Application and Analysis of Various Flowrate Measurement Instruments/Methods

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A Venturi meter, orifice meter, rotameter and a direct fluid weight measuring system are used to measure the flow rate in a measurement apparatus. The Venturi meter and orifice meter change the geometry of the flow and measure corresponding changes in pressure to get the rate of the flow. The rotameter uses a weight/float, and the forces of the flow to balance in a equilibrium state proportional to the flow. The last, direct method, measures the time it takes for certain intervals of weight of the flow to fill a tank. We found that the Venturi meter was the most accurate in measuring the flow rate and it also has a low uncertainty and had loss. The rotameter was quite accurate as well, having a linear calibration curve, but it was not perfect, possibly due to hysteresis and frictional effects. The orifice meter get values that were a little higher than actual, which might be due to unsteadiness around the measurement areas, and head loss was also very high due to this sudden blocking device. The efficiency of the pumps followed a quadratic trend with respect to the flow rate and the efficiency of the series pump is a little less than twice that of the parallel pump.

INTRODUCTION

In this lab, flowrate is measured in many instruments and their methods. To calibrate the elements of this experiment, a direct fluid weight measuring system is used, where the flow is filled into a collection tank which is balanced with set weights that are place don the other side of the balance when the bucket tips. By measuring the time in between weight placements and amount of the weights, the actual flow rate is achieved. The fluid flow measuring devices that are used are a Venturi meter, rotameter, orifice meter, and a direct fluid weight measuring system.

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The flow apparatus that was used in this experiment is shown in Figure 1. It consists of a flow of water going through a Venturi meter, wide-angle diffuser, orifice meter, and rotameter.

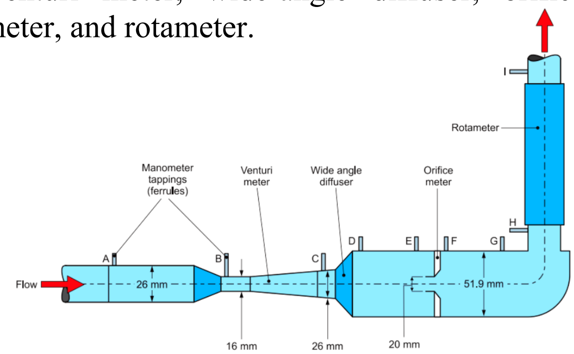

Figure 1. Flow Measurement Apparatus

In the Venturi meter, the flow is led through a pipe with a contraction section followed by a throat with increasing cross-sectional area, but still smaller than the pipe diameter. The contraction increases the velocity of the flow, which causes a fall in static pressure, which is proportional to the flow speed. In the throat, as the cross-sectional area increases, the velocity decreases back to the mean velocity and the pressure increases to a value a little less than the initial, which was lost due to frictional losses. Equation 1 gives the relation between the actual flowrate, and the cross-sectional areas and static pressures at locations A and B in the pipe. Figure 2 shows the change in velocity and the location of the pressure taps A and B (1 and 2 corresponding to Figure 2).

$$Q_{actual} = A_B V_B = A_B \left[\left(\frac{2g}{1 - \left(\frac{A_B}{A_A} \right)^2} \right) \left(\frac{p_A}{\rho g} - \frac{p_B}{\rho g} \right) \right]^{\frac{1}{2}} \qquad [1]$$

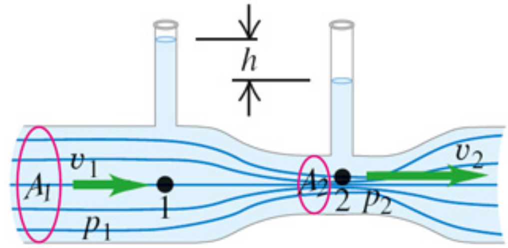

Figure 2. Venturi Tube Control Volume

An orifice meter is implemented by connecting a flat orifice plate with a hole drilled in it, in series with the pipe. The change in pressure across the plate due to the velocity change can be used to find the flow rate using Bernoulli's equation. For an incompressible flow, like the one used, Equation 2 can be used to find the flowrate using the cross sectional areas and static pressures at location E (pipe) and location F (throat). The constant C is called the discharge coefficient, which is related to the geometry of the orifice plate. In this experiment, C is equal to 0.601. Figure 3 shows the location of the pressure taps and the flow due to the orifice plate.

$$Q_{actual} = A_F \bar{V}_F = C A_F \left[\left(\frac{2g}{1 - \left(\frac{A_F}{A_E} \right)^2} \right) \left(\frac{p_E}{\rho g} - \frac{p_F}{\rho g} \right) \right]^{\frac{1}{2}} \qquad [2]$$

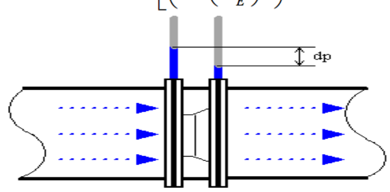

Figure 3. Orifice Meter Flow Diagram

The rotameter consists of a graduated tapered vertical tube with a flow directed upward. In the tube, there is a float, like that shown in Figure 4, which is acted upon by gravity on its own weight, buoyancy, pressure forces, and viscous drag forces. Because the cross sectional area of the tube increases with height, as the flow increases, the pressure force and viscous drag force upward both increase, so the float is lifted up to a higher position, until it reaches equilibrium, the height at which the flow rate corresponds to the calibrated value.

