CE 3105 - Mechanics of Fluids Laboratory

Experiment 3: Flow Measurement Apparatus

http://bit.ly/ce3105lab3

1 Objectives

- To understand the typical methods of measuring the discharge of an essentially incompressible fluid
- Apply Continuity equation and Bernoulli's equation to determine flowrates

2 Theory

Flowrate can be measured indirectly with venturi meter, orifice plate meter and rotameter by using continuity, Bernoulli's equation, head losses and mass flowrate concept. They can be combined together to make the flow measurement apparatus (Figure 1). The venturi meter is the combination of a converging tube, a throat and a diverging tube. The discharge of fluid is calculated by measuring the pressure differential between the inlet and the throat which is caused by the differences in diameters.
From continuity:

$$\rho V_A A_A = \rho V_B A_B$$

The discharge,

$$Q = A_B V_B$$

$$Q = A_B[\frac{2g}{1-(A_B/A_A)^2}(\frac{P_A}{\rho g} - \frac{P_B}{\rho g})]^{1/2} \tag{1}$$

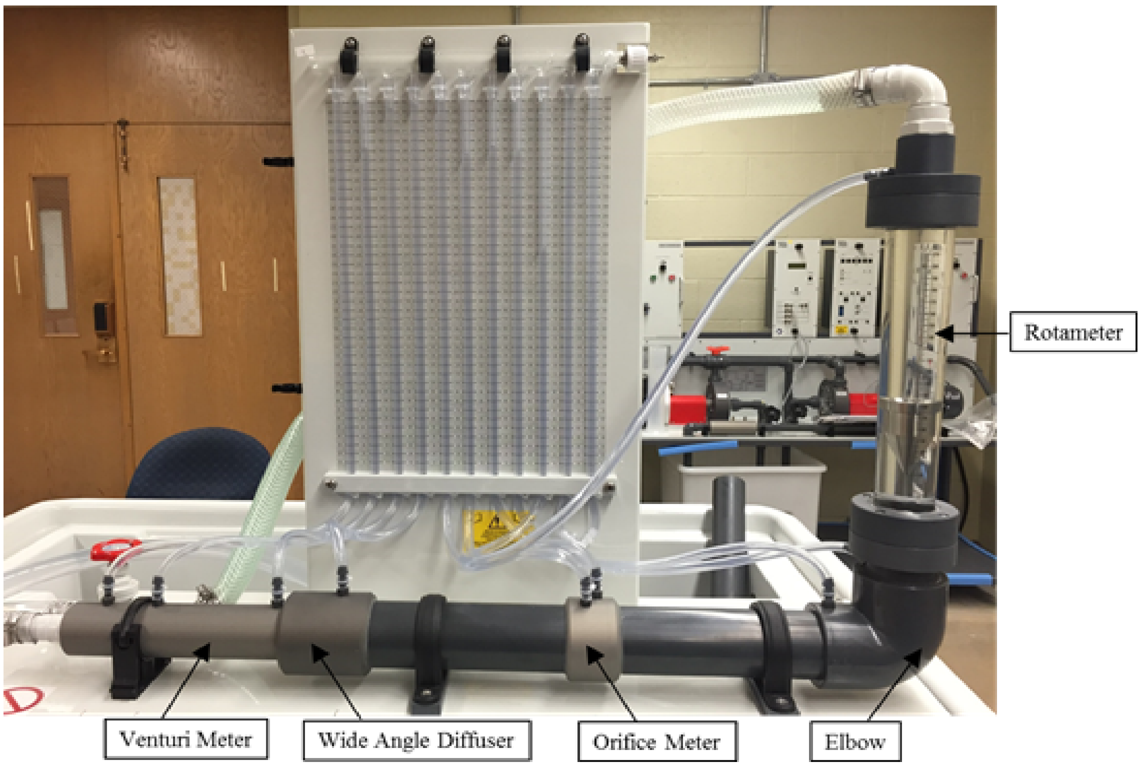

Figure 1: Water Flowing through the Flow Measuring Apparatus

An orifice meter is a round opening in a plate. This device is then put within the pipe so that it is perpendicular to the direction of flow. Discharge is again quantified by measuring the head loss between the upstream and downstream of this device. Head loss can be written in terms of a coefficient K. K value varies with the type of the orifice meter.

$$\frac{V_F^2}{2g} - \frac{V_E^2}{2g} = K^2(\frac{P_E}{\rho g} - \frac{P_F}{\rho g})$$

$$Q = A_F V_F$$

$$Q = K A_F [\frac{2g}{1-(A_F/A_E)^2}(\frac{P_E}{\rho g} - \frac{P_F}{\rho g})]^{1/2} \tag{2}$$

There are ten manometers in the flow measuring apparatus (Figure 2).

