Estimation of Flow Meter Losses

T. Littleton

Abstract. *In this article, experimental data concerning flow rates, discharge coefficients, pressure losses, and energy losses of water flowing through flow meters will be discussed. A venturi, orifice, and rotameter flow meter were used in the experiment. The actual coefficients did not deviate too far from what the theoretical coefficient was. And the calculated theoretical coefficients lined up to what would be expected from the given flow meters. Given this information, the energy losses and pressure losses at various flow rates seen were those of what could be expected were the experiment to be run again. Repetition of the experiment and larger sample sizes of flow rates would potentially yield more accurate results and help eliminate error in the calculations but also give an idea of the error inherent in the provided system.*
Keywords. *Venturi, orifice, rotameter, flow meter, discharge coefficient*

INTRODUCTION

When a fluid flows through obstruction flow meters, there is expected to be a certain amount of head loss. Depending on the type of flow meter, that head loss could vary greatly. In this experiment, a venturi flow meter, orifice flow meter, and rotameter flow meter were all used to find these head losses along with energy loss and each meter's discharge coefficient. A venturi flow meter is one in which the area gradually decreases and remains constant for a certain distance then gradually increases back to the original area. An orifice flow meter is one in which a plate with a small opening is placed in the pipe, causing a sudden decrease, then increase in area of the flow. This causes significant head loss in the flow. A rotameter flow meter is a vertical, tapered pipe with a shaped weight inside that rises as it is forced upwards by rising flow rates. The rising flow rates cause the drag force of the fluid eventually exceeds the gravitational force acting down on the weight, causing it to rise.

OBJECTIVES

The objectives were to estimate the discharge coefficients for a venturi and orifice flow meter and to quantify the energy losses through a venturi, orifice, and rotameter flow meter due to the flow.

MATERIALS AND METHODS

An FNE18 Flow Meter Modules from Edibon and a stopwatch were used in this experiment. Water was used in the system as well. The equipment used for this study is housed in the Biosystems Engineering Department at Auburn University.

Preparation and Procedure of Experiment

All knobs and valves were checked to be closed (or open depending on its purpose) before starting to run water through the system. Then, systematically, the two knobs were turned to let water run through the system. They were adjusted to ensure neither that neither the readings in taps 1-3 got too high nor that the readings in taps 5-7 got too low. At various points, the timer and dump valve system were used to gather volumetric changes in liters that would later be used in the analysis of the collected data. During these times, the knobs were not turned and the height readings on the seven taps were recorded

Analytical Procedure

The height of the water was measure in millimeters and the volume of water was measured in liters. Later, they were both converted to meters and cubic meters, respectively. From the changes in the readings from taps 1and 3 and from 5 and 8, the pressure differences were calculated for the venturi and orifice flow meters respectively. From there, the energy losses from each meter at each flow rate were calculated. The volumetric flow rates were calculated to find the both the Reynolds number and the theoretical drag coefficient. Using the slope of the plots in figure 2, the theoretical discharge coefficient was calculated.

RESULTS AND DISCUSSION

The data obtained during the experiment were water heights, time elapsed, and volume changes, and can be found in table 1. All referenced figures, tables, and formulas can be found below in the TABLE, FIGURES, AND FORMULAS section.

Analysis of Gathered Data

Figure 1 shows the plot of the energy losses in each flow meter at the various recorded volumetric flow rates. The venturi flow meter showed a positive linear relationship, though the incremental increase of energy loss per increase of flow rate is relatively small for the given flow rates. The rotameter flow meter showed a constant relationship or little to no increase in energy loss per increase in flow rate. The orifice flow meter showed to have an exponential, positive relationship between the energy loss and increasing flow rate.

Figure 2 shows the plot of the volumetric flow rates versus the pressure losses in the flow meters for each flow meter. The venturi flow meter had a strong, positive, linear relationship between increase in flow rate and increase in pressure change with a steep slope. The rotameter showed little to no change in pressure difference within the flow meter as the flow rate was increased. The orifice flow meter showed a strong, positive, linear relationship between the two variables, similar to the venturi flow meter. Unlike the venturi flow meter, the orifice flow meter’s plot had a slightly gentler slope and broader range of values for pressure difference.

Discussion

The energy losses in the venture and orifice flow meters lack similarity because the energy loss in the flow meter, over various flow rates, rose exponentially. The energy loss in the venture flow meter due to rising flow rates rose linearly. This could be due to the nature of the meter itself. The gradual change in area in the venturi versus the abrupt changes in area in the orifice could cause the latter to lose energy at an exponential rate with rising flow rates, while the latter experiences a linear rise in energy loss for the same conditions. The changes in area affect the changes in pressure at each end of the flow meters. The flow in a venturi flow meter id accelerated and decelerated gradually, causing low amounts of head loss. The abrupt change in area in an orifice flow meter causes considerable swirl and significant head loss, while the design of the venturi flow meter prevent flow separation and swirling (Cengel and Cimbala, 2014). The constant energy loss in the rotameter could be explained to its shape as well. The area gradually increases but never decreases. While the orifice and venturi meters start and end at the same area, the rotameter does not. It is also designed more for determining flow rates as its primary purpose. The pressure losses in the flow meters may be explained in a similar fashion.

