**Experiment: Viscosity Measurement A**

 **Thomas-Stormer Viscometer**

**Purpose**

The purpose of this experiment is to measure the viscosity of an unknown polydimethylsiloxane (PDMS) fluid with a Thomas-Stormer viscometer.

**Learning Objectives of the viscosity experiments**

The viscosity exercises involve measurements and analysis related to fluid density, fluid viscosity, hydrodynamic interactions, and flow characteristics.

 After successfully completing the two exercises students should be able to

* Determine the density of a fluid particle
* Determine the density and viscosity of an unknown fluid
* Determine the uncertainty in the density and viscosity measurements
* Identify any discrepancies within the experimental results and provide a plausible explanation for observed discrepancies.

**Apparatus**

Figure 1 is a schematic of a Thomas-Stormer Viscometer. A weight, W, is used to drive a rotor that is partially submerged in a sample of liquid. The torque exerted by viscous shear of the rotor is balanced by the work input of the falling weight. The experiment involves measuring the time it takes for a known number of revolutions of the rotor.

Figure 1. Schematic of a Thomas-Stormer viscometer

**Theory**

Analysis of the viscometer assumes a linear velocity profile in the gap between the rotor and the fixed cylinder and limited shear on the outside the thin gap region. If the velocity profile is linear, the viscous shear stress on the surface of the rotor is
  = k

[1]

where  is the viscous shear stress,  is the fluid viscosity, *k* is a constant that depends only on the geometry of the viscometer, and  is the angular velocity of the rotor. Given the shear stress from Eqn. 1, the torque exerted by the rotor on the fluid is

[2]

where *A* is the wetted surface area of the rotor, and *rr* is the radius of the rotor. The area, *A*, accounts for the inner and outer surfaces of the rotor. Since the fluid is in contact with both surfaces rr is an effective radius.

Neglecting any friction in the pulleys and bearings, the power dissipated by viscous stresses in the fluid, *Pf*, is equal to the power input of the falling weight, *Pw*. Thus *Pf* = *Pw* and

[3]

where *W* is the magnitude of the weight, and *V* is the velocity of the falling weight. Combining Eqn. 1 and Eqn. 3 yields

[4]

The velocity of the weight falling a distance *L* in time *t,* *L*/*t* is

[5]

where *ns* is the number of revolutions of the spindle and *rs* is the radius of the spindle. The angular velocity of the rotor is

[6]

where *nr* is the number of revolutions of the rotor in time *t*. Substituting Eqn. 5 and Eqn. 6 into Eqn. 4 and rearranging yields

[7]

where  = *ns*/*nr* is the overall gear ratio between th spindle and the rotor. Defining the viscometer constant as

[8]

Eqn. 7 becomes

[9]

The constant *C* depends only on the geometry of the device if the model of viscous shear assumed in Eqn. 1 is valid. In reality, the constant may incorporate shear outside the thin gap and additional dissipation which is a function of the flow regime.

**Procedure**

Use of the Thomas-Stormer viscometer requires determination of *C* in Eqn. 9 by calibrating the instrument with a fluid having a known, similar viscosity. With *C* determined from the calibration step, the viscosity of the unknown fluid may be obtained by measuring of *W* and  and applying Eqn. 9. The overall procedure may be divided into three phases: (1) setting up the viscometer, (2) adjusting the weight in preparation for the tests, and (3) running the tests.

1. Set Up the Viscometer
2. Fill the test cup to the top of the side vanes. Make sure that the depth of the fluid is the same for all tests.
3. Replace the test cup in the viscometer.
4. Raise the platform that supports the bath and test cup until the fluid is at least 0.6cm (0.25 inch) above the top of the rotor. Add fluid if necessary. Make sure that the platform is raised so that it touches the stop.
5. Allow the system to come into thermal equilibrium and record the temperature. Note that most samples have been in sitting in the lab overnight. Unless the fluid temperature has been disturbed, e.g. by excessive handling, it should be in reasonable thermal equilibrium with the viscometer and the surroundings.
6. Adjust Weight in Preparation of Tests

The viscosity measurement is based on the assumption that the flow on the surface of the rotor is laminar. After placing a new sample of liquid in the test cup, and raising the cup into position, add weight to the spindle line and release the weight. The revolution rate should be less than 1 rev/s. Faster revolution rates may cause turbulent flow and significant deformation of the free surface. This may result in erroneous viscosity values. Note: the flow field observed during the calibration experiments and the unknown fluid tests must be similar for the constant *C* to be valid. The preliminary weight adjustment will allow you to become familiar with the measurement procedure.

All data runs should be taken over a range of weights no greater than the weight that gives 1 revolution in one second. You will also need to allow the viscometer to attain a steady state angular velocity. Plot revolutions as a function of time determine if steady state has been achieved. Then make at least an additional 20 revolution measurements.

1. Running Tests

Once the instrument is set up, the calibration runs and the viscosity measurement runs use the following procedure.

1. Turn the brake on, remove any weight and rewind the spindle counter-clockwise until the swivel (weight attachment point) nearly touches the pulley. Then attach the desired weight. DO NOT rewind the spindle with weight attached as it may break the apparatus or introduce significant bubbles into the fluid sample.
2. Release the brake one quarter turn and allow the weight to slowly descend. Record the revolutions turned as a function of time as the weight descends.
3. Repeat the measurement for several weights (at least 5 if possible).

**Data Reduction**

Eqn. 9 may be written as

[10]

The constant C is determined from the calibration runs by applying a least squares fit to  versus W/. Note that many software packages provide the capability for finding curve fits of the form

[11]

but Eqn. 10 requires a0 = 0. If the curve does not pass through (*W*/,) =(0,0) the value of the slope (and hence *C*) will be in error.