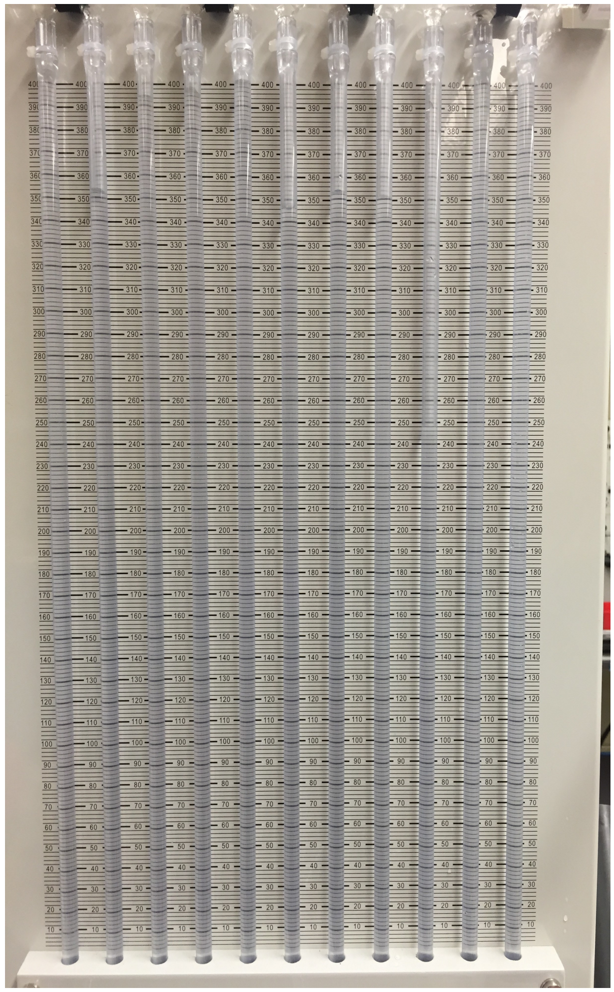

Figure 2: Water Columns in Manometers

The rotameter measures flowrate by detecting the position of the float. It is a vertical tapered tube with a float inside. It is one kind of variable-area flow-meter. Because of the greater flow area at the top, velocity is relatively lower there than the bottom. The flowing fluid lifts the float up by the drag force created by the fluid. The weight of the fluid acts downward. The equilibrium position of the float depends on the flowrate which is indicative of the rate with which the fluid is passing.

$$\begin{aligned}\pi(R_t^2 - R_f^2) &= 2R_f^2\delta \\ &= Cross\ sectional\ area \\ &= Discharge/Constant\ peripheral\ velocity\end{aligned} \tag{3}$$

Mass Flow (in general):

$$\dot{m} = \rho Q \tag{4}$$

Venturi meter, wide angle diffuser, orifice meter, elbow and rotameter are explained in Figure 3.

