Experiment FL Flow

Introduction

Steady flows are driven by forces that are balanced by resisting forces. For instance, the amount of water coming out of a shower depends on the water pressure as provided by private or municipal water systems, and the resistance of the many small holes in the shower head. Depending on the diameter of the holes and the velocity of the flow, the resistance can be due to viscosity (the friction of water against water when there are differences in velocity within the flow), momentum given to the fluid as it speeds up as it passes through the holes, and additional resistance when the flow becomes turbulent and there is vortex motion in the fluid.

Experiment

You'll measure the rate at which water flows out of a container through a tube placed near the bottom. You'll do this for different length tubes. For each tube length you will calculate characteristic time constant for the flow rate. You will then compare these time constants as a function of the tube length. This experiment is primarily about taking data but later in the semester you will interpret your data to determine the viscosity of water.

Apparatus

You have a 0.5 liter clear plastic bottle which you will cut to make a cylindrical container, four cups, one piece sugarless chewing gum, four stirrers (plastic tubes about 130 mm long and 2.8 mm inside diameter), two paper plates, one push pin, one 8 penny nail, one 1 1/2"length poly tube, and paper towels. You also have a photocopy of a ruler on your parts list. You can use thermometer in your Red Box that will be used in Expt ET. You'll need either a stopwatch, or a clock or watch with a sweep second hand for timing the drop in water height.

Use the attached three copies of *Data Sheet for EXPERIMENT FL: FLOW* for experiments I, II, and III, with 3, 2 and 1 stirrers, respectively. There are spaces for recording the length of the tube, the diameter of the tube (see parts list), room and water temperatures at start and finish of each experiment, and a table with six columns: one for water level (the "head"), three columns for three sets of time measurements, one for the calculated average time, and one for the standard deviation of the average time. Record any relevant circumstances, phenomena, troubles, etc. in the space below labeled *notes.*

There are attached to the write-up four pieces of linear graph paper and three pieces of semi-log graph paper although you may plot your data using a computer.

Procedure

Open up the cap of the bottle and empty the contents. You should have one piece of sugarless chewing gum, four stirrers (plastic tubes about 130 mm long and 2.8 mm inside diameter), one and one half inch length of poly tube, one 8 penny nail, rubber bands, and a push pin.

You will first connect three stirrers together with small pieces of poly tubing. Cut a 15 mm piece of the poly tubing and place the end of one stirrer into the tubing (Figure 1).

Figure 1: Stirrer inserted into poly tube

Fit a second stirrer into the other end of the tubing until the stirrers meet together in the middle of the poly tube (Figure 2). This step is delicate, you can easily rip the stirrer.

Figure 2: Two stirrers connected by a poly tube

Now cut another 15 mm piece of the plastic tubing and connect a third stirrer to the other two. **Measure and write down the length of this tube. (It should be about 390 mm).**

Cut the plastic bottle with scissors about 15 mm from its bottom so as to make a cylindrical container that tapers down to the screw cap at the end. In order to cut the container begin by making a hole with the push pin and enlarging it with the nail so that you can get the scissors in to cut the bottle.

Make sure the cap is screwed on tight. Turn the container upside down and put it in one of the cups. You will make a hole in the container at a point that is just above the rim of the paper cup. Mark a spot for your hole with a pen. This hole will be about 65 mm from the bottom of the cap.
(You can now take the container out of the cup).

Start making the hole with a push pin. Enlarge this small hole with the point of the nail, turning the nail like a drill. The stirrer should just fit; press it in about 10 mm. (If you wish, you can practice beforehand making holes in the otherwise useless cut off part of the container). Use a small amount of chewing gum to seal around the plastic tube and black tape or gum to seal undesired holes. If necessary, cut away the rim of the cup to make room for the gum seal.

You'll need to measure the depth of water in the container in 10 mm steps to within ±1 mm or less. You have a photocopy of a ruler on the side of your Experiment Flow parts list. Attach the ruler to the side of the container with rubber bands so that zero of the metric scale is at the center of the hole and so that it extends upward about 90 mm.

Figure 3: Container, ruler, and stirrer inserted in hole

Your apparatus will consist of the upside down container in a cup; an upside down second cup that supports the tube; and a third cup that will collects the outflow. Make sure that the stirrers are straight. Figure 4 shows the apparatus when two stirrers are connected together.

Figure 4: Apparatus with two stirrers

Remove items from your desk that might be damaged by water and arrange your apparatus as shown in figure 4 but with three stirrers instead of two. Sand, pebbles or coins might be put in the bottom of the container support cup to make it sit steadier. Use the paper plates under the container support cup and the collector cup to contain spills. Paper, folded or wadded, can be used to adjust heights so that the tube is reasonably level.

