MEEG331 Incompressible Fluids Laboratory

4. Flow Measurement and Losses (Venturi Meter)

Objective

The purpose of the experiment is to demonstrate typical **flow measurement** devices for incompressible fluids: (1) Venturi meter, (2) Orifice plate, and (3) Rotameter. Each flow measurement device will be compared to the standard method using the catch-tank and stopwatch. In addition, you are also asked to determine the **head-loss** incurred by each of these devices. Extensive use will be made of the steady-state mechanical energy equation for a streamline, and the Bernoulli equation.

Apparatus

The two figures below show the details of the apparatus. Water from the hydraulic bench enters the equipment through a venturi meter consisting of a short nozzle, a throat, and a long diffuser. Next, the water flows into a rapidly diverging section, followed by a settling length, and through an orifice plate. Following a further settling length and a right-angle bend, the flow enters a rotameter. The rotameter is a transparent tube of gradually diverging cross-section in which the "float" takes an equilibrium position; the vertical position of the float is a measure of the flow rate.

After the rotameter, the flow returns via a control valve to the hydraulic bench where the flow rate can be measured using the catch-tank and a stopwatch (TA will explain how the catch-tank is to be used). The test-section has nine pressure taps (A to I) as shown in the second figure, each of which is connected to its own piezometer for immediate read-out.

Theory— Flow Measurement

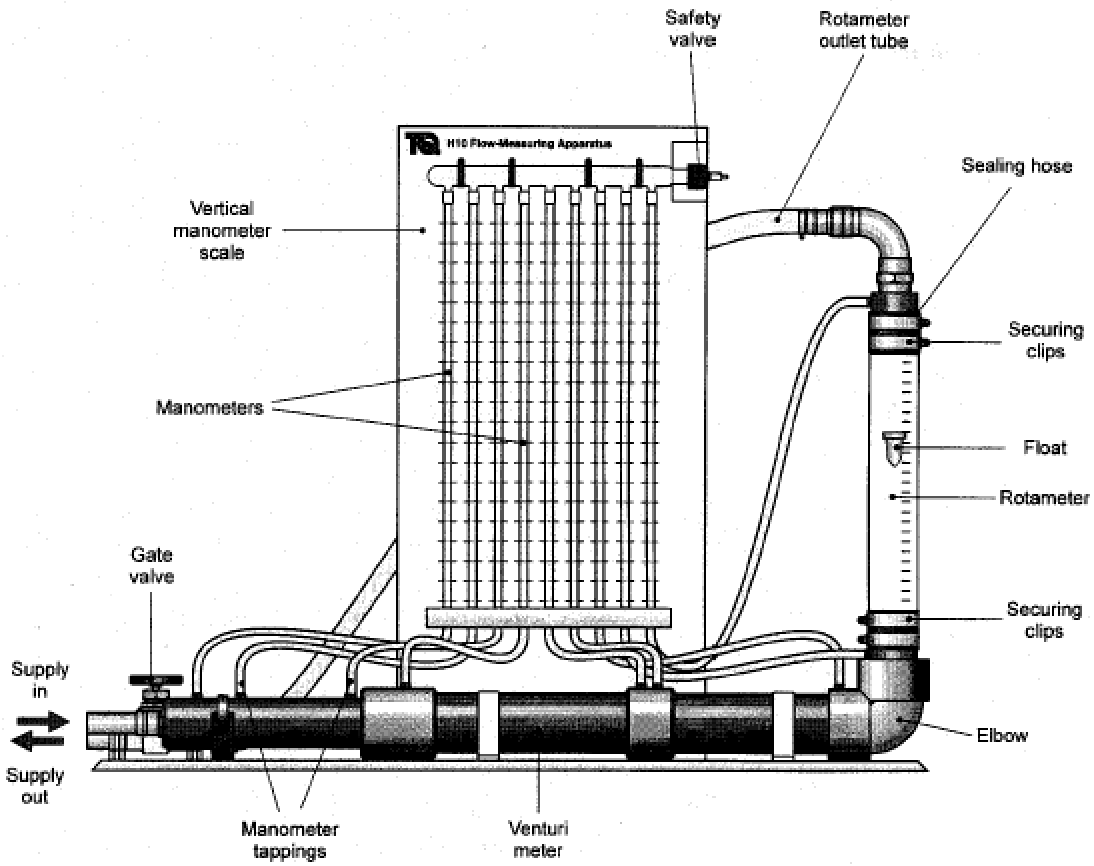
1. Venturi Meter:
In the converging section of the venturi meter, the flow is accelerated continuously, and therefore, the losses are small. It is appropriate to apply the Bernoulli equation between A and B. You are asked to show that:

