LEBANESE AMERICAN UNIVERSITY

SCHOOL OF ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

CIE 312 Fluid Mechanics –Lab

Lab report # 4

Different flow Measuring Apparatus

Venture meter, Orifice plate and Rotameter

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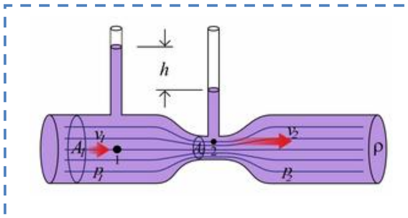
Introduction

The measurement of water flow rate is an important topic in the study of fluid dynamics. In this report we are discussing three commonly used flow measuring devices:

- Venturi
- Orifice plate
- Variable area meter

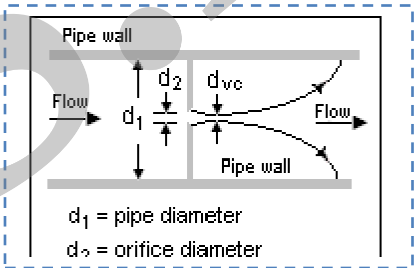


Venturi meter:

The Venturi effect is the reduction in fluid pressure that results when a fluid flows through a constricted section of pipe. The Venturi utilizes pressure drop across a fixed geometry.

The Venturi effect is named after Giovanni Battista Venturi (1746–1822), an Italian physicist.

Orifice plate:



An orifice plate is a device used for measuring the rate of fluid flow. It uses the same principle as a Venturi nozzle, which states that there is a relationship between the pressure of the fluid and the velocity of the fluid.
When the velocity increases, the pressure decreases and vice versa.
An orifice plate is a thin plate with a hole in the middle. It is usually placed in a pipe in which fluid flows. When the fluid reaches the orifice plate, with the hole in the middle, the fluid is forced to converge to go through the small hole; the point of maximum convergence actually occurs shortly downstream of the physical orifice, at the so-called ***vena contracta*** point. As it does so, the velocity and the pressure changes. Beyond the vena contracta, the fluid expands and the velocity and pressure change once again. By measuring the difference in fluid pressure between the normal pipe section and at the vena contracta, the volumetric and mass flow rates can be obtained from Bernoulli's equation.

An orifice plate utilizes pressure drop across a fixed gemoetry.

Variable area meter:

A variable area meter is a meter that measures fluid flow by allowing the cross sectional area of the device to vary in response to the flow, causing some measurable effect that indicates the rate.

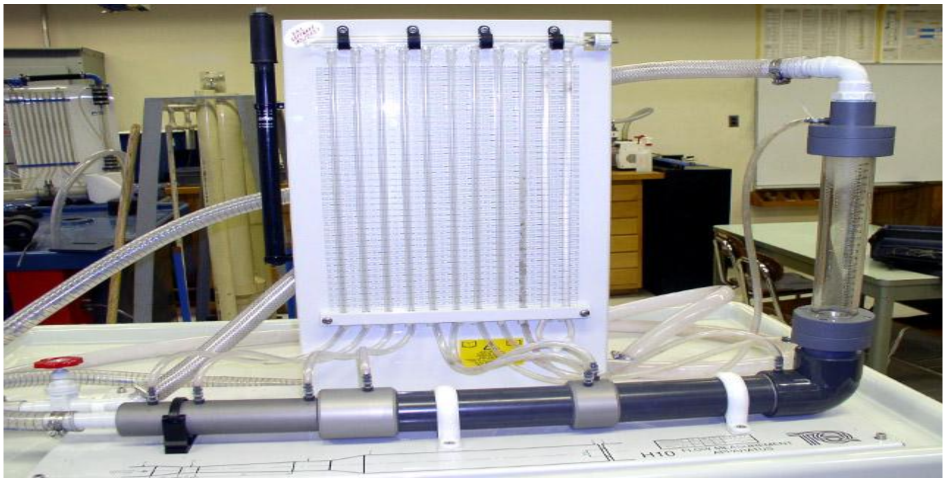
A **rotameter** is an example of a variable area meter.