Taking Data

Your first data measurements will use a tube made from three stirrers. You will fill the container and then record the time it takes for the water level in the container to pass successive 10 mm (1 cm) scale marks. You will repeat the experiment three times. Then you will detach the third stirrer and repeat the process making three more trial runs. You will then detach the second stirrer and repeat the process making three more trial runs.

Fill a cup with water as close to room temperature as possible, as indicated on your thermometer that you will find in your red box. **Record room and water temperatures at the start and finish of your experiment. Record the length of your stirrers. Record your results on the accompanying Data Sheet for Experiment Flow.**

Fill the container and observe what happens as the water level drops. You and your partner should decide on a method for taking data. For instance, one partner can call out as the water level passes successive 10 mm (1 cm) scale marks and the other writes down the time to the nearest second as the level passes each mark. Refill the container using the collector cup, keeping water from flowing until you're ready by putting a finger lightly over the end of the tube. Have another cup at hand to catch any extra flow. Note that at some level the nature of the flow changes from a continuous stream to a series of drops. Either stop timing or, if you wish, record the level and time corresponding to this change. **Take data for three trial runs. Record your results on the accompanying Data Sheet for Experiment Flow.**

Repeat the above procedure after shortening the plastic tube from 3 stirrers (about 390 mm) to 2 stirrers (about 260 mm) and then to 1 stirrer (about 130 mm). **Take data for three trial runs for two stirrers and take data for three trial runs for one stirrer. Record your results on the accompanying Data Sheet for Experiment Flow.**

Averaging

For each combination of stirrers, you have three time measurements for each height that the water level passes. Average the three times to give an average time corresponding to each water level. **Record your results on the accompanying Data Sheet for Experiment Flow.**

Graphing the Data

You have four linear and three semi-log graph papers. In addition you have one linear graph paper for the time constants vs. length of tube graph.

On three linear graph papers, **plot the level of the water above the hole (the "head") in mm versus the average time in seconds to reach that level for each of the tube lengths.** (You should have three graphs.)

On the semi-log paper, **plot the head vs. average time for each of the tube lengths**. On semi-log paper, the horizontal axis is a normal linear scale, but the vertical axis is marked off in proportion to the logarithms or natural logarithms of the numbers represented. (Recall logarithms in base 10 are proportional to natural logarithms according to $\log_{10} u = \ln u / \ln 10$.) So you can choose the numbers 1,2,3 etc on the vertical axis to represent 10 mm, 20 mm, 30 mm, etc. So a data point like (30 mm, 55 sec) is placed at the 3 on the vertical axis and at the 55 on the horizontal axis. You should have three semi-log graphs. Draw the best straight lines through the points as judged by eye. (When choosing the `best straight line', consider which points are most reliable. Are the first and last measurements as reliable as the others?)

Reporting the Data

Your linear graph of head vs. average time should be an exponentially decaying function,

$$h(t) = h_0 e^{-\alpha t} \tag{10.1.1}$$

where h_0 is the value of the head at $t=0$ and α is a constant. The time constant τ associated with this exponentially decay is defined to be the time that it takes for the head to reach a value of $h(\tau)=h_0 e^{-1}=h_0/0.368$. Since $h(\tau)=h_0 e^{-\alpha\tau}$. The time constant τ is related to the constant α according to

$$\alpha\tau = 1 \text{ or } \tau = 1/\alpha .$$

Your semi-log plot should be nearly a straight line. The natural logarithm of Equation 10.1.1 is

$$\ln h(t) = \ln h_0 - \alpha t .$$

So a plot of $\ln h(t)$ vs. time t will be a straight line with

$$\text{slope} = -\alpha = -1/\tau .$$

Finding the Time Constant

Method 1

Obtain the time constant τ for the flows with the three tube lengths by the following procedure that will use results from both your semi-log graph or your linear graph. Use your best straight line in the semi-log paper graph to determine the value of the head, h_0, at $t=0$ for each of the three experiments. (Note: if you just choose your initial value from your data sheet you are ignoring the rest of your data values.) You can obtain the time constant from the linear graph of head vs. average time by directly reading off the time that the head reaches the value $h_0/0.368$. Determine the time constants for each of your three experiments. **Report your results in the table Time Constants for Experiment Flow that is attached to the write-up.**

Method 2

From your semi-log plot, calculate the slope of your best-fit straight line. Compute the time constant according to $\text{slope} = -\alpha = -1/\tau$.

Make a plot of tube length vs. time constant. Is there any nice curve that passes through the data points? What does the extrapolation to zero tube length mean?

