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| **NUCL 355 Experiment 3** |
| Basic Flow Measurement  Professor S. T. Revankar |
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| School of Nuclear Engineering  Purdue University  Report of the Experiment By:  Weston Cundiff, Stephen Cox, Kara Luitjohan, Patrick Burk, Dominic Ghering, Michael Stryker, Austin Curtis, Matt Metzger, et. Al. |
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# Introduction and Theory

The theory introduced in this experiment is basically the theory behind different types of flow meters, specifically orifice and Venturi meters. These are used in combination throughout fully developed flow inside the experimental apparatus to measure the flow, and to measure calculated with experimental and actual values of the discharge coefficient.

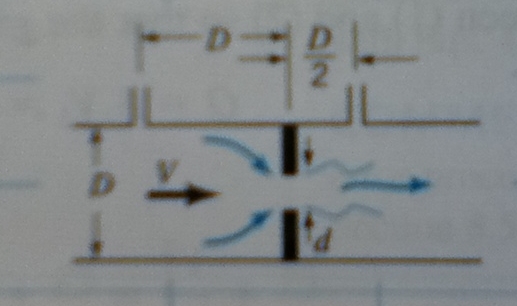
The orifice meter is simply made of a circular plate with a circle cut out of it. The edges around the cutout are machined into a point to create the orifice and avoid the development of pipe flow through the orifice. This orifice will create a distinct flow profile, as shown to the left. This flow profile includes an entrance region, where the velocity of the flow is increased because of the higher volume of water rushing to a smaller opening, and then an exit region, that exhibits interesting characteristics. The flow recombines in a turbulent region, where velocity goes down disproportionately because of this turbulent recombination. Then, flow slowly develops back into laminar flow, where it is the velocity it would be predicted to be at without the orifice.

Figure .1 Orifice Flow

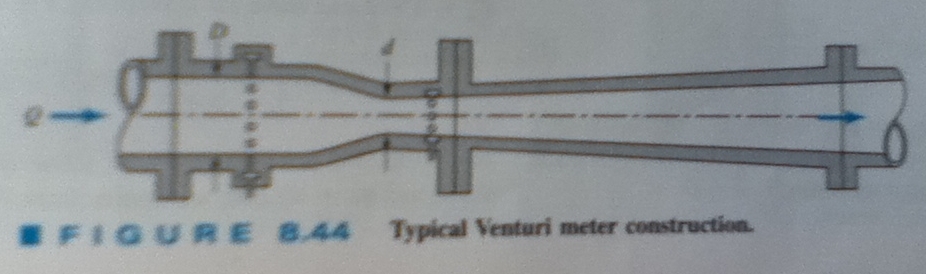
A venturi meter is very similar to an orifice, but it was created with more thought to the amount of loss created by the meter. The venturi meter creates the same diameter contraction that is created in an orifice, but it has slowly sloping walls that remove the turbulent entrance and exit regions that occur in orifice flow. A typical venturi design is shown below.

Figure . Typical Venturi Design

Orifice and venturi meters both are used to calculate the flow rate before and after the contraction. In an effort to minimize the error while using these instruments, correction factors have been calculated. These are called discharge coefficients, and estimate the ratio of the actual flow to the predicted flow (if the orifice/venturi contraction had not been there). These are given in equation form (using geometric properties), or through a chart.

Another simple and common instrument used to characterize flow, is a pitot-static tube, especially adjustable ones. A pitot-static tube converts the entire dynamic head of a flow into stagnation pressure, allowing it to be measured directly and removing major and minor loss from the calculation. This allows a very accurate velocity to be created. With an adjustable pitot-static tube, accurate velocities can be taken at different radial positions within the tube. This can give the flow profile within that tube, which should look like exponentially growing velocities to the highest velocity at the center of the tube.