The discharge coefficient is the ratio of the actual discharge versus the theoretical discharge, as in the mass flow rate at the end of the given flow meters versus the mass flow rate at the end of an ideal flow meter (Mannan and Lee, 2005). The calculated discharge coefficients aligned with the theoretical coefficients. Due to its streamlined design, the expected coefficient for a venturi flow meter would be between 0.95 and 0.99 (Cengel and Cimbala, 2014). The calculated theoretical and actual coefficients, 0.98 and 1.3 respectively, match up well with this assumption. The calculated theoretical and actual coefficients for the orifice flow meter were 0.63 and 0.68, respectively. When no other information is known, it can be assumed that the coefficient for an orifice flow meter is between 0.61 and 0.63 (Huffman et. al., 2013). The calculated coefficients for the orifice flow meter line match up closely with this assumption as well. The errors in both sets of coefficients may be explained by error in the experiment. Human error in readings, timing, and calculations can be attributed to much of the error in the data. As well, the inherent error in the Edibon Flow Meter Module could attribute to the error in the data recorded.

A larger sample size of readings and flow rates could provide more information on the linearity of the relationships and reduce error in the calculated coefficients. Repetition of the procedure would be beneficial to determine the precision and consistency of the data collected.

TABLES, FIGURES, AND FORMULAS

TABLE 1. Data collected from the experiment

Q (m3/s)	V_1 (L)	V_2 (L)	Time (s)	P_1 (mm)	P_2 (mm)	P_3 (mm)	P_4 (mm)	P_5 (mm)	P_6 (mm)	P_7 (mm)	P_8 (mm)
5.56E-05	3	8	90	292	294	292	292	60	60	56	56
1.22E-04	3	14	90	315	310	313	311	78	80	65	69
1.53E-04	9	18	90	332	322	329	325	91	94	68	76
1.83E-04	7	18	60	353	336	349	340	106	111	79	81
2.67E-04	8	24	60	382	351	375	358	123	132	50	73
3.33E-04	10	30	60	431	380	420	390	154	169	29	69

TABLE 2. The Energy Loss of Each Flow Meter at Each Flow Rate

Flow Rate, Q	Venturi (P_1-P_3)	Rotameter (P_4-P_5)	Orifice (P_6-P_8)
5.56E-05	0.000	2.276	0.039
1.22E-04	0.020	2.286	0.108
1.53E-04	0.029	2.296	0.177
1.83E-04	0.039	2.296	0.294
2.67E-04	0.069	2.305	0.579
3.33E-04	0.108	2.315	0.981

TABLE 3. The Square Root of the Pressure Change within Each Flow Meter at Each Flow Rate

Flow Rate, Q	Venturi (P_1-P_2)	Rotameter (P_4-P_5)	Orifice (P_6-P_7)
5.56E-05	4.43	47.71	6.26
1.22E-04	7.00	47.81	12.13
1.53E-04	9.90	47.91	15.97
1.83E-04	12.91	47.91	17.72
2.67E-04	17.44	48.01	28.36
3.33E-04	22.37	48.12	37.06

TABLE 4. Information Calculated to Obtain Discharge Coefficients

	Slope	Re	β (d/D)	Act. Discharge Coef.	Theo. Discharge Coef.
Venturi	2.00E-05	7373.1	0.625	1.311	0.980
Orifice	9.00E-06	6740.5	0.542	0.680	0.630