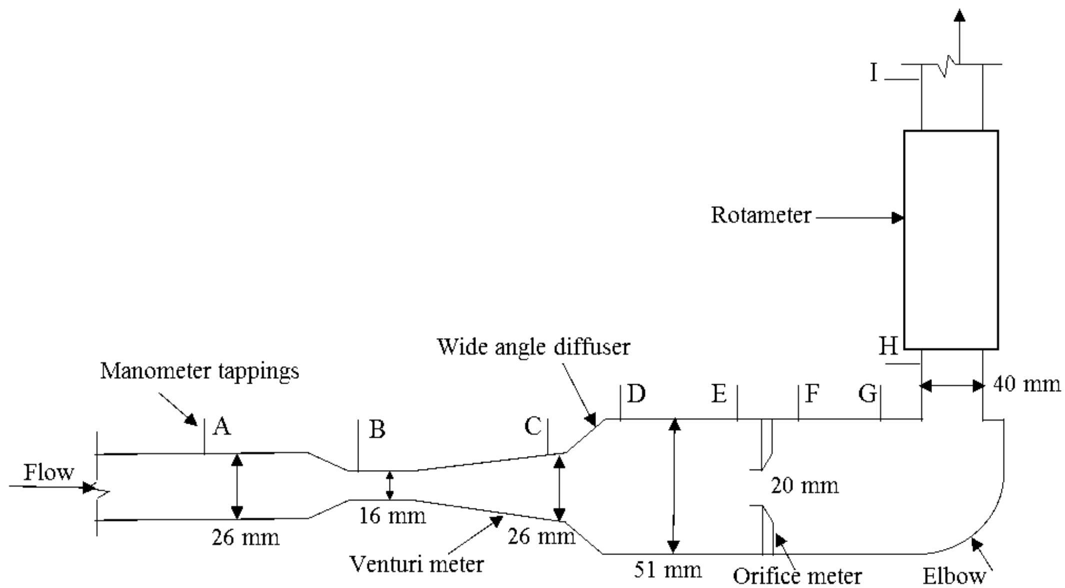

Figure 3: Diagram of the Flow Measuring Apparatus

Automatic flowmeters are becoming popular in civil applications as the data can be logged in a computer and the system can be monitored remotely by sending data through the cloud. There are many different sensors available in the market today. Flow measurement sensors based on the 'Hall Effect' are popular and we shall make use of it in the lab. The Hall Effect states that if electric current is made to pass through a conductor in a magnetic field, then one can measure an appreciable voltage drop across the conductor. The Hall Effect based flowmeter consists of an impeller which rotates at different speeds when different flowrates of water (or any other fluid is pass through it). One of the blades of the impeller is magnetic and completes a magnetic field when it passes the magnet in the sensor assembly causing a voltage drop (pulse). If the flow rate is high the number of revolutions of the impeller increases which in turn can me measured by the number of voltage pulses and converted to obtain the required flowrate.

Figure 4: Hall Effect Flow Sensor

3 Variables/Units

Variables	Description (Units)	Variables	Description (Units)
ρ	Liquid Density (lb/ft^3)	$V^2/2g$	Velocity Head (ft)
V	Velocity (ft/s)	K	Coefficient of discharge =0.601
A	Flow Area (ft^2)	R_f	Float Radius (ft)
Q	Flow Rate (ft^3/s)	$2R_t$	Local Bore of the Rotameter (ft)
g	Gravity (ft/s^2)	$\dot{m}$	Mass Flow Rate (lb/s)
$P/\rho g = h$	Pressure Head (ft)	h_L	Head Loss (ft)

4 Procedure

1. Turn on the hydraulic bench pump
2. Open the apparatus valve until the rotameter shows a reading of about 10mm
3. Measure the volumetric discharge at the outlet of the Hydraulic Bench to ensure steady-state flow
    (a) Your successive measurements must be close to one another
4. Record the readings of the manometers and rotameter
5. Repeat this procedure for a number of equidistant values of rotameter readings up to a maximum of approximately 220mm
    (a) Take at least 6 measurements
6. Turn off the apparatus valve and pump

5 Calculations

1. For each flow rate observed, calculate the discharge and mass flow using the venturi meter
2. For each flow rate observed, calculate the discharge and mass flow using the orifice meter
3. Use 3 measurements of the rotameter to construct a calibration curve
4. Calculate the discharge and the mass flow for the remaining 3 flows using the rotameter calibration curve constructed in step 3
5. For each flow rate observed, calculate the discharge and mass flow using the weigh tank

6 Interpretation Questions (for Report)

1. How did the different flow rate measurements compare?

2. How did the different mass flow measurements compare?

3. How different were the measured head losses across the pipe?

4. How can someone reduce the head losses associated with the wide-angled diffuser and the right-angled bend?

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Experiment: Flow Measurement Apparatus - Data Sheet
Date of Experiment:
Name:
Experimental Data:
Temperature of water, T= celsius
Water density, $\rho =$ (lb/ft^3)
Gravity, g= 32.2 (ft/s^2)

		Test Numbers				
		1	2	3	4	5
Manometer Levels (mm)	A					
	B					
	C					
	D					
	E					
	F					
	G					
	H					
	I					
Rotameter Level (mm)						
Water Volume (L)						
Time (seconds)						
Digital flow rate 1 (L/min)						
Digital flow rate 2 (L/min)						

Instructor's Signature

For Calculation:

		Test Numbers				
		1	2	3	4	5
Mass Flow Rate (lb/s)	Venturi					
	Orifice					
	Rotameter					
	Weigh Tank					
Head Loss (ft)	Venturi					
	Orifice					
	Rotameter					
	Diffuser					
	Elbow					
ΔH/Inlet Kinetic Head	Venturi					
	Orifice					
	Rotameter					
	Diffuser					
	Elbow					