MEEG333 FLUIDS LABORATORY

X2. Flow Measurement Methods

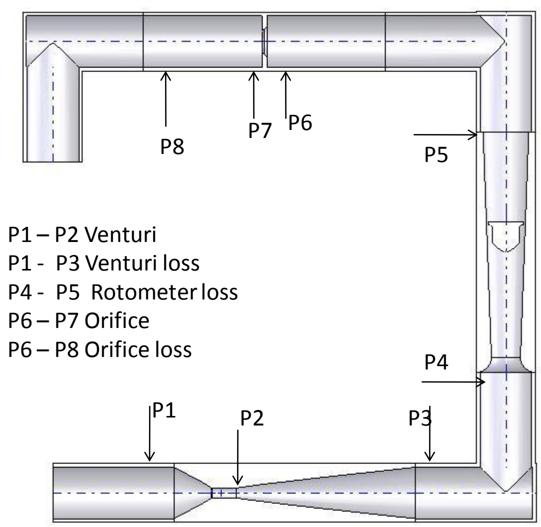
Objectives

The purpose of the experiment is to demonstrate widely used flow measurement devices for incompressible fluids: (1) Venturi meter, (2) Orifice plate, (3) Rotameter. In addition, you will measure the head-loss, or permanent pressure 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.

The design objective will ask you to recommend the appropriate flow metering device for a common industrial unit op called a Thermosyphon Reboiler.

Apparatus

The apparatus is shown diagrammatically below. Pressures are measured with a bank of manometers attached at the points indicated. Water enters at the lower left, flows through each meter in series, and exits at the upper left into the catch-tank. Ideally, each meter should register the same flow rate.



Theory

You should refer to the information presented at the X2 Lab Discussion (posted on Sakai), and also to the textbook Example 3.15 and to Equation 6.104. The latter references exhibit derivation of the relation between flow rate and pressure difference for orifice and venture type instruments.

Both the venturi and the orifice are pressure difference meters. The rotameter scale gives a direct reading of the flow rate in liters/min. Note that the manometers are reading the pressure difference in mm of water. This will need to be converted to either meters of water, or N/m^2. The pressure difference between the upstream and at the minimum diameter ("throat") is used for measurement.

The general expression for both the venturi and the orifice plate is (from text eqn 6.104)

$$Q = C_d A_t \left[2(p_i - p_t)/\rho/(1 - \beta^4)\right]^{1/2}$$

where $\beta = d/D$, or the ratio of the throat diameter to the upstream pipe diameter.

A_t = the throat or orifice area

Q = flow in m^3/sec

Subscripts i and t imply Inlet and Throat

Because **$p = \rho gh$**, the equation above can also be written as

$$Q = C_d A_t \left[2g(h_i - h_t)/(1 - \beta^4)\right]^{1/2}$$

which is simpler to use because we are recording data in meters.

Values for C_d for the venturi and the orifice are supplied by the apparatus manufacturer (See table below). We will not measure them for ourselves in this experiment.

Each meter causes an overall pressure decrease from fluid friction, called the permanent pressure loss. This is effectively a cost of using the instrument. The smaller it is the better.

Manometer adjustment. Ideally, all of the manometers should start at the same level when there is no flow. However, we have found this difficult to do. Note however, that the important measurements are all Δp or Δh between two points. The absolute pressure is not needed. Adjust the levels so that to begin with all of the water levels are at least in the lower half of the manometer bank. They do not have to be at the same level. <u>This does require careful data recording</u>.

Procedure

For five different flow rates, beginning with a low flow and going to high flow (use the rotameter readings as a guide), note down the following:

1. The manometric heights for each of the pressure taps. Label your data sheet carefully.

2. The rotameter reading (l/min). Convert to m^3/sec

   (Note 2017: we are using the rotameter as the reference flow rate instead of using a timed bucket test. Experience shows that uncetainty in the bucket test is greater than rotameter)

3. Before leaving the lab, the TA will show you on another apparatus a turbine meter. We will use it later in the semester. For now, just observe it briefly. Note the readout: digital, to four decimal places. Do you believe it?

Data on test apparatus:

	Venturi	Orifice
Upstream Pipe Diam	0.03175 m	0.03175 m
Throat diameter	0.015 m	0.020 m
Upstream taper	21^o	none
Downstream taper	14^o	none
C_d	0.98	0.63

Data Analysis

1. Calculate the flow indicated by the measured delta P's using the equations above.
2. Plot the flows indicated by the rotameter (x-axis) versus the flows indicated by the orifice and the venturi.
3. Plot on one chart the permanent pressure loss (y-axis) of each instrument as a function of indicated flow. IMPT- The pressure difference between inlet and outlet of the rotameter is primarily from the change in elevation $\Delta p = \rho g \Delta h$. Its friction loss is negligible.