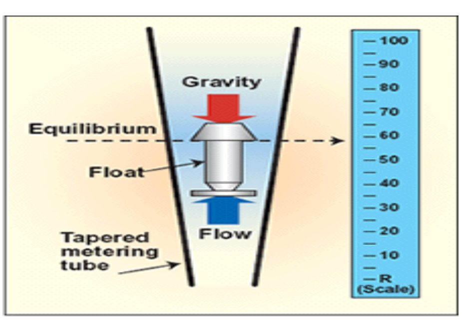

Figure 4. Rotameter Mechanism Diagram

To compare these devices against a more robust and direct measurement, we use a water collection tank and hydraulic bench as shown in Figure 5, which has a 1:3 leverage ratio between the weights and the tank so that every 1 kg of weights that are placed on the hook on one side, there is 3 kg of water in the tank. By timing how long it takes to tip the scale for each weight placement, the flow rate can be directly calculated by dividing the weight by the time it took and multiplying by 3, the leverage ratio. This method is used in conjunction with the others to give an accurate measurement to compare against.

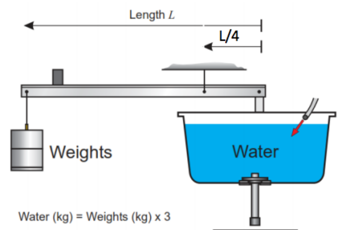

Figure 5. Hydraulic bench with Tank

The experiment is performed with 2 pumps in series and in parallel and the efficiency of the pumps is compared for each configuration. We used a manometer to get the pressures at the corresponding points in the system, the rotameter to get the direct flow measurement, and times for the direct measurement and performed calculations to get the flow rate. We repeated this for flow rates of approximately 20-180 mm using the control valve to change the opening. Head losses throughout the experiment are calculated using Bernoulli's equation, Equation 3 and the efficiency of the pumps is calculated using Equation 4.

$$\left(\frac{p_1}{\rho g} + \frac{\bar{V}_1^2}{2g} \right) = \left(\frac{p_2}{\rho g} + \frac{\bar{V}_2^2}{2g} \right) + \Delta H_{12} \qquad [3]$$

$$\eta = \frac{Q \Delta p}{\dot{W}} \qquad [4]$$

RESULTS AND DISCUSSION

The rotameter seems to agree very well with the direct measurement results. The calibration curve for this device is shown in

Figure 6. The linear behavior shows that there is not much hysteresis error and that the rotameter responds quite well to the changes in flow rate.

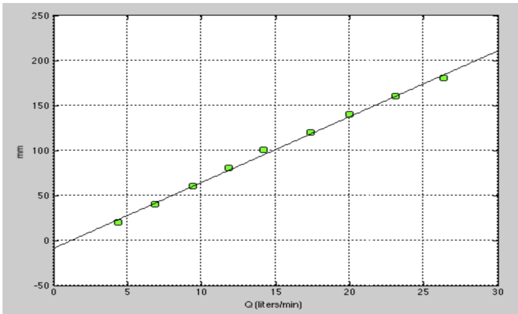

Figure 6. Calibration Curve of Rotameter vs. Actual Flow Rate Measurement

For the Venturi meter and orifice meter, equations 1 and 2 are used with the actual areas to get the flowrates and are very close to what the direct measurement was. Figure 7 shows the calibration curve for these two measurement devices compared to the actual flowrate. The Venturi meter is very close to the actual measurement, while the orifice meter is slightly higher than the actual. This could be due to turbulences in the flow when reaching the orifice. Not having a smooth, laminar flow can affect the pressures measured at both ends and could have increases the inlet pressure or decreased the throat pressure, causing an increase in flow rate measurement.

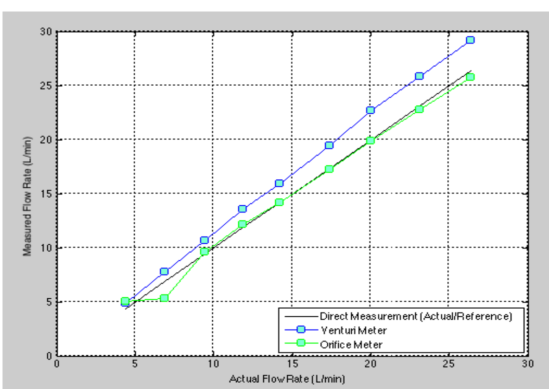

Figure 7. Calibration Curve of Venturi Meter & Orifice Meter vs. Actual Flow Rate

Throughout the flow apparatus there are certain head losses (loss in flow energy) that are attributed to each meter (Venturi, Orifice, and Rotameter) and with the wide-angled diffuser and right angle bend which are mainly due to frictional effects. These losses are calculated using Bernoulli's Equation, Equation 3. Figure 8 shows a plot of the head losses attributed to each of the devices. The head losses calculated are dimensionless (relative to the inlet kinetic heads).