The float inside the rotameter is made of steel. The reason it floats up when the flow is turned on is due to 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. As a consequence, the float has a unique position for each flow rate; the higher the flow rate, the higher the position. The float position will be used to determine the flow rate.

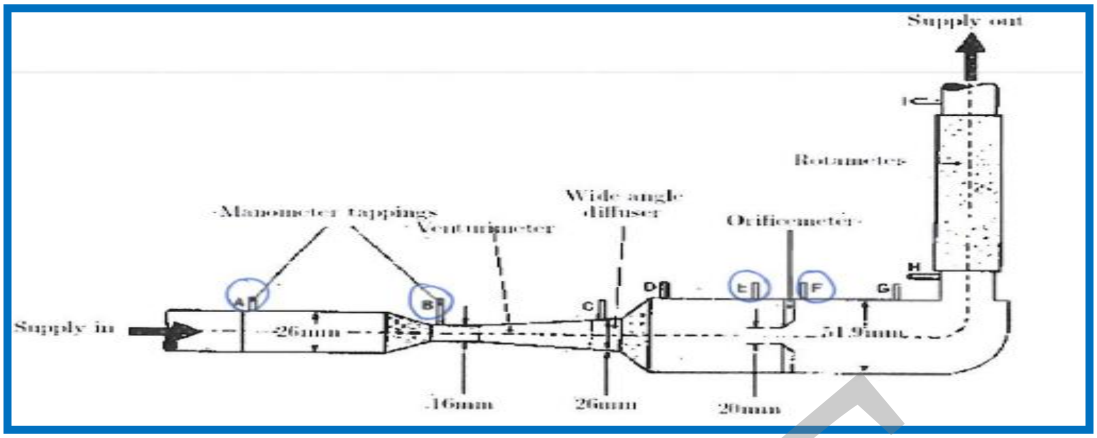
Objectives

The experiment which can be carried out with the Water Flow Measuring Apparatus provides a comparison of flow measurements using the following devices:

1- Flow measurement using a sudden enlargement
2- Flow measurement using a venturi meter
3- Flow measurement using an orifice plate
4- Flow measurement using a rotameter



Apparatus



- Venturi meter (write Bernoulli Equation between Point A and B)
- Orifice meter (write Bernoulli Equation between Point E and F)
- Rotameter (write Bernoulli Equation between Point H and I or in our case, since we do not have the measurements of the rotameter, we will simply assign to each reading a corresponding mass flow rate using a given graph)

The pressure drop across any length of pipe can be used as a means of measuring the flow as can the pressure drop across any fitting or combination of fittings. In this apparatus a sudden enlargement and an elbow are also included, however, the pressure drop across them is very small and the possibility of secondary effects detracts from their use.

Procedure

1- Connect the supply hose from the hydraulic bench to inlet of venture meter and secure with a hose clip

2- Water enters the apparatus through the lower left-hand end

3- Water flows horizontally through a sudden enlargement into a transparent venture-meter, and into an orifice plate.

4- A 90 degrees elbow changes the flow direction to vertical and connects to a variable area flow meter(a rotameter)

5- A second bend passes the flow into a discharge pipe which incorporates an atmospheric break

6- Connect a hose to the control valve outlet and direct its free end into control hole in the bench

7- With the air purge valve closed, close the apparatus valve fully then open it by about 1/3

8- Switch on the bench and slowly open its valve until water starts to flow

9- Allow the apparatus to fill with water then continue to open the bench valve until it is fully open. And the close the apparatus valve fully

10- Couple the bicycle pump to the purge valve and pump down until all manometers read approximately 280 mm

11- Remove entrained air from the manometer by gentle tapping with fingers

12- Check water levels and maintain it constant

13- Check the tube ferrules and top manifold as free from water blockage, which will suppress the manometer level ferrules blockage can be cleared by a sharp burst of pressure from bicycle pump.