The region of the flow where it is exponentially growing is called the boundary layer. The boundary layer occurs because of friction effects between the wall and the fluid passing through the pipe. This boundary layer is a layer where the velocity is less than 99% of the steamline velocity (Vinfinity). The flow profile of a flow will clearly show this boundary layer, which is important to fully understanding pipe flow.

While flow profiles radially show the changes in flow within a pipe, it also must be profiled along the entire steamline. This is especially interesting through an orifice. As explained earlier in the orifice flow description, there will be a stage of increased velocity right at the contraction. This will be followed immediately by a decrease in velocity from the turbulence and recombination. After recombination, there is recovery of the steamline flow, where the flow velocity tends to be the same value it would be without the orifice inside of the pipe. This is important to understanding the spatial distribution of the flow, along a steamline. Using this along with flow profiles radially gives a good three dimensional picture of pipe flow.

# Analysis and Discussion of Data

## Station 1

### Orifice Flow

The orifice flow data collected in this experiment was simple, a pressure measured in a manometer to give the pressure drop across the orifice. With this data, it is then possible to start to quantify the ratio of the flow rate occurring, and what would be occurring without the orifice. This is determined following several steps. First, the static head is calculated, and the pressure drop across the orifice. These must be converted from inches of water column, as shown in the sample calculations. Then, according to equations set out, the discharge coefficient is calculated. The Reynold’s Number is calculated so that the coefficient can be compared to charted values. It is then that an equation for the flow rate through an orifice is used to give a real experimental value for the discharge coefficient. These are given in tabular form below, for ease of comparison. Because the only variables in orifice equations depend only on geometry, the values are the same for each type of flow.

|  |  |  |  |
| --- | --- | --- | --- |
| Flow | Discharge Coefficient From Chart | Discharge Coefficient Calculated | Discharge Coefficient Actual |
| 1 | 0.6200 | 0.9311 | 0.9200 |
| 2 | 0.6200 | 0.9311 | 0.9200 |
| 3 | 0.6200 | 0.9311 | 0.9200 |
| 4 | 0.6200 | 0.9311 | 0.9200 |
| 5 | 0.6200 | 0.9311 | 0.9200 |

Table .1 Orifice Discharge Coefficients

As shown in the tables above, the calculated coefficient from the equation is very close to the actual experimental value. The value taken from the chart is much smaller than these calculated coefficients though, and this may be because it is often used for liquids with higher densities and kinematic viscosities.

### Venturi Nozzle Flow

Analyzing the venture flow data is a very similar process to the orifice flow. The data collected is again a pressure drop, which is converted to Pascals and then to dynamic head, and finally to the velocity of the fluid. The Reynold’s number is calculated and used in the calculated version of the discharge coefficient. This means that for different flows, the discharge coefficient will change. The actual discharge coefficient is calculated the same way it is for orifice flow, comparing the ratio of the expected flow through the geometry with the actual flow that occurred. This data is shown in the table below.

|  |  |  |
| --- | --- | --- |
| Flow | Discharge Coefficient Calculated | Discharge Coefficient Actual |
| 1 | 0.9660 | 0.9205 |
| 2 | 0.9781 | 0.9205 |
| 3 | 0.9689 | 0.9205 |
| 4 | 0.9724 | 0.9205 |
| 5 | 0.9764 | 0.9205 |

Table .2 Venturi Discharge Coefficients

It is obvious again that the values are very close. The calculated discharge coefficient approximates the actual value very well. An interesting point is that, in this mathematical method, the actual discharge coefficient does not change with the flow parameters, when it logically should. The calculated discharge coefficient sufficiently shows that flow parameters should affect the discharge coefficient.

