

Viscosity of ethanol–water mixture

Viscosity is the physical quantity specifying the flowing properties of liquids. Viscosity itself is physically expressed as transportation phenomenon of momentum in flowing liquids. Viscosity is important properties for engineering such that designing chemical plants requires precise information about the viscosity of solutions. Also, dynamic properties are sometimes influenced by the static microscopic structures in solutions. Here, we would like to employ the Ubbelohde type viscometer to determine the viscosity of ethanol aqueous solutions.

Theoretical Background

In flowing liquid, the each small domains have flowing velocity dependent on position x . Such velocity distribution depends on viscosity. Consider two planes 1 and 2 in a liquid under stationary flow, *e.g.* viscosity distribution are independent of time, flowing at constant velocity $v_0 + v$ and v_0 . Each has the same area A , and the separation between planes l . There exists the force F between the two planes resulting from the shear viscosity. The force F is given by

$$F = \eta \frac{Av}{l}, \tag{1}$$

where the proportional coefficient η is called as viscosity of the liquid. In a liquid of large viscosity, the shear between planes causes the strong force between two planes which result in small velocity gradient and thus small spacial distribution of velocity. According to the equation (1), viscosity has the dimension of $[MT^{-1}L^{-1}]$, which gives the unit of $[Pa\ s]$ in MKS system, and $[P]$ or $[Poise]$ in cgs system. These units convert as $1\ Pa\ s = 10\ P$.

Consider the flowing down of liquid in the capillary which has cylindrical and concentric velocity distribution under stationary state. Applying the equation (1) to the small planes in liquid vertically flowing down in the capillary, using the cylindrical symmetry of velocity distribution, and integrating from the center to the side of capillary where the velocity is assumed to be zero. The flowing rate u is obtained as

$$u = \frac{\pi (P_1 - P_2)R^4}{8 \eta L}. \tag{2}$$

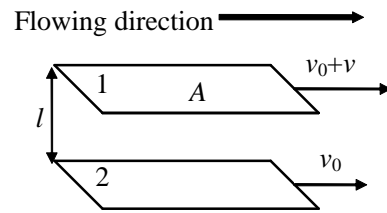


Fig. 1. Forces between two planes in flowing liquids.

Here, P_1 and P_2 are pressures at the entrance and the exit of capillary, R and L the radius and length of capillary. When P_1 and P_2 are constant, flowing rate u is inversely proportional to the viscosity η . Period t during which a given volume V of liquid flows down through the capillary is given by

$$t = \frac{V}{u} = \frac{8}{\pi} \frac{\eta LV}{(P_1 - P_2)R^4}, \quad (3)$$

indicating the inversely proportion of t against η .

When the radius and length of capillary are given, absolute value of viscosity is obtained via eq. (3) by determining the flowing rate. In practice, as it is impossible to determine these quantities with enough precision, η is obtained as relative value η_r against that of standard substance η_0 (usually water), as follows:

$$\eta_r = \frac{\eta}{\eta_0}. \quad (4)$$

Obviously relative viscosity η_r is dimensionless quantity. On the other hand, since the origin of pressure difference in eq. (3) in the actual experiment is gravity working on liquid itself, pressure difference between entrance and exit has to be proportional to sample density as follows:

$$P_1 - P_2 = \rho gL. \quad (5)$$

Here ρ is the density of the liquid and g the gravitational acceleration. From eq. (3) the viscosity is

$$\eta = \frac{\pi}{8} \frac{gR}{V} \rho t, \quad (6)$$

indicating the proportionality to the product ρt . Therefore, relative viscosity is given by

$$\eta_r = \frac{\rho t}{\rho_0 t_0}, \quad (7)$$

where ρ and ρ_0 are densities of sample and reference liquids, t and t_0 the flowing time of sample and reference liquids measured with the same viscometer.

