ENERGY LOSSES THROUGH VENTURI, ORIFICE, AND ROTAMETER FLOWMETERS

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Abstract

The Edibon Flowmeter System was used to compare the energy losses due to friction of a Venturi, orifice, and rotameter flowmeter, along with the discharge coefficients of the Venturi and orifice flowmeters. It was found that the rotameter has the highest energy loss due to friction, but this loss stayed constant as velocity increased, similar to the Venturi flowmeter. The orifice flowmeter's energy loss increased as velocity increased because of the abrupt change in diameter of the orifice's design. A Venturi flowmeter would be the best choice if a system cannot handle a large change in pressure. The percent errors of the discharge coefficients for the Venturi and orifice flowmeters were 33.8% and 7.9%, respectively. The Venturi error takes into account the fact that the discharge coefficient was greater than 1, as discharge coefficients must be less than 1. Though Venturi and orifice flowmeters are common in irrigation systems, these flowmeters would not be acceptable for irrigation use because the percent error must be less than 5%.

Introduction

When a pipe is constricted at a point because of a change in pipe diameter, it creates a drop in pressure due to the increase of velocity. This pressure change, measured by a manometer, can be used to estimate the flow rate in a pipe (Cengel & Cimbala, 2014). Two types of obstruction flowmeters are the Venturi and the orifice flowmeters. The orifice flowmeter consists of a plate with a hole in the middle and can be easily manufactured, however they can be susceptible to stagnation points and undesired head loss (Replogle & Wahlin, 1994). Venturi flowmeters are created from converging and diverging cones. A rotameter uses a floating object in a clear tapered tube to measure flow rate. Because drag force increases with a flow's velocity, the flow can be determined by where the float is on the tube's outer scale (Cengel & Cimbala, 2014).

The flow rates taken from these obstruction flowmeters must be adjusted for the loss due to friction using a discharge coefficient, or the ratio of the actual discharge to the theoretical discharge. The friction due to the change in diameter causes a loss of pressure, thus making the actual velocity less than the measured velocity (Cengel & Cimbala, 2014). The discharge coefficient is a representation of the irrecoverable pressure loss. Though usually the discharge coefficient is calculated experimentally, it can also be calculated theoretically using the Reynolds number and the ratio of the areas. This drop in pressure also creates a loss of energy through the flowmeter.

These flowmeters are used to determine flow for many fluid transport systems, such as crop irrigation and plumbing. An accurate flow rate is important in order to determine what size pump is needed to transport the fluid. If the discharge coefficient isn't taken into account, then issues such as pipe damage caused by cavitation or a decrease in efficiency can occur.

Objective

The purpose of this experiment was to determine the energy losses due to flow through Venturi, orifice, and rotameter flowmeters, and to estimate the discharge coefficients of the Venturi and orifice flowmeters.

Materials and Methods

The Edibon Flowmeter System (Fig. 1) was used to measure the height changes of manometers connected to the Venturi flowmeter on the bottom of the system (manometers 1, 2, and 3), the orifice flowmeter on the top (4 and 5), and rotameter flowmeter on the right (6, 7, and 8). The two black valves were turned simultaneously in order to control the flow of water through the system. The volume change per time was measured with a dump valve system by calculating the initial and final volume in a certain amount of time during each manometer reading.

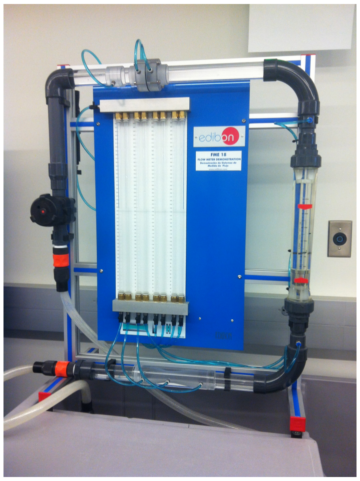
Figure 1: Edibon Flowmeter Module with 8 manometer tubes

The heights from each manometer were converted to meters, and then used to calculate the pressure at each point (Eq. 1). From the change of pressures at the each flowmeter listed above, the energy loss (Q) due to a drop in pressure was calculated (Eq. 2). The slope of the plot volumetric flow rate vs. square root of pressure drop was used with the two pipe diameters in order to determine the discharge coefficient of the Venturi and orifice flowmeters (Eq. 3).