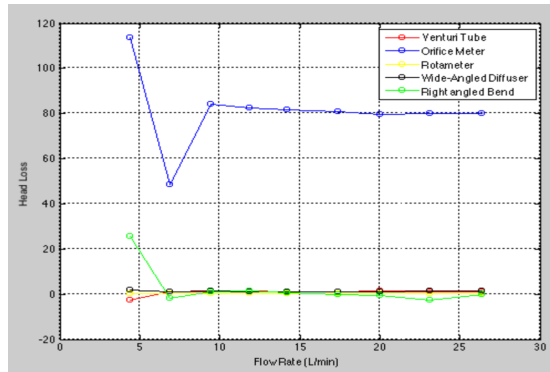

Figure 8. Head Loss vs. Flow Rate Graph for various elements

As shown in Figure 8, the head loss attributed to the orifice meter is highest, which converges to around 80 at higher flow rates. On the other hand, the head loss from the Venturi meter, Rotameter, wide-angled diffuser, and right angle bend are around the same, at around 1 inlet kinetic head. The head loss in the right angle bend is measured to be negative towards the end, which is an error, which can be due to the manometer friction effects or air being stuck, which did not give accurate measurements. Other than that, the calculated values agree well with intuition and other lab results.

There are multiple sources of error in the experiment that have possible effects on the data acquired. The time measurement of the direct weighing method has an approximate error of half a second along with its random uncertainty. The rotameter has only a resolution error of 1 mm. The significant source of error in the Venturi meter and orifice meter are from the uncertainty in the pressure measurements. These uncertainties are plotted together in Figure 9 to show their relative significance. The very high uncertainty for the direct measurement at low flow rate is mostly a factor of its random uncertainty due to the very low number of measurements made (3). In the future, with more time measurements, this uncertainty would decrease significantly. The other uncertainty errors were considerably low.

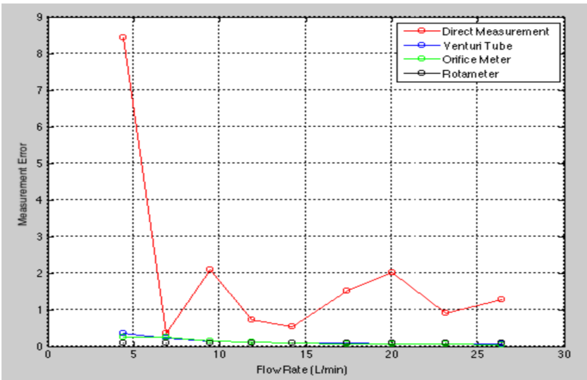

Figure 8. Uncertainty Error Analysis

Lastly, the performance of the 2 pumps used to drive this flow is calculated for the different flow rates using Equation 4. The efficiency of pump 1 in both series and parallel seems to peak at between 4 and 5 x 10^{-4} m^3/s as shown in Figure 9. The performance of pump 2 in series is very similar and in parallel is the same and is this not shown. A quadratic approximation curve is done on top of the measurement points to show this relation that the efficiency has with flow rate. The series pump efficiency is almost twice as much as the parallel pump efficiency.

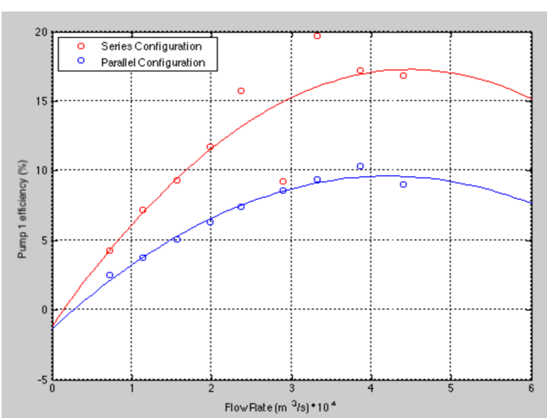

Figure 9. Efficiency of Pump 1 in Series & Parallel.

CONCLUSIONS

In this experiment, many devices were used to measure the flow through a pipe system. We proved that these systems are reliable under given conditions and can produce agreeable measurements. To compare against an actual direct measurement, we used a tank/weight configuration and timing method to calculate actual flow rate. We compared this to the flow rate gotten from the Venturi meter, orifice meter, and rotameter.

After getting these flow rates, we calculated the uncertainty in each measurement and the head loss that was attributed to each device. Lastly, we analyzed the performance of each pump by calculating the efficiency for the pumps in both series and parallel for the many flow rates. The results were as expected, having a quadratic relation with the flowrate.

REFERENCES

[1] Gere, J.M., Mechanics of Materials, 5th ed, Chapman and Hall, London, 2000.