Data Sheet for Experiment Flow

Expt. I: Length of tube =

Room Temperature: Start_____Finish _____

Water Temperature: Start_____Finish _____

Water level (mm)	T_1 (sec)	T_2 (sec)	T_3 (sec)	T_{ave} (sec)

Notes:

Data Sheet for Experiment Flow

Expt. II: Length of tube =

Room Temperature: Start_____Finish _____

Water Temperature: Start_____Finish _____

Water level (mm)	T_1 (sec)	T_2 (sec)	T_3 (sec)	T_{ave} (sec)

Notes:

Data Sheet for Experiment Flow

Expt. III: Length of tube =

Room Temperature: Start_____Finish _____

Water Temperature: Start_____Finish _____

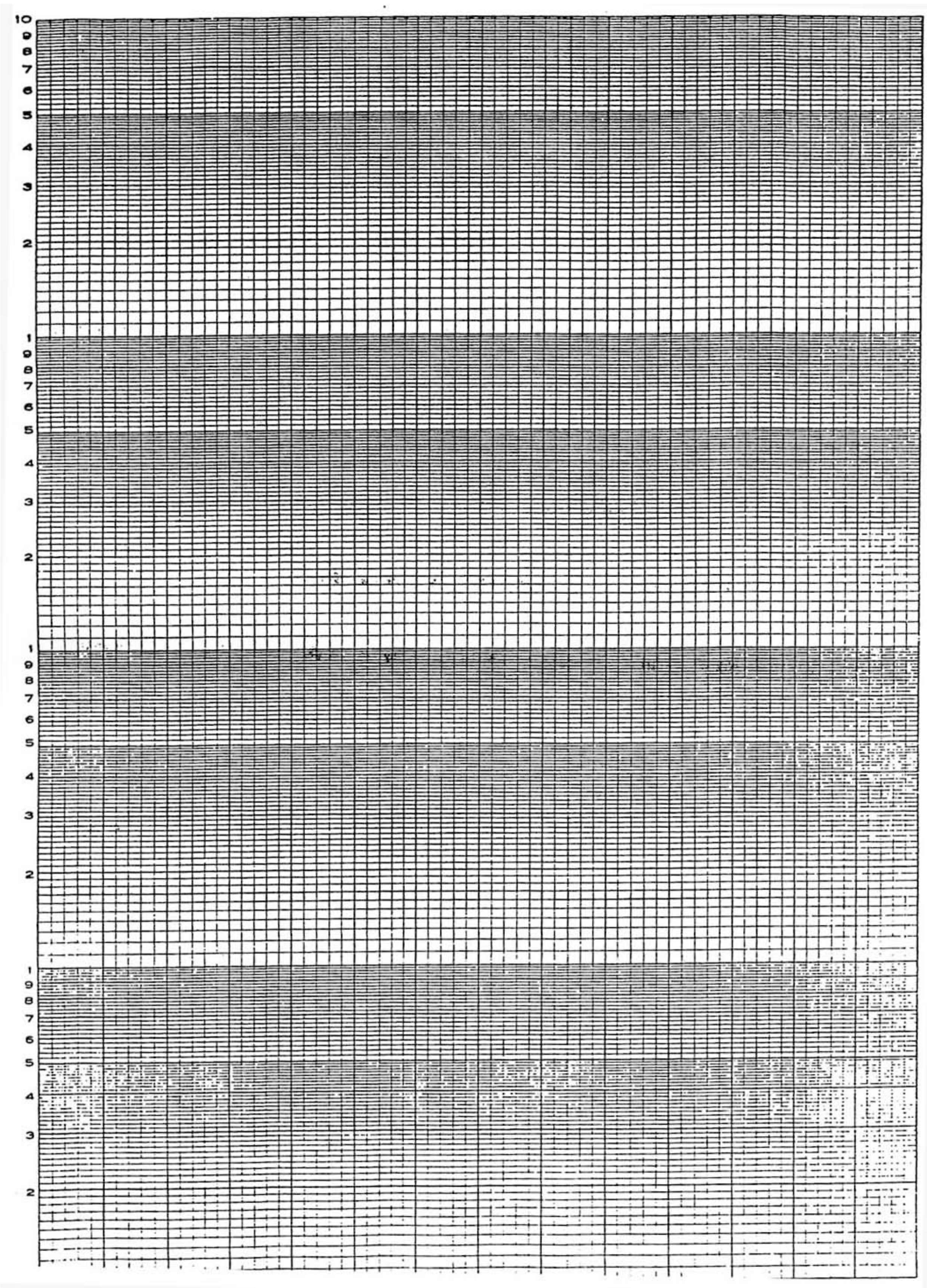
Water level (mm)	T_1 (sec)	T_2 (sec)	T_3 (sec)	T_{ave} (sec)

Notes:

Time Constants for Experiment Flow

Trial	Tube length (mm)	Time constant (sec)	Container diameter (mm)	Temperature start (^0C)	Temperature finish (^0C)
Experiment I					
Experiment II					
Experiment III					

Notes: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