Laminar Flow Viscometer

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Nomenclature

A	cross-sectional flow area
d	inside diameter of a pipe or "device"
f	Darcy friction factor: for laminar flow, $f = 64/\text{Re}_d$
g	gravitational constant (9.81 m/s^2)
h	head, i.e. elevation of a fluid column
h_{major}	major head loss (height of water column) due to friction in a pipe
h_{minor}	minor head loss (height of water column) due to a "device" in the pipe system
$\Delta h_{L,\text{ total}}$	total irreversible head loss, including major and minor losses: $\Delta h_{L,\text{ total}} = \sum h_{\text{major}} + \sum h_{\text{minor}}$
K	nondimensional minor loss coefficient
L	length of a pipe or capillary tube
L_e	entrance length required to establish fully developed flow in a pipe or capillary tube
$\dot{m}$	mass flow rate through the pipe
P	static pressure
Re_d	Reynolds number based on diameter d: $\text{Re}_d = \rho VD/\mu = Vd/\nu$
t	time
T	temperature
V	mean velocity in a pipe
$\mathcal{V}$	volume
$\dot{\mathcal{V}}$ (or Q)	volume flow rate
$\dot{W}_{\text{pump}}$	work done *to* the control volume by a pump
$\dot{W}_{\text{turbine}}$	work done *by* the control volume on a turbine
$\dot{W}_{\text{viscous}}$	viscous work done *on* the control volume by a moving wall
z	elevation in vertical direction
α	kinetic energy correction factor in energy equation for a control volume
μ	coefficient of dynamic viscosity (also called simply the viscosity)
ν	coefficient of kinematic viscosity (for water, $\nu \approx 1.0 \times 10^{-6}$ m^2/s at room temperature)
ρ	density of the fluid (for water, $\rho \approx 998$ kg/m^3 at room temperature)

Educational Objectives

1. Provide an opportunity for students to apply their knowledge of laminar internal pipe flow to the practical problem of measuring fluid viscosity.
2. Provide an opportunity for students to plan their own experiment and to develop a sound experimental procedure, using the available equipment.

Equipment

1. laminar flow viscometer test stand (see Figure 1)
2. immersion heater (installed in reservoir, as in Figure 1)
3. capillary tubes of various diameters and lengths (diameters are labeled on each tube)
4. stopwatch
5. graduated cylinders of various capacities
6. hot plate and insulated gloves, Pyrex beakers
7. thermometer and/or thermocouple
8. digital balance scale

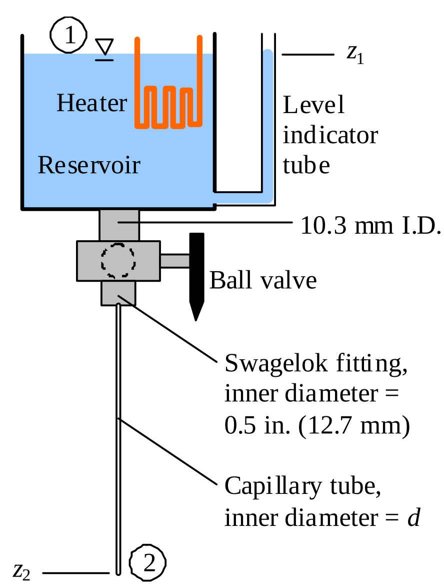

Figure 1. Schematic diagram of laminar flow viscometer.

9. ruler or tape measure
10. level
11. shop air supply with nozzle (for blowing out the tubes)
12. personal computer

Background

Viscosity is a very important fluid property, especially in pipe flow systems where the pressure drop through a pipe (and hence the required pumping power) is strongly affected by viscosity. There are many experimental techniques commonly used to measure the viscosity of a liquid. Examples include the rotating cup viscometer and the falling-ball viscometer.

The viscosity of a liquid, such as water, typically decreases with temperature, while that for a gas typically increases with temperature. A simple way to remember this is to think about starting a car in the winter time. In very cold temperatures, the engine oil is extremely viscous (most people call it “thick”), and the engine is hard to start. However, the oil in a warm engine has a much lower viscosity, and is much easier to start.

One of the simplest viscosity measurement techniques involves forcing the liquid through a very small diameter pipe (capillary tube). Because of the slow speeds and small diameter, the flow is laminar, and an analytical expression for viscosity is obtainable. Namely, viscosity can be calculated as a function of easily measurable parameters, such as tube diameter, tube length, volume flow rate, etc.

In this lab experiment, you will obtain an analytical equation for μ, the coefficient of dynamic viscosity. You will design a procedure, using the available equipment, which will enable you to measure the viscosity of water at several temperatures. Your results will then be compared to published data.

References

1. Çengel, Y. A. and Cimbala, J. M., *Fluid Mechanics – Fundamentals and Applications*, McGraw-Hill, NY, 2006.
2. White, F. M., *Fluid Mechanics*, Ed. 5, McGraw-Hill, NY, 2003.