Viscosity measurements with the falling ball viscometer (Item No.: P2140400)

Curricular Relevance

Area of Expertise: Physics
Education Level: University
Topic: Mechanics
Subtopic: Mechanics of Fluids and Gases
Experiment: Viscosity measurements with the falling ball viscometer

Difficulty	**Preparation Time**	**Execution Time**	**Recommended Group Size**
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Difficult	1 Hour	3 Hours	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

liquid, Newtonian liquid, Stokes law, fluidity, dynamic and kinematic viscosity, viscosity measurements

Overview

Short description

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.

Fig. 1: Experimental set up: Viscosity measurements with the falling ball viscometer.

Equipment

Position No.	Material	Order No.	Quantity
1	Falling ball viscometer	18220-00	1
2	Thermometer, 24...+ 51 ºC, for Falling ball viscometer	18220-02	1
3	Precision Balance, Sartorius ENTRIS623-1S, 620 g / 0,001 g	49294-99	1
4	Immersion thermostat Alpha A, 230 V	08493-93	1
5	Bath for thermostat, makrolon	08487-02	1
6	Cooling coil for thermostat Alpha A	08493-01	1
7	External circulation set f. thermostat Alpha A	08493-02	1
8	Retort stand, h = 750 mm	37694-00	1
9	Universal clamp with joint	37716-00	1
10	Right angle clamp	37697-00	1
11	Pycnometer, calibrated, 25 ml	03023-00	1
12	Volumetric flask 100 ml, IGJ12/21	36548-00	9
13	Glass beaker DURAN®, short, 250 ml	36013-00	1
14	Pasteur pipettes, 250 pcs	36590-00	1
15	Glass beaker DURAN®,tall, 150 ml	36003-00	11
16	Rubber caps, 10 pcs	39275-03	1
17	Stopwatch, digital, 1/100 s	03071-01	1
18	Hose clamp for 5-12 mm diameter	40997-00	10
19	Rubber tubing, i.d. 10 mm	39290-00	1
20	Rubber tubing, i.d. 6 mm	39282-00	6
21	Tubing connector, ID 6-10mm	47516-01	2
22	Wash bottle, plastic, 500 ml	33931-00	2
23	Methanol 500 ml	30142-50	2
24	Water, distilled 5 l	31246-81	1

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.

Set-up and procedure

Perform the experimental set-up according to Fig. 1. 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!).

In addition, 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 Tab. 1) in such a manner that it is bubble-free.

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. 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.

$m(CH_3OH)/g$	$m(H_2O)/g$	$\rho/g \cdot cm^{-3}$	$\eta/mPa \cdot s$
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

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

	Water		Methanol	
T/K	$\rho = /g \cdot cm^{-3}$	$\eta/mPa \cdot s$	$\rho/g \cdot cm^{-3}$	$\eta/mPa \cdot s$
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

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

Note

The measurements are time consuming and take approximately 10 hours when painstakingly performed. It is therefore appropriate to divide the experiment according to the three given tasks or to have them performed optionally. Another possibility is to have the complete experiment carried out on two laboratory days.

Theory and evaluation

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.

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

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

$$\upsilon = \frac{\eta}{\rho} \quad (2)$$

$$\varphi = \frac{1}{\eta} \quad (3)$$

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.

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

(Stokes Law)

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).

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

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).

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

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:

$$\eta = Kt(\rho_1 - \rho_2) \quad (7)$$

(*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 eqn. (7), can be calculated using the relationship

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

(*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 enthalpy.

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

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

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

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

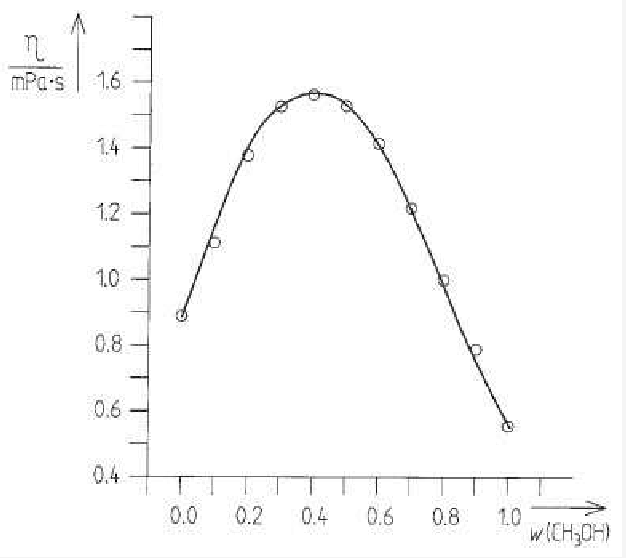

Fig. 2: Dependence of the viscosity η of the methanol water system on the composition described by the mass traction at constant temperature (T = 298 K).