Experimental Protocol

Preparation of samples

Prepare the solutions of mole fraction x of 0, 10, 12, 15, 17, 20, 22, 25, 27, 30, 35, 40, 50, 60, 80 and 100%. You can prepare them as precise as possible with the following procedure: Put proper

amount of water into weighed 50 mL Erlenmeyer flask (mass m_0) and weigh with the chemical balance (reading of m_1). Obtain the amount of water you put and calculate the amount and mass of ethanol to be added (m_2^{ex})

$$m_2^{\text{ex}} = m_1 + \frac{(m_1 - m_0)}{M_{\text{water}}} \times \frac{x}{1-x} \times M_{\text{ethanol}} . \quad (8)$$

Here, x is mole fraction of ethanol you intend to prepare, M_{water} and M_{ethanol} are the molar masses (or molecular weight) of water and ethanol, respectively. Add ethanol weighing on a balance and try to make to the reading as close to m_2^{ex} as possible. When you make the reading close enough for you to satisfy, stop at the top of the Erlenmeyer and weigh precisely (m_2).

- You will need about 10 mL of sample solution for the measurement and another ~10 mL of sample for rinsing viscometer when you changed your sample. So you should make at least 30 mL of solutions.
- In this experiment, what is important is not to prepare samples of exact concentration value but to know the precise concentration you made. In this sense, you do not have to make 20.00 mole % for example, but is 21 mole% also fine. However, the one who is good at experiment would try to make 20.0 or 20.00 mole %. This is because he will get more beautiful data and graph, especially for experiments changing concentration finely like this.

Measurement

Put the sample of 5 to 10 mL into well-cleaned (rinsed with sample for a couple of times) Ubbelohde type viscometer and put the triple legged glass with rubber tubes and fix it vertically in the thermostat controlled at 30 °C. Check that all portion of touch with sample solution locate under the surface and leave as it is for about 15 min in order to equilibrate the temperature of sample with thermostat.

Stop at the by-passing tube with stop cock, pinch the rubber tube at the top of capillary with your fingers to lift up the liquid meniscus above the upper marked line. Remove the stop cock and your fingers from the tube, start running down and start the stopwatch at the time when the meniscus passes through the upper marked line. Stop the stopwatch at the time when the meniscus passes through the lower marked line. Record the time of duration. Repeat this for a couple of times to check the reliability. If the running duration comes long for each time, it might not be enough for temperature equilibration. Repeat the measurements until the time comes almost constant.

- When you lift up the liquid, you would sometimes find a bubble at the bottom of capillary. This may cause the resistance of flow resulting in the error. Try to remove the bubble, by flicking the capillary, before you start measurement.

Start your measurement from distilled water, and then two ethanol solutions with different concentration. When you change your sample, discard the sample, rinse the viscometer with new

sample for a couple of time and then put the new sample of about 10 mL. Fix the viscometer at the thermostat and continue the experiments.

Data Analysis

Evaluation of viscosity

Calculate the density ρ of each solution at 30 °C from the table by interpolating linearly the neighboring values. Literature values for density are obtained from the links of Takeda's web site (<http://ostwald.naruto-u.ac.jp/~takeda/takedae.htm>) related to the class. Also obtain the density of water ρ_{water} and viscosity of water η_{water} in the same manner.

- You can get more precise values by interpolating with the 2nd order polynomial function determined with the least squares method. Do you know any other method of interpolation? Check it up.

By means of eqs. (4) and (7), viscosity of the sample is obtained from the time of flowing down of water and the sample as follows.

$$\eta = \eta_{\text{water}} \frac{\rho t}{\rho_{\text{water}} t_{\text{water}}} . \quad (9)$$

Presenting results and discussion

Plot the viscosity values against the mole fraction of ethanol. Do not forget to plot your friends' data along with yours. Discuss the reason why the viscosity of aqueous ethanol solution shows a maximum against the concentration. Take it into account the effect of *hydrophobic interaction* between water molecules and ethyl groups.