Results

1. Water at 25°C have a density of:
   $\rho = 997.1 kg/m^3$
   and a dynamic viscosity of:
   $\mu = 0.894 * 10^{-3} Ns/m^2$

2. Volume flow rate Q calculated using:
   a. Venturi Meter:

Runs	h_A (mm)	h_B (mm)	$h_A - h_B$ (mm)	V_A (m/s)	$Q_{calculated}$ * 10^-3 (m³/s)
1	185	120	65	0.462	0.245
2	212	125	87	0.535	0.284
3	233	128	105	0.587	0.312
4	255	129	126	0.643	0.342
5	300	133	167	0.741	0.393

- Continuity equation:

$$Q_A = Q_B \Leftrightarrow (V_A)(A_A) = (V_B)(A_B) \Leftrightarrow V_B = V_A \left(\frac{A_A}{A_B}\right)$$

- Bernoulli equation:

$$z_A + \frac{P_A}{\gamma} + \frac{v_A{}^2}{2g} = z_B + \frac{P_B}{\gamma} + \frac{v_B{}^2}{2g} \qquad \left(z_A = z_B \;\&\; h_A = \frac{P_A}{\gamma}, h_B = \frac{P_B}{\gamma}\right)$$

$$\Rightarrow h_A - h_B = \frac{1}{2g}\left(V_B{}^2 - V_A{}^2\right) = \frac{1}{2g}\left[\left(\frac{A_A}{A_B}\right)^2 - 1\right] V_A{}^2$$

$$\Rightarrow V_A = \sqrt{\frac{2g(h_A - h_B)}{\left(\frac{A_A}{A_B}\right)^2 - 1}}$$

$$\Rightarrow Q = A_A \times \sqrt{\frac{2g(h_A - h_B)}{\left(\frac{A_A}{A_B}\right)^2 - 1}}$$

b. Orifice Plate:

Runs	h_E (mm)	h_F (mm)	$h_E - h_F$ (mm)	V_F (m/s)	$Q_{calculated}$ * 10^-3 (m³/s)
1	180	108	72	0.178	0.378
2	207	105	102	0.212	0.449
3	229	102	127	0.237	0.501
4	250	100	150	0.258	0.545
5	298	97	201	0.298	0.631

- Continuity equation:

$$Q_E = Q_F \Leftrightarrow (V_E)(A_E) = (V_F)(A_F) \Leftrightarrow V_E = V_F\left(\frac{A_F}{A_E}\right)$$

- Bernoulli equation:

$$z_E + \frac{P_E}{\gamma} + \frac{v_E{}^2}{2g} = z_F + \frac{P_F}{\gamma} + \frac{v_F{}^2}{2g} + \Delta h$$

$$\left(z_E = z_F \ \& \ \frac{P_E}{\gamma} = \frac{P_F}{\gamma} = 0 \ \& \ \Delta h = h_E - h_F\right)$$

$$\Rightarrow \Delta h = \frac{1}{2g}\left(V_E{}^2 - V_F{}^2\right) = \frac{1}{2g}\left[\left(\frac{A_F}{A_E}\right)^2 - 1\right]V_F{}^2$$