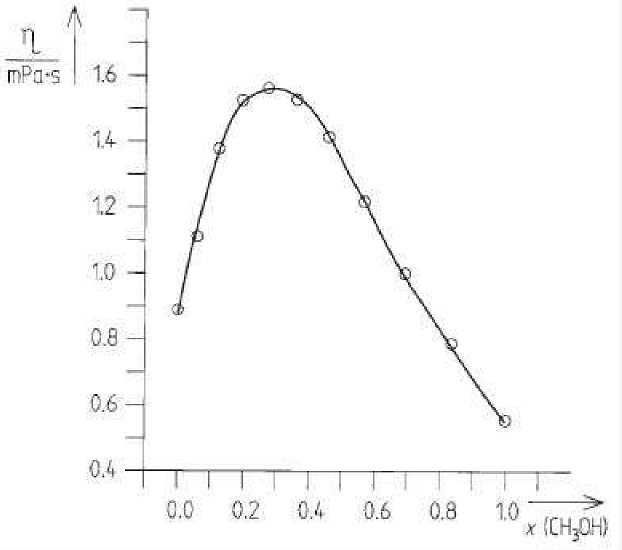

Fig. 3: Dependence of the viscosity η of the methanol water system on the composition described by the mole fraction x at constant temperature (T = 298 K).

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

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

$R = 8.31441\ \mathrm{J} \cdot\ \mathrm{K}^{-1} \cdot\ \mathrm{mol}^{-1}$, universal gas constant

In this relationship which is analogous to the Arrhenius equation, *C* represents a system-dependent constant; *E* is an expression of the molar energy which is required to overcome the internal friction. This activation energy can be determined from the slope obtained by the linear relation (10.1) between ln η and 1/T (Fig. 4)

ln $\eta = \frac{E}{R}\frac{1}{T}$ - ln C (10.1)

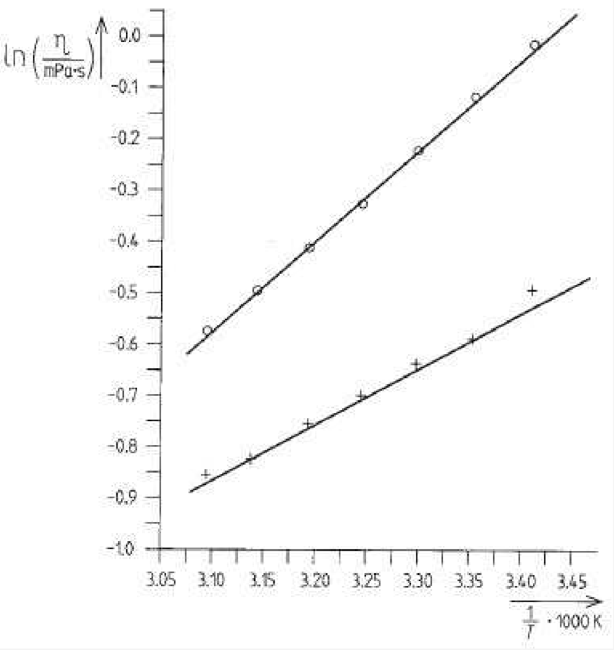

Fig. 4: Temperature dependence of the dynamic viscosity η of water (o) and methanol (+), respectively.

Data and results

The experimentally determined viscosities are presented graphically in the Figures 2 to 4 as a function of the composition of the methanol-water mixtures or of the temperature.

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

$\Delta(\ln\eta)/\Delta(1/T) = 1.799 \cdot 10^3\ \mathrm{K}\ (\mathrm{H_2O})$ and

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

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

$E = 14.8\ \mathrm{kJ \cdot mol^{-1}}\ (\mathrm{H_2O})$ and $E = 9.4\ \mathrm{kJ \cdot mol^{-1}} (\mathrm{CH_3OH}).$

The energy barriers, which are obtained by using the literature values for η (given in Table 2), are $E = 15.9\ \mathrm{kJ \cdot mol^{-1}}$ and $E = 11.1\ \mathrm{kJ \cdot mol^{-1}}$.