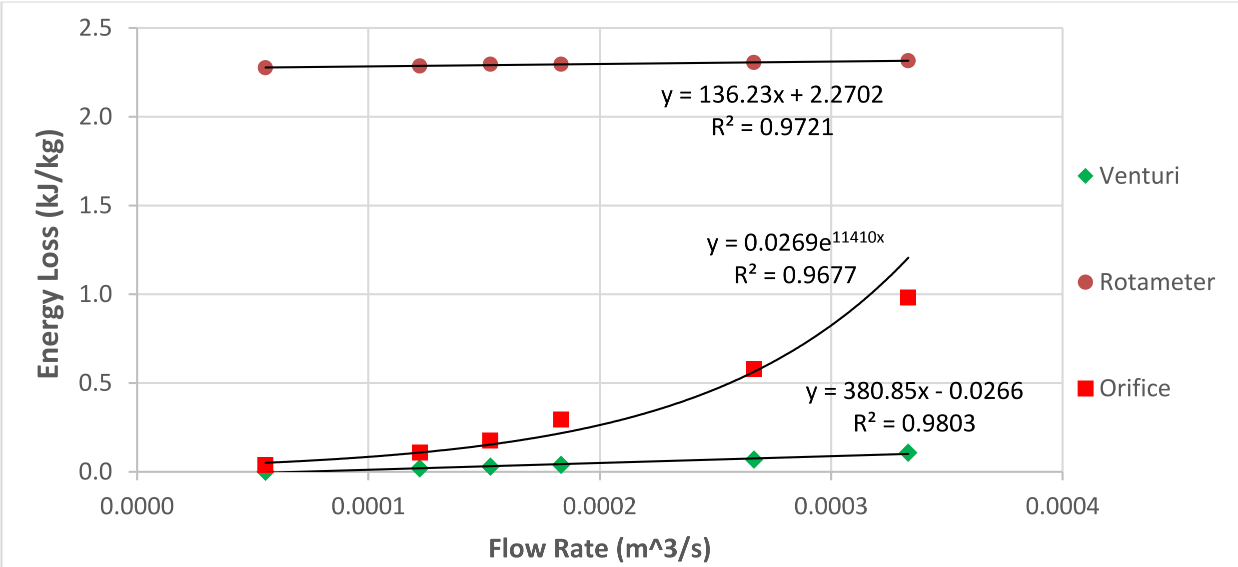

FIGURE 1. Energy Loss in Each Flow Meter (kJ/kg) versus Volumetric Flow Rate (m^3/s)

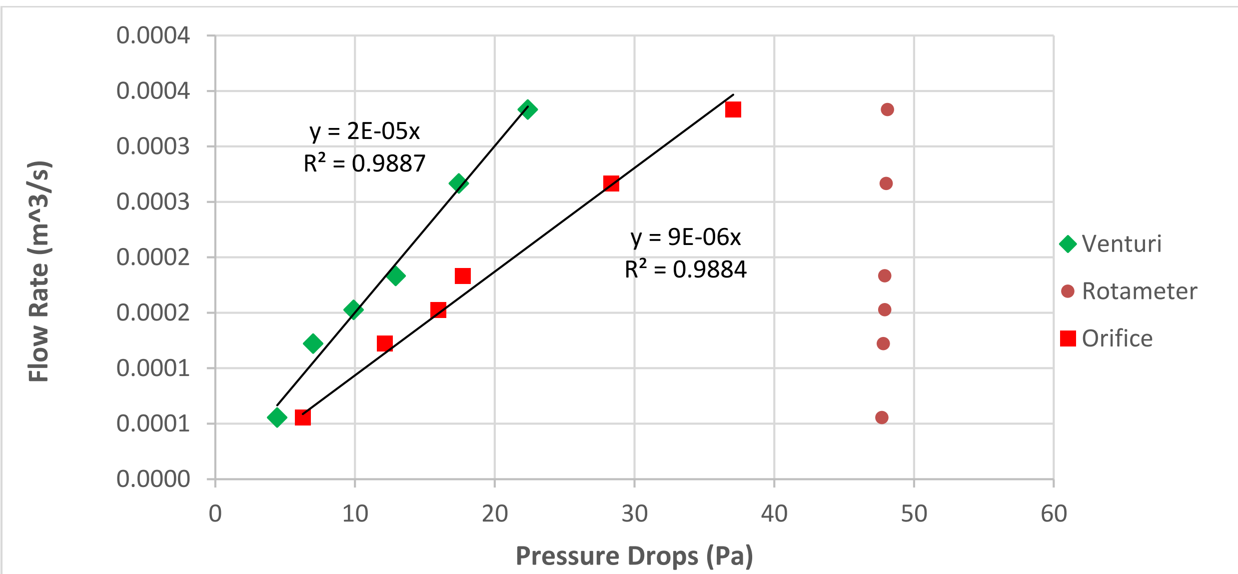

FIGURE 2. Volumetric Flow Rate (m^3/s) versus Change in Pressure within Each Flow Meter (Pa)

CONCLUSIONS

The analysis showed that based on the calculated coefficients, the experiment yielded reliable results for energy loss in the flow meters. The actual coefficients did not deviate too far from what the theoretical coefficient was. And the calculated theoretical coefficients lined up to what would be expected from the given flow meters. Given this information, the energy losses and pressure losses at various flow rates seen were those of what could be expected were the experiment to be run again. Repetition of the experiment and larger sample sizes of flow rates would potentially yield more accurate results and help eliminate error both in the calculations but also give an idea of the error inherent in the provided system. The actual coefficients were found to be sufficient to what would be expected due to the venturi's coefficient being above 0.95 and the orifice's coefficient being near 0.6. They were far enough from the theoretical coefficient to cause concern of how much error occurred in the experiment and where. As stated before, repetition and larger sample sizes may eliminate some of this error.

REFERENCES

Cengel, Y., & Cimbala, J. (2014). Chapter 8: Internal Flow. In *Fluid Mechanics: Fundamentals and Applications* (Third ed.) McGraw-Hill.

Huffman, Rodney L., Fangmeier, Delmar D., Elliot, William J., Workman, Stephen R. (2013). Chapter 6: Open Channel Flow. In *Soil and Water Conservation Engineering* (Seventh ed.)

Mannan Sam, Lee, Frank P., (2005) *Lee's Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control*, Volume 1, Elsevier Butterworth Heinemann.