$$Q = A_B \sqrt{\frac{2g(h_A - h_B)}{1 - (A_B/A_A)^2}} \qquad (1)$$

where, Q is the volume flux, A_A and A_B are the cross-sectional areas, and h_A and h_B are the heights in the piezometer tubes at A and B respectively.

2. Orifice Meter:
The orifice meter is a plate with a central hole introduced into the flow path. It is the easiest to install between existing pipe flanges. However, the head loss associated with the orifice meter is large. The mechanical energy equation between E and F gives:

$$\frac{p_E}{\rho g} + \frac{V_E^2}{2g} = \frac{p_F}{\rho g} + \frac{V_F^2}{2g} + h_{f_{E \to F}} \qquad (2)$$



Typically, the head loss is expressed in terms of a coefficient K, where:

$$\frac{V_F^2}{2g} - \frac{V_E^2}{2g} = K^2 \left(\frac{p_E}{\rho g} - \frac{p_F}{\rho g} \right) \tag{3}$$

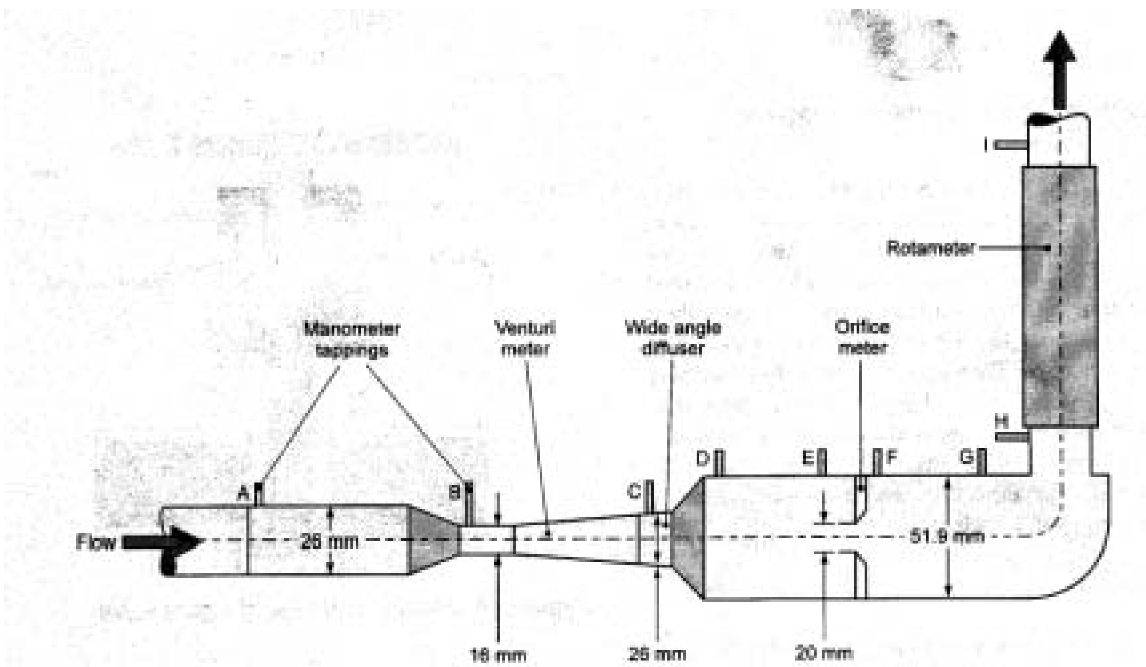
For the given orifice plate, $K = 0.601$. Show that the above may be rewritten as:

$$Q = K A_F \sqrt{\frac{2g(h_E - h_F)}{1 - (A_F/A_E)^2}} \tag{4}$$

Here, A_E is the tube area upstream of the orifice plate, and A_F is the area of the orifice.