## Station 2

A pitot-static tube is a good way to measure the velocity of a fluid through a tube, and it is especially useful when it is adjustable. The data collected using the pitot-static tube consists of dynamic heads throughout the entire diameter of the pipe. This gives the pressure distribution within the pipe, but must first be normalized against the static head. This was done by removing the same value as the static head. This provides numbers that are the pressure drops across the tube, with values of zero occurring near the wall. Using these dynamic heads, it is now possible to calculate the velocities of the flow. This again creates a profile, with zero velocity at the wall condition, and with the same highest velocity happening several times in the middle of the tube. This was charted using velocity on the ordinate and distance from wall on the abscissa to match conventions.

Figure .1 Velocity Profiles across a Tube

As per convention, the velocity profile throughout the tube looks like an exponential function with an asymptote at a certain value. It is shown above that v-infinity occurs at a much lower distance from the wall for flow 1 than flow 2, and respectively all the way to flow 5. This accurately depicts the concept of the boundary layer. The boundary layer should be smaller for smaller flow rates (flow 1 is the smallest flow rate). This is dramatically proven wrong for flow 2, showing that closing the flow makes the velocity much higher than expected.

## Station 3

The data collected in Station 3 is more of a multi-step processes than the other flow data that was collected. For each flow, the pressure drop was taken at certain distances from an orifice. This was able to give us a spatial distribution for the velocities of the flow, this time along the streamline and not radially (as in station 2). The dynamic head again was normalized against the static head, and then the velocity calculated from this dynamic head per the calculation in sample calculations. This is then charted against the steamline position down steam from the orifice.

Figure .2 Velocity Profile across down-steam Pressure Taps

The distribution above shows clearly the entire pressure drop and recovery stage that occur after an orifice. It is obvious that a velocity drop occurs directly after the orifice, general reaching a minimum just under 5 cm after the orifice. The flow then moves back up sharply, probably where the flow has finally combined and is no longer turbulent. Then, during the recovery phase, the velocity starts to drop across a long distance after this spike, until it reaches values well below what it was before the orifice. These flow profiles correctly fit their expected shape, and are also correctly distributed in their order of speed.

# Conclusions

Discharge coefficients were effectively compared in this experiment. These coefficients allow for the correct modeling of flow through orifices and venturi meters. These coefficients were calculated in several different manners, including analytical approximations, actual experimental values, and values taken from previous experiments via a chart. For orifice flow, the calculated values and actual values fit very closely, with values of .9311 and .9200 respectively, but this did not fit with the value of .6200 from previous experiments. This makes it possible that the values from previous experiments, and evaluated in the charts were created using fluids with much higher kinematic viscosities. In these fluids, the flow would be turbulent for a longer period after the orifice, creating more loss (thus the lower discharge coefficient values).

Discharge coefficients were similarly calculated in a venturi tube. Venturi tubes should have much lower loss because they are created to change as gradually as possible. The venturi tube tested had very similar loss to the orifice tested, with values ranging from .9660 to .9764 (theoretical) and at .9205 (actual). These are only slightly higher than the values for the orifice, but are very good approximations of each other. It is possible that in the fluid air, recovery happens so quickly because of its low kinematic viscosity. This would create the effect that the loss would be much closer between the two different types of flow meters, with very small differences indicating large geometric differences.

Boundary layers and flow profiles are often used to understand the full picture of developed flow within a pipe. The boundary layers were well defined within this experiment, and the flow profiles could be charted and easily analyzed. The analysis yielded several conclusions. First, within this experiment, the concept of boundary layers was present, and clearly showed parabolic profiles for the flow within the tube. Vinfinity was able to be calculated in all flows, and ranged from 4.1764 to 9.7307 m/s. These velocities along the streamline in the tube then exponentially decayed all the way to the wall, where friction dominated and the velocities were zero.