Discussion

Based on your measurements and observations, which instrument would you choose as most accurate?

Re-read the notes from the Lab Discussion that listed the pros and cons of each instrument. Does that change your opinion about your choice?

Uncertainty Analysis

1. Plot the flows indicated by the rotameter (x-axis) versus the flows indicated by the orifice and the venture. Draw a 45-degree line on the plot. What does the result indicate about accuracy of each instrument? What factor(s) might make the data not fall on the 45 degree line?

Design Objective.

Given an industrial unit operation called a thermosyphon reboiler, specify the type or types of flow meters that would be appropriate to insert in the lines where indicated. <u>You may consider other types, not just the ones tested in the lab.</u>

Note that there is no pump in this reboiler system, which can make this device attractive in a plant. Why does the fluid circulate? The fluid in the big tank is liquid, and is attached to the heat exchanger. The boiling fluid in the heat exchanger tubes has a much lower density, so that it is pushed up and around by the liquid fluid. Hence the name, thermosyphon. Without a pump however, one does not want much flow restriction in the line.

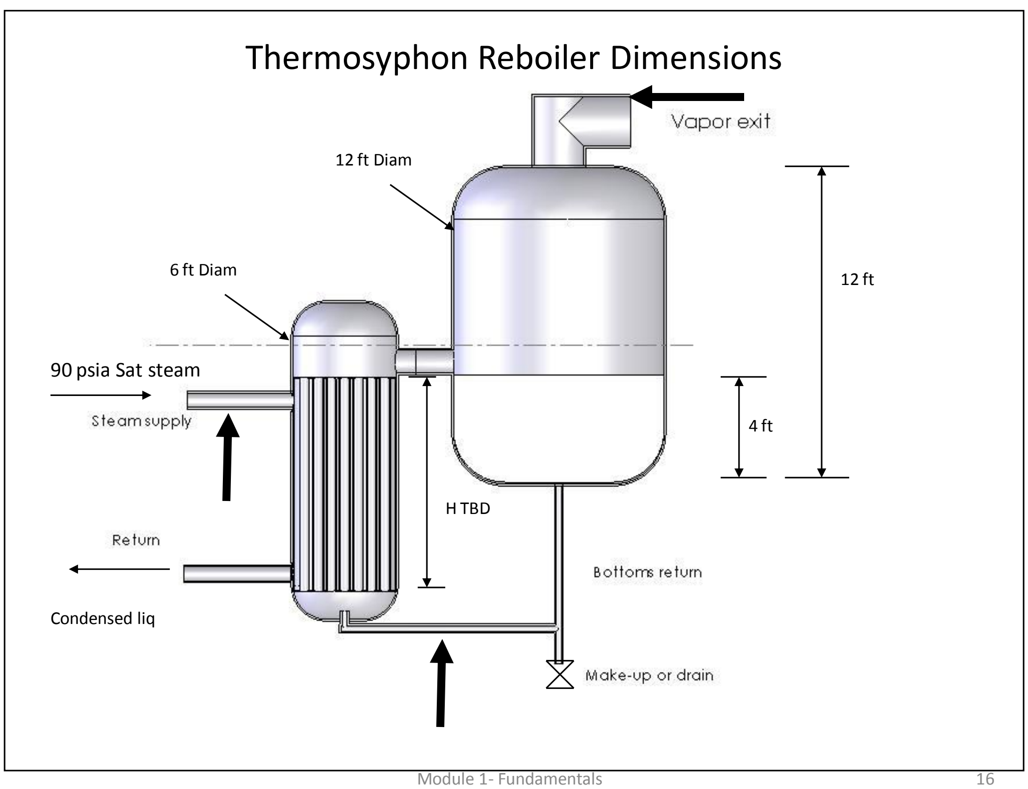
Here are nominal conditions in the reboiler:

The primary fluid is water, with trace amounts of VOC (Volatile Organic Compounds). When the water is boiled, the VOC's come out of solution and are vented. Cleaner water returns to the big tank to go around again. When the water is purified sufficiently, it is drained off and fresh contaminated water added. Alternatively, the VOC's may be a commercial product and collected.

The steam supplied is superheated vapor at about 160 C and 620 kPa. Flow velocity is around 30 m/sec.

The recirculating water is moving at about 1 m/sec in a 5 cm pipe.

The VOC off gas is hot, with a velocity of about 10 m/sec in a 10 cm duct. The hot VOC may be corrosive.



Indicates meter location