<u>3. Rotameter</u>:

The "float" inside our rotameter is actually made of steel. The reason it "floats" up when the flow is turned on is due to the drag force exerted by the water as it flows in the annular gap between the float and the rotameter tube. The rotameter tube has a diverging cross-sectional area. (Explain why this is needed.) As a consequence, the float has one unique position for each flow rate; higher the flow rate, higher the float position. Determine the flow rate by noting the float position.



Theory— Head Losses

1. Venturi Meter:
While the the nozzle section has small losses, the same is not true for the diverging section of the Venturi meter. Apply the mechanical energy equation between sections A and C and show that

$$h_{f_{A\to C}} = h_A - h_C \tag{5}$$

Express the head loss as a fraction of the inlet kinetic head $V_A^2/2g$. (You can determine V_A by knowing the flow rate Q and the area A_A.)

2. Orifice Meter:
Applying the mechanical energy equation between E and F would yield an excessively large value for the head loss; the reason is that, an obstruction such as an orifice plate causes a small increase in the pressure due to the impact (or ram) pressure of the flow against the plate which is then conveyed to the pipe wall. Therefore, it is customary to rely on a correlation to obtain the head loss for an orifice plate. For this case, the head loss is given as 0.83 times the measured head difference, i.e.,

$$h_{f_{E\to F}} = 0.83(h_E - h_F) \tag{6}$$

Express this head loss in terms of the inlet kinetic head (by taking a ratio of the two quantities). It will be sizable.

3. Rotameter:
Apply the mechanical energy equation between H and I. You may ignore the kinetic head change between H and I, because the rotameter tube diverges rather gradually (areas are approximately same, so velocities are approximately equal). Show that:

$$h_{f_{H\to I}} = h_H - h_I. \tag{7}$$

The head loss for the rotameter will be seen to be approximately constant irrespective of Q. Express the head loss in terms of the inlet kinetic head. You will see that for small Q the head loss will be many times the inlet kinetic head.

Procedure

For 10 different flow rates (start at 2 cm and work your way up in $\sim$ 2 cm increments on the rotameter) note down the following:

1. The manometric heights $h_A, h_B, \ldots, h_I$.
2. The rotameter reading in centimeters.
3. The volume of water collected in the catch tank V in time t.

Data analysis and discussion

1. Prepare a calibration graph for the rotameter: Q (on y-axis) vs. rotameter reading in cm (on x-axis). Determine the calibration constants by a least-squares straight line fit to the data.
2. Determine the volume flow rate Q as given by (i) the Venturi meter, (ii) the orifice plate, and (iii) the Rotameter (using the calibration constants you just determined). Compare with the most direct method using the catch-tank and stopwatch. Plot the volume flow rate from all four devices on the y-axis of the same graph against the serial number of the reading on the x-axis. The differences will be highlighted if you plot $(Q_{\text{meter}} - Q_{\text{catch-tank}})$ on a separate graph.
3. Plot the head-loss due to the various devices as a function of Q in two ways: (i) plot the head-loss in mm; and (ii) as a fraction of the inlet kinetic head. How does the head loss vary with Reynolds number? Discuss your results. Based on your results, which device would you recommend? Note that each device has its own advantages and disadvantages. Read up about these devices and discuss.
4. Derive the following equations: 1, 4, 5 and 7. Why must the rotameter have a slightly diverging cross-section?

Error Analysis

Using the propagation of statistical errors, determine the error in Q from all 4 methods. Similarly, determine the error in head loss for the three different devices.