The radial analysis done in station two was followed by a steamline analysis done in station 3. The steamline analysis was able to show conclusions about the flow parameters that happen along a steamline through an orifice. The conclusions showed that there are several stages to the flow that occur through an orifice. The first stage is an increased velocity right at the orifice, which in the experiment ranged from 17.2919 to 45.4769 m/s. This is followed by a disproportional drop in velocity that occurs where turbulence occurs when the flow is recombining. This drop ranged from 12.4293 to 35.2969 m/s in the experiment. The last stage is recovery, and is where the flow becomes laminar and similar to the original flow. This includes a slow decline in the flow velocity as it moves down the pipe. The final velocities, after this slow decay, ranged from 12.2272 to 34.2216 m/s. These shapes helped along the conclusion about the different stages of flow after an orifice.

# Works Cited

Munson, Y. O. (2009). *Fundamentals of Fluid Mechanics.* Hoboken, NJ: Wiley and Sons, Inc.

Revankar, S. (2011). *Experiment #3: Basic Flow Measurement.* West Lafayette, IN: Purdue University School of Nuclear Engineering.

# Appendices

## Original Data

### Station 1

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Flow | Tap 1 (cm) | Tap 2 (cm) | Tap 3 (cm) | Tap 4 (cm) |
| 1 | 22.8 | 21.2 | 22.9 | 21.4 |
| 2 | 27.4 | 16.6 | 27.3 | 16.8 |
| 3 | 23.2 | 20.9 | 23.2 | 21.0 |
| 4 | 23.8 | 20.2 | 23.9 | 20.2 |
| 5 | 25.8 | 18.1 | 25.7 | 18.3 |

Table .1 Pressure Taps from Left to Right

### Station 2

|  |  |  |
| --- | --- | --- |
| Flow 1 | Slow Open |  |
|  | **Position (in)** | **Pressure** |
|  | 1 | 0.95 |
|  | 0.9 | 0.95 |
|  | 0.8 | 0.95 |
|  | 0.6 | 0.95 |
|  | 0.5 | 0.95 |
|  | 0.4 | 0.95 |
|  | 0.3 | 0.955 |
|  | 0.2 | 0.96 |
|  | 0.1 | 0.97 |
|  | 0.075 | 0.975 |
|  | 0.05 | 0.98 |
|  | 0.025 | 0.985 |
|  | 0 | 0.985 |

Table .2 Flow 1 Pressure Profile

|  |  |  |
| --- | --- | --- |
| Flow 2 | fast closed |  |
|  | Position (in) | Pressure |
|  | 1 | 0.33 |
|  | 0.75 | 0.34 |
|  | 0.5 | 0.35 |
|  | 0.25 | 0.375 |
|  | 0.15 | 0.4 |
|  | 0.1 | 0.44 |
|  | 0.075 | 0.47 |
|  | 0.05 | 0.51 |
|  | 0.025 | 0.515 |
|  | 0 | 0.52 |

Table .3 Flow 2 Pressure Profile

|  |  |  |
| --- | --- | --- |
| Flow 3 | fast open |  |
|  | Position (in) | Pressure |
|  | 1 | 0.905 |
|  | 0.75 | 0.905 |
|  | 0.5 | 0.91 |
|  | 0.25 | 0.915 |
|  | 0.15 | 0.925 |
|  | 0.1 | 0.93 |
|  | 0.075 | 0.94 |
|  | 0.05 | 0.945 |
|  | 0.025 | 0.95 |
|  | 0 | 0.95 |

Table .4 Flow 3 Pressure Profile

|  |  |  |
| --- | --- | --- |
| Flow 4 | fast half open |  |
|  | Position (in) | Pressure |
|  | 1 | 0.805 |
|  | 0.75 | 0.81 |
|  | 0.5 | 0.815 |
|  | 0.25 | 0.825 |
|  | 0.15 | 0.835 |
|  | 0.1 | 0.85 |
|  | 0.075 | 0.87 |
|  | 0.05 | 0.87 |
|  | 0.025 | 0.875 |
|  | 0 | 0.875 |

Table .5 Flow 4 Pressure Profile

|  |  |  |
| --- | --- | --- |
| Flow 5 | slow and closed |  |
|  | Position (in) | Pressure |
|  | 1 | 0.54 |