$$P = \rho * g * h \qquad \textit{(Eq. 1)}$$

$$Q = \frac{\Delta P}{\rho} \qquad \textit{(Eq. 2)}$$

$$Slope = C_d A_2 \sqrt{\frac{2}{\rho\left(1-\left[\frac{A_2}{A_1}\right]^2\right)}} \qquad \textit{(Eq. 3)}$$

where:
P = pressure (Pa)
g = gravitational acceleration (9.81 m/s^2)
ρ = density of water (1000 kg/m^3)
Q = energy (kJ/kg)
C_d = discharge coefficient
A_1 = outer area (m^2)
A_2 = inner area (m^2)

To calculate the theoretical discharge coefficient of the orifice flowmeter (Eq. 4), the Reynolds number was found (Eq. 5) and the ratio of areas, β (Eq. 6). The Venturi theoretical discharge coefficient was said to be 0.98 because specific data was not available (Cengel & Cimbala, 2014).

$$C_d = 0.5959 + 0.0312\beta^8 + \frac{91.71\beta^{2.5}}{Re^{0.75}} \qquad \textit{(Eq. 4)}$$

$$Re = \frac{V_{avg} D\rho}{\mu} \qquad \textit{(Eq. 5)}$$

$$\beta = \frac{A_2}{A_1} \qquad \textit{(Eq. 6)}$$

where:

V_{avg} = average velocity (m/s^2)

D = diameter (m)

μ = dynamic viscosity (kg/m*s)

Results and Discussion

The energy loss due to pressure change was plotted against volumetric flow rate for each flowmeter (Fig. 2). The slope of the rotameter was nearly horizontal, showing that there was little variation of energy loss as volumetric flow rate increased. However, this energy loss was significantly higher than the Venturi and orifice flowmeters. This high energy loss is due to the large drop in pressure due to friction. One reason the loss is higher than the other two flowmeters could be because friction is not only created from the wall of the pipe, but also from the float.

The orifice's energy loss was affected more by the change in volumetric flow rate. As the volumetric flow rate increased, the energy loss due to friction increased. This is because of the design of the orifice. When the obstruction makes a sudden change in diameter, the streamlines cannot change direction suddenly. This creates a swirl behind the orifice, and as the velocity of the flow increases, the vena contracta decreases. The smaller the vena contracta gets the greater the pressure difference, and thus the higher the energy loss.

The Venturi flowmeter has a smaller energy loss than the other two flowmeters because of the structure of the Venturi. The system has a gradual change in diameter. The flow streamline through a Venturi does not have to drastically change direction like the orifice flowmeter and are not obstructed by a float like the rotameter.

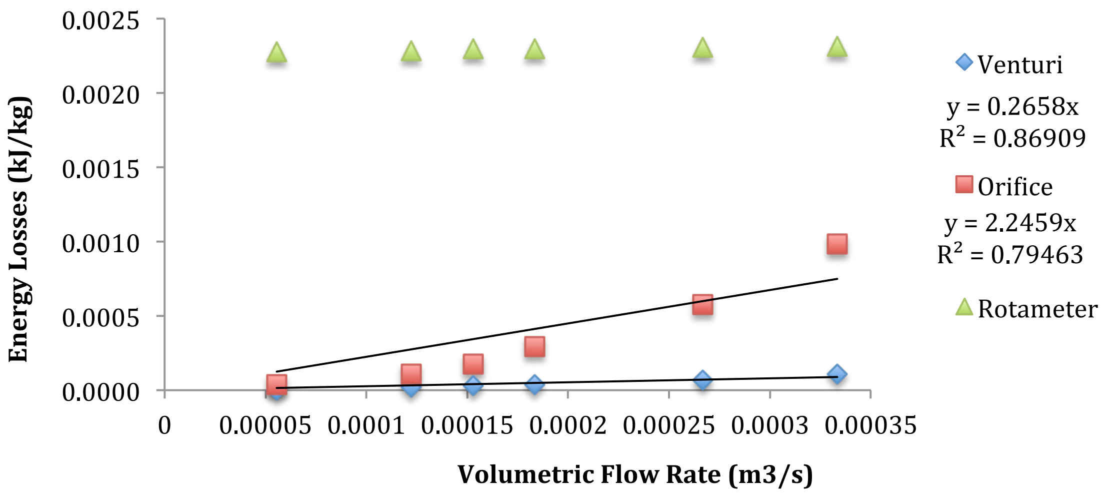

Figure 2: Energy losses versus volumetric flow rate for Venturi, orifice, and rotameter flowmeters

