the given viscosity range. Its characteristic data can be obtained from the enclosed test certificate. After the ball has been placed in the gravity tube, first allow the viscometer to equilibrate to the selected working temperature T for approximately 10 minutes before determining 3 to 5 falling times t. Calculate the arithmetic mean of the measured values in each case.

A constant working temperature of 298 K is recommended for the viscosity measurements in methanol-water mixtures (Tasks 1).

Conduct the investigations on the temperature dependence of the viscosity of pure liquids (Tasks 2 and 3) in steps of 5 K in the temperature range between 293 K and 323 K. Parallel to this, determine the density of the respective liquids, which is required for the calculations.

To do this, weigh the clean and dry pycnometer; fill it with the liquid to be investigated; fix it to the retort stand, and equilibrate it in the thermostatic water bath for approximately 15 minutes.

Procedure (2/2)

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	Water		Methanol	
T/K	$\rho=/\mathrm{g}\cdot\mathrm{cm}^{-3}$	$\eta/\mathrm{mPa}\cdot\mathrm{s}$	$\rho/\mathrm{g}\cdot\mathrm{cm}^{-3}$	$\eta/\mathrm{mPa}\cdot\mathrm{s}$
293.15	0.9982	1.002	0.7915	0.608
298.15	0.9970	0.897	0.7868	0.557
303.15	0.9956	0.797	0.7819	0.529
308.15	0.9940	0.726	0.7774	0487
313.15	0.9922	0.653	0.7729	0.458
218.15	0.9902	0.597	0.7690	0.425
323.15	0.9880	0.548	0.7650	0.396

Table 2

Subsequent to bubble-free closure with the accompanying stopper and a quick external drying, reweigh the filled pycnometer. From the mass difference of the two weighings and the volume of the pycnometer, determine the density of the liquid. Rinse the gravity tube and the pycnometer thoroughly with the next liquid to be investigated each time before it is refilled.

Table 2: Literature values for the density and the dynamic viscosity of water and methanol at different temperatures

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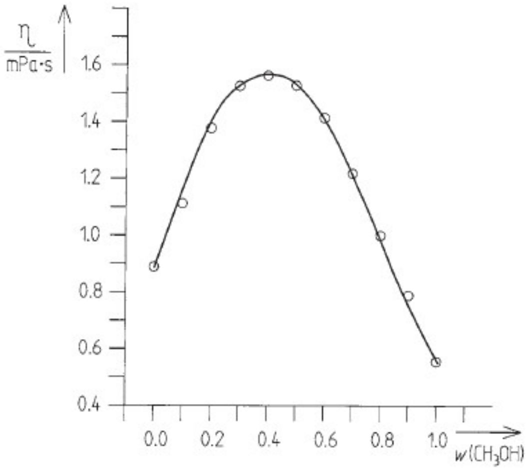
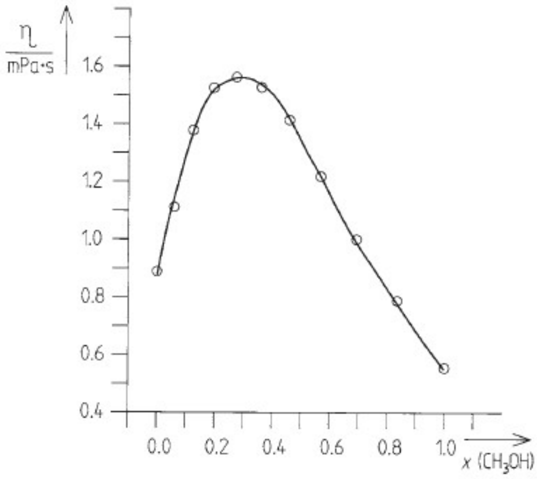
Evaluation (1/5)



Dependence of the viscosity η of the methanol water system on the mass fraction.

Figure shows the dependence of the viscosity η of the methanol water system on the composition described by the mass traction at constant temperature (T = 298 K).

Evaluation (2/5)



Dependence of the viscosity η of the methanol water system on the mole fraction.

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Evaluation (3/5)

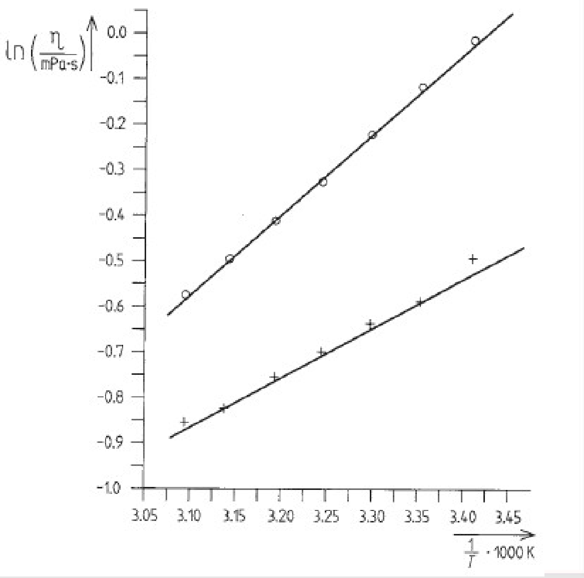

Figure shows the dependence of the dynamic viscosity η of water (o) and methanol (+) on temperature.

The following values are determined for the slopes of the linear relationships between $ln\,\eta$ and $1/T$, which are obtained by linear regression analysis:

$$\Delta(ln\,\eta)/\Delta(1/T) = 1.799 \cdot 10^3\,K(H_2O)$$

and

$$\Delta(ln\,\eta)/\Delta(1/T) = 1.134 \cdot 10^3\,K(CH_3OH)$$

Evaluation (4/5)

Substituting these values in Eq. (10.1), the corresponding energy barriers are obtained

$E = 14.8\,kJ \cdot mol^{-1}\ (H_2O)$ and

$E = 9.4\,kJ \cdot mol^{-1}\ (CH_3OH)$

The energy barriers, which are obtained by using the literature values for η (given in Table 2), are

$E = 15.9\,kJ \cdot mol^{-1}$ and

$E = 11.1\,kJ \cdot mol^{-1}$

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Evaluation (5/5)

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Fill in the blank:

The resistance of a fluid to flow during the presence of an external force is defined as ____________, meanwhile ____________ results from the resistive flow of a fluid under the weight of gravity.

dynamic viscosity | kinematic viscosity

Check

Fill in the missing words

If the temperature increases, the viscosity of the fluid ________ due to the ________ in intermolecular forces.

Check

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