Viscosity

Objective

The objective of this laboratory is for you to understand the science and practical aspects of how a quartz crystal monitor can be used to measure the viscosity of fluids and fluid mixtures.

Preparation

Read 2007 paper by Tsionsky posted at the Compass web-site and the section on "Liquid Contact Measurements" (pp. 29-32) of the operating manual for the quartz crystal monitor.

Equipment and samples

- Quartz crystal monitor; electronics and frequency counter; computer; labview software.
- Two syringe pumps; syringes; tubing and vessel to collect waste; in-line bubble blocking membranes.
- Water, methanol, ethanol, propanol, butanol, glycerol.

Introduction

In first half of MSE 308, we studied heat conduction and diffusion. In steady-state, the transport of heat is governed by the thermal conductivity; the ratio of the thermal conductivity to the heat capacity is the thermal diffusion coefficient. In this lab, you will study the transport coefficient for shear momentum in a fluid, i.e., the viscosity. (Viscosity is typically written as the Greek letter "eta" but "mu" is also common.) The ratio of the viscosity to the mass density is called the "kinematic viscosity" and, like the thermal diffusivity and mass diffusivity, has units of m^2/s. The MKS units of viscosity are Pa-sec but the cgs unit of poise is also commonly used. For example, the viscosity of water has a relatively strongly temperature dependence and crosses through 1 cP near room temperature: η=1.8 cP (centipoise) at T=0°C; 1.0 cP at 20°C; and 0.28 cP at 100°C. (1 cP= 0.001 Pa-sec.)

A quartz crystal monitor can be used to measure the square root of the product of the viscosity and density, $\sqrt{\rho\eta}$. (The analogous quantity in heat transfer is the thermal effusivity, $\sqrt{C\kappa}$.) In MSE 307, you used the frequency shift of the oscillator to determine the mass of water per unit area adsorbed by a polymer film. The principle here is similar, only now the mass that is measured is the layer of the liquid that lies within the "shear-momentum diffusion length" from the surface of the quartz crystal. This momentum diffusion length L scales as

$$L \sim \sqrt{\frac{\eta}{\rho\pi f}} ,$$

where f is the frequency of the oscillator. Since the mass per unit area of the fluid layer is Lρ, the frequency shift of the oscillator scales as

$$\Delta f \propto \sqrt{\frac{\rho\eta}{\pi f}} \quad .$$

The complete equations are given in the operating manual for the quartz crystal monitor that is posted at the Compass web-site. These equations are only valid if the surface roughness of the quartz crystal is much smaller than *L*.

In many cases, transport coefficients and susceptibilities of mixtures and composites can be estimated from the properties of the pure components and effective medium theories. The simplest effective medium theory is a "rule of mixtures" where the property of the mixture is a weighted average of the properties of the two components.

Session 1: Measure the viscosities of n-alcohols and simple mixtures.

- Load a syringe with a fluid (methanol, ethanol, n-propanol, isopropanol, or butanol) and the ultrasonic bath to drive out dissolved gases. Use the syringe pump to transfer the fluid to the QCM flow cell at a controlled rate. A flow rate of 1 mL/min will accelerate the process and help drive out any remaining bubbles. Reduce the flow rate to 0.2 mL/min and determine the viscosity using the shifts in both frequency and resistance. Compare your measurements to known values. Which approach seems more reliable? Does a higher or lower flow rate during the measurement help the situation?

- Load one syringe pump with isopropanol and the other with either ethanol or water. Using the two syringe pumps, vary the concentrations of the mixtures and measure the viscosities. Does a rule-of-mixtures apply in each case? You can assume that the density does follow a rule-of-mixtures.

Session 2: Measure the viscosity of a polyelectrolyte.

- Prepare a dilute solution of polyelectrolyte in water and load one syringe with this mixture and the other syringe with pure water.

- Measure the viscosity of this dilute polyelectrolyte from pure water to the largest concentration in the first syringe.

Instrument procedures

Syringe pump

Turn on the switch in the back of the unit. Place the syringe in the v-groove and place the clamp over it. Press the “Select” button on the unit. Use the arrows to set the flow rate and cut-off volume of the pump. Press select until the volume counter (indicated by a solid black arrow in the LED display) appears. To begin pumping, press the “Start” button. Pressing this button again will stop the flow.

Quartz crystal microbalance

Using tweezers, place the crystal in the flow cell with the large circular electrode surface up and the electrodes on the bottom surface over the contact pins. Screw on the cap tightly. Adjust the null capacitance by switching the monitor to “Adjust” on the face of the unit. When the two null lights are steady, flip the switch back to “Hold” mode.

Other notes

Attach the tubing to the syringes via the Luer-lock connectors. The recommended liquid flow rate for the cell is 0.2 mL/min, but this can be exceeded.

When flowing mixtures, bubbles can nucleate either in the flow cell or in the tubing before the cell. If the frequency is not equilibrating, tap on the flow cell with a pen to release any bubbles on the surface of the crystal.