The discharge coefficients of the Venturi and orifice flowmeters were obtained from the graph of volumetric flow rate versus square root of pressure difference (Fig. 3). The rotameter data was included to show that a discharge coefficient couldn't be determined due to the slope of the line. From the slopes of the trendlines, the discharge coefficients were found to be 1.311 for the Venturi flowmeter and 0.6797 for the orifice flowmeter (Eq. 3). After determining the theoretical discharge coefficients for Venturi and orifice to be 0.98 and 0.6299 (Eq. 4), respectively, the percent error was calculated. The Venturi discharge coefficient had an error of 33.8% while the orifice discharge coefficient had an error of 7.9%. The high Venturi error supports the fact that the calculated discharge coefficient was over 1, because discharge coefficients must be less than 1. The low error for the orifice shows that the actual discharge coefficient was almost similar to the theoretical one. The percent error should be less than 5% for these flowmeters, especially for irrigation use (Replogle & Wahlin, 1994), which means that they should not be used for accurate flow rate measurements.

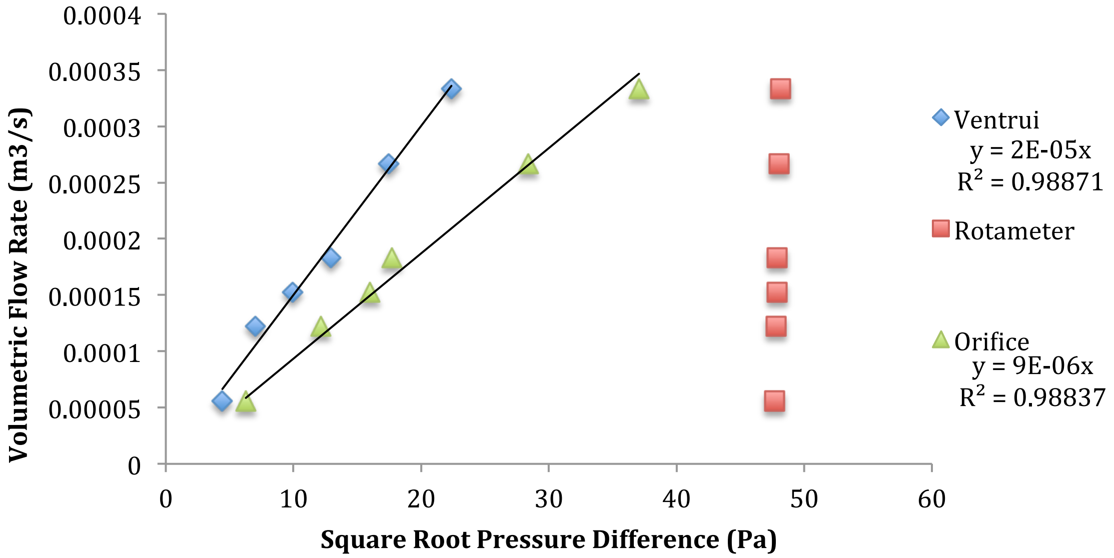

Figure 3: Volumetric flow rate versus square root of pressure differences for Venturi, rotameter, and orifice flowmeters

Conclusions

The energy losses for the rotameter and the Venturi flowmeter were found to stay relatively constant as velocity increased. This was not the case for the orifice flowmeter, whose energy loss increased as velocity increased. It acted differently than the rotameter and Venturi because it has a sudden change in pipe diameter as opposed to a gradual one. When looking for a flowmeter to use for a certain device, a rotameter should only be used if a large drop in pressure is acceptable, as the energy loss for the rotameter was much higher than the Venturi and orifice. A Venturi flowmeter should be used if a large change in pressure will damage the pipes.

The discharge coefficients for the Venturi and orifice were 1.3111 and 0.6797 with the percent errors being 33.8% and 7.9%, respectively. Because irrigation flowmeters typically have a percent error of less than 5%, these particular flowmeters should not be used if accurate testing is required. Error could have arisen from an inaccurate measurement of the manometer reading or volumetric flow rates, or from a flaw in the flowmeter itself, such as air in the pipes. In order to further determine where the error came from and how to fix it, multiple tests can be performed in order to reduce the human error through repetition.

References

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Replogle, J.A., Wahlin B (1994). Venturi Meter Construction for Plastic Irrigation Pipelines. *Applied Engineering in Agriculture, 10*(1), 21-26.