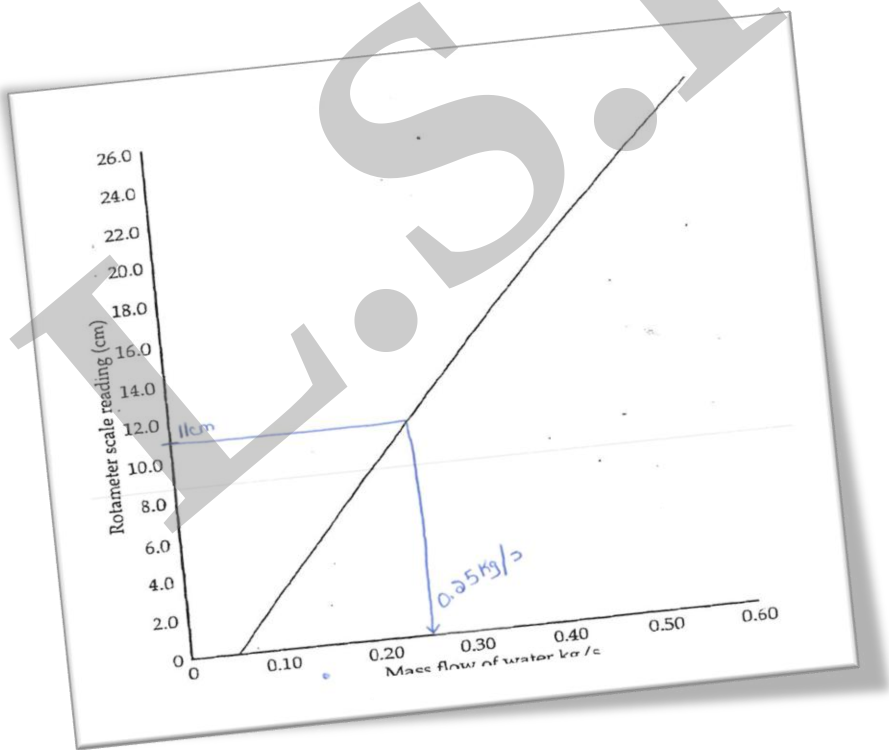
$$\Rightarrow V_F = \sqrt{\frac{2g\Delta h}{\left(\frac{A_F}{A_E}\right)^2 - 1}}$$

$$\Rightarrow Q = A_F \times \sqrt{\frac{2g\Delta h}{\left(\frac{A_F}{A_E}\right)^2 - 1}}$$

c. Rotameter:

Runs	height in rotameter (cm)	Mass flow rate (kg/s)	Volume flow rate ($Q_{calculated}$) *10^-3 (m^3/s)
1	10	0.225	0.226
2	12	0.275	0.276
3	13.5	0.300	0.301
4	14.9	0.325	0.326
5	17.3	0.375	0.376

- From the curve below showing the relationship between the rotameter reading and the mass flow of water inside it, we can tell for different runs (different rotameter readings) the correspondent mass flow.



- Then, to find the volumetric flow rate:

$$Mass\ flow\ rate = \rho_{water} \times Q \quad \Leftrightarrow \quad Q = \frac{Mass\ flow\ rate}{\rho_{water}}$$

3. Mass flow rate was calculated using the previous equation in the:

a. Venturi Meter:

Runs	Mass flow rate (kg/s)
1	0.245
2	0.283
3	0.311
4	0.341
5	0.392

b. Orifice Plate:

Runs	Mass flow rate (kg/s)
1	0.376
2	0.448
3	0.500
4	0.543
5	0.629

c. Rotameter:

Runs	Mass flow rate (kg/s)
1	0.225
2	0.275
3	0.300
4	0.325
5	0.375

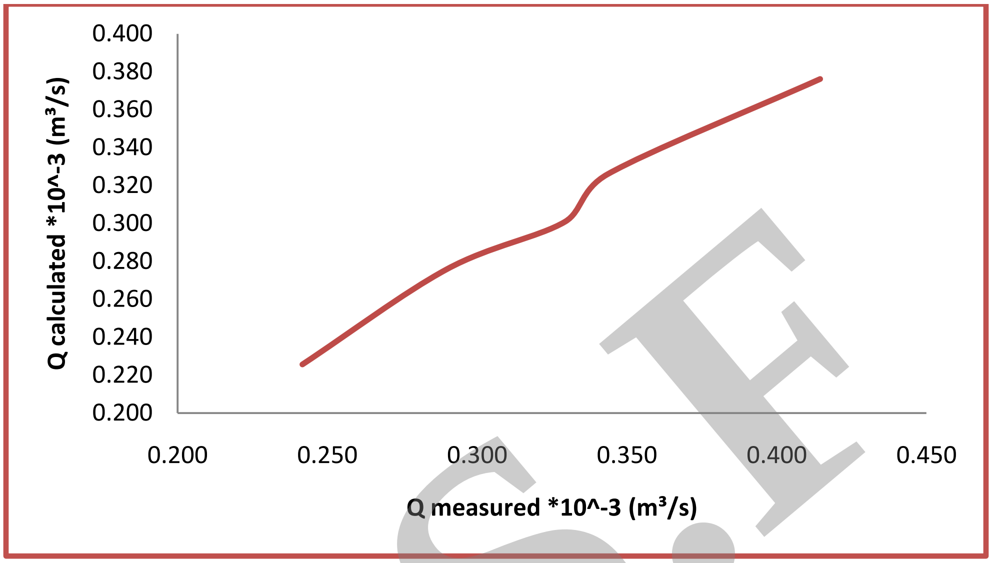
4. Flow rate collected in the volumetric measuring tank:

Runs	Volume (L)	Time (s)	$Q_{measured}$ *10^-3 (m^3/s)
1	5	20.69	0.242
2	5	17.25	0.290
3	5	15.18	0.329
4	5	14.55	0.344
5	5	12.06	0.415

- Volumetric measured flow:

$$Q_{measured} = \frac{volume}{time}$$

5. Plot of the flow rate calculated using the rotameter versus the flow rate measured in the tank:



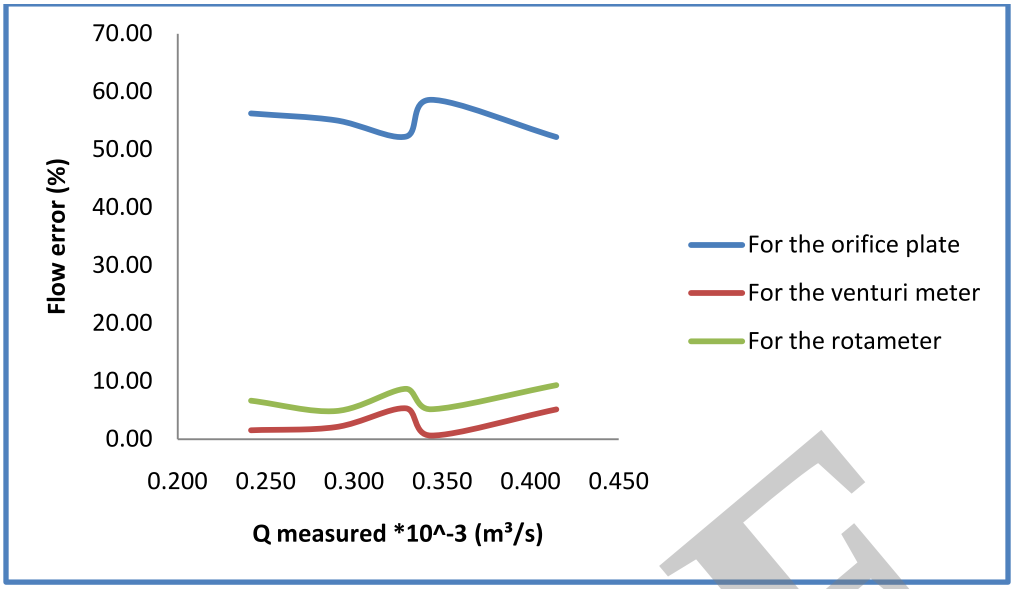
6. The error in reading the flow rate in each device is given by:

Runs	Flow error in Venturi Meter (%)	Flow error in Orifice Plate (%)	Flow error in Rotameter (%)
1	1.52	56.24	6.62
2	2.08	55.05	4.85
3	5.33	52.25	8.66
4	0.60	58.59	5.15
5	5.15	52.17	9.29

- Flow error:

$$\% \, error = \frac{|Q_{measured} - Q_{calculated}|}{Q_{measured}} \times 100$$

In addition, the graph of these errors with respect to the measured flow is shown:



7. The discharge coefficient for both the venture meter (C_d) and the orifice plate (K) is given in the following table:

Runs	C_d	k
1	0.985	0.640
2	1.021	0.645
3	1.056	0.657
4	1.006	0.631
5	1.054	0.657

- Discharge coefficient:

$$C_d \ \ OR \ \ k = \frac{Q_{measured}}{Q_{calculated}}$$

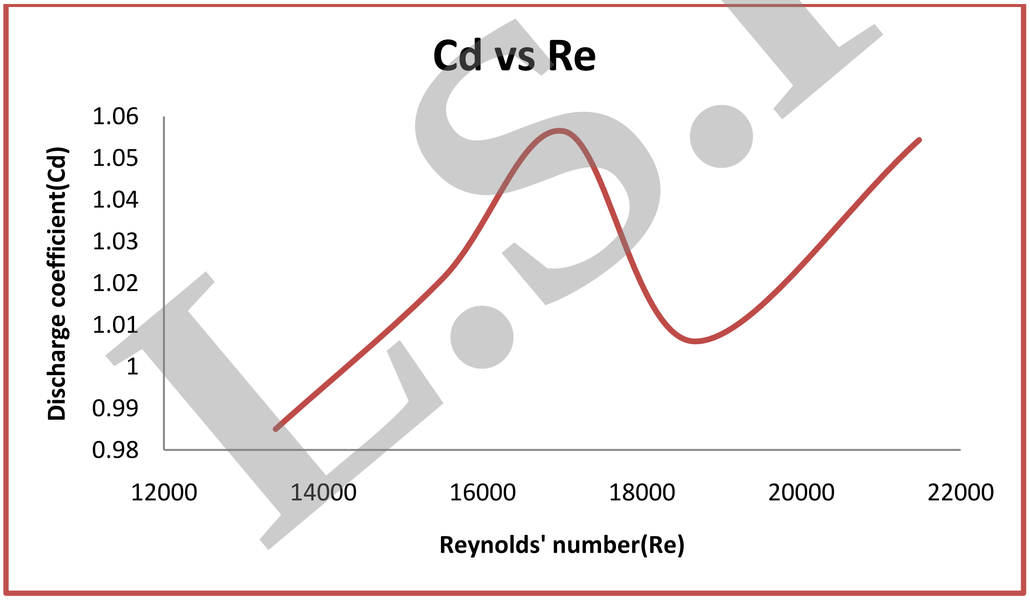
8. The Reynolds' number for both venturi meter and orifice plate is given as follows:

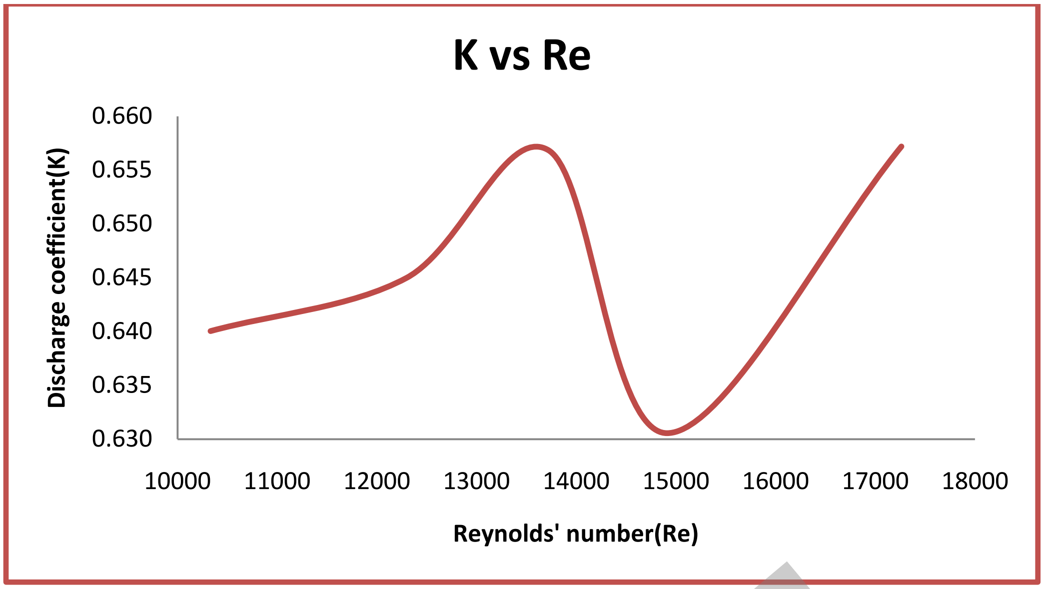
Runs	$\mathbb{R}e$ in the venturi meter	$\mathbb{R}e$ in the orifice plate
1	13399	10331
2	15502	12297
3	17030	13721
4	18656	14912
5	21478	17262

- Finding Reynolds' number using dynamic viscosity:

$$\mathbb{R}e = \frac{\rho V D}{\mu}$$

9. For the venture meter as well as for the orifice plate, the relationship between the discharge coefficient and the Reynolds' number is shown in the following graph:





10. Finally, the difference between the three devices is given by this table:

	Venturi meter	Orifice Plate	Rotameter
Accuracy (%)	97.06	45.14	93.09
Pressure Loss (Pa)	1075.97	1275.51	1324.42/972.29

- The accuracy represents which among these devices will give a better result (more accurate answer):

$$\% \ of \ Accuracy = 100 - \% \ of \ Error$$

- The pressure loss must be lowered in order to have a better result:

$$Pressure \ Loss = \Delta P = \Delta h \times \gamma$$

Where Δh is the average of the difference between the height of water in the manometers (or the rotameter) at the beginning and end of each device.

Discussion

- Comparing the calculated flow errors for the venturi meter, the rotameter and the orifice plate shows that the values found using the venturi meter are the most accurate, since they range between 0.60 and 5.33 %(average of 2.94%). Those found using the rotameter are close behind, with flow errors going from 4.85 to 9.29 %(average of 6.91%).
  However, the flow errors for the values found using the Orifice plate are very large and exceed 50%(average of 54.86%). This difference in flow errors can be seen in the corresponding graph.

- The previous observations are supported by the calculated values of the the pressure loss which indicate that the orifice plate is responsible for the highest loss of pressure (1275.51 Pa) then comes the venturi meter (1075.97 Pa) and at last the rotameter with the lowest value(972.29 Pa).

- The discharge coefficient for both the venturi meter and the Orifice plate was calculated then drawn with respect to the Reynolds‘ number. These two graphs reveal the difference between the two devices; in fact, the line that belongs to the venturi meter has a different range of alternation from the other graph (from 13000 to 22000 for Re and from 0.98 to 1.06 for Cd), on the other hand, the orifice plate’s line has a narrower range (from 10000 to 18000 for Re and from 0.63 to 0.66). for the same flow of water passing through the apparatus, these devices give different values for both the Reynolds‘ number and the discharge coefficient. The Cd values for the Venturi meter vacillate around 1 (having an average of 1.025) which is not within the given bounderies (0.975-0.995) due to several sources of error. Furthermore, the value given for k (0.601) is different from the average of k calculated (0.646).

- Finally, the accuracy percentage shows clearly that the venturi meter (97.06%) and the rotameter (93.09%) yield values that are more precise than the orifice plate (45.14%).

- The experimental results were not exactly accurate due to many experimental factors, including:
  - Imprecision in recording the readings of the manometers and the rotameter
  - Imprecision while using the stop-watch to record the time
  - Imprecision while converting from the rotameter scale reading to the mass flow of water using the given calibration curve
  - The friction between the water and the tube which we ignored by considering water an ideal fluid

Conclusion

This experience has allowed us to measure the water flow rate using different devices: Venturi meter, enlargement, orifice plate, 90°elbow and rotameter. However, we only discussed the difference between three of them. As a result, the orifice plate has the lower accuracy percentage, but the venturi and the rotameter have encountered the least error. Nevertheless, in real life, building a venturi meter is the most difficult since a lot of precise measurements must be taken.

References

Elementary Fluid Mechanics, by R. Street, G. Watters, and J. Vennard, John Wiley and Sons, Inc.