

Viscosity of Liquids

Introduction

The viscosity of a fluid is its resistance to flow. It is a quantitative property of a fluid, be it liquid or gas, and can be used as an index in quality control applications of oils, paints or other fluids where flow is a critical property. Viscosity arises from the directed motion of molecules past each other and the transfer of momentum.

Poiseuille (1844) did much work concerning the interpretation of liquid flow through tubes. One important result of his mass transport analysis is the following equation:

$$h = \frac{\eta r^4 P t}{8 V L}$$

where η is the viscosity, t is the elapsed time, V is the volume of liquid passing through the tube, P is the hydrostatic pressure of the liquid and L is the distance traveled by the liquid in time t . Although not an official SI unit, the unit of viscosity (η), still used by many, is named in his honor and is called the poise (P). It has units of 1 g/cm-s (or dyne-seconds/cm²). Many liquids at room temperature have viscosities about 0.002 to 0.04 and the unit of the cP (10⁻² P) is used. The official SI unit has units of kg/m-s (or Pascal-seconds). 1 cP = 10⁻³ Pa-s.

This equation above is directly applicable to a device such as the Ostwald viscometer. A liquid is allowed to flow through a small bore capillary between two etched marked and the time is measured. Since the distance L will remain the same in all work and since the pressure P depends on density D it is possible to rearrange the above equation to obtain

$$\eta = k D t$$

where k is a constant that incorporates the constant factors. In practice a liquid of known viscosity and density is used to calibrate the Ostwald viscometer. Then for any other liquid

$$h = \frac{h_r D t}{D_r t_r}$$

where the subscripted r values refer to the reference sample. In this experiment we will explore the viscosity of two sets of mixtures, methanol/water and toluene/p-xylene. The viscosity of water will be our reference and we will compare the influence of mixing on viscosity. The viscosity of water at 25°C is 0.8904 centipoise (cp).

Temperature also changes viscosity, rather dramatically. Arrhenius (1912) expressed this dependence as

$$h = A \exp\left(\frac{E_h}{RT}\right)$$

with A a constant for a given liquid and E_h the activation energy for viscous flow. This is the energy barrier that must be surmounted in order for a molecule to “squeeze” by its neighbors. A plot of $\ln \eta$ vs. $1/T$ should be linear and have a slope equal to E_h/R . We will also want to investigate and determine the influence of temperature on viscosity and the activation energy of viscous flow.

Procedure

Week One

1. Make up 10 ml solutions of water/methanol that are 0, 20, 40, 60, 80, and 100 percent by volume methanol. Use deionized water. Determine the density of these solutions using a 5 ml pipette.
2. Make up 10 ml solutions of toluene/p-xylene that are 0, 20, 40, 60, 80, and 100 percent by volume p-xylene. Determine the density of these solutions as before.

Week Two

1. Suspend the viscometer into a large beaker of water that is as close to 25° C as possible. Pipette 5 ml of deionized water of known density into the Ostwald viscometer and allow time for the liquid to equilibrate to the temperature of the bath. Then use a pipette bulb to push or pull the liquid level up above the upper fiducial mark on the viscometer. Allow the water to run back down and start the timer exactly as the meniscus passes the upper mark. Stop the timer just as the meniscus passes the lower mark. Repeat at least twice. Your flow times should agree to within about 0.4 seconds.
2. Clean and dry the viscometer by running a few milliliters of acetone through it. Drain the acetone and aspirate for about a minute to evaporate all the acetone.
3. Determine the flow times of each of your methanol/water solutions at 25° C. Repeat each at least twice. Your flow times should agree to within about 0.4 seconds.
4. Clean and dry the viscometer as before.
5. Determine the flow times of each toluene/p-xylene solution as in step 3. End the determinations with the pure p-xylene.
6. For our temperature work heat the water bath in roughly 10 to 15 degree increments and determine the flow time of the pure p-xylene as before at each temperature. Stop at about 65° C.

Calculations

1. Determine the viscosity coefficient of each mixture and for the temperature runs. Compare the viscosity of the methanol/water mixtures to the toluene/p-xylene mixtures by graphing the value of the viscosity coefficient (η) versus the volume percentage of each mixture. Comment on the shape of the graphs.
2. Next look at the dependence of viscosity on temperature. Plot $\ln \eta$ vs. $1/T$ and determine the activation energy and the error in the activation energy. (Use Excel to get the error in the slope and use it in a simple propagated error analysis)

Reference

A. Halpern and J. Reeves, *Experimental Physical Chemistry*, 1988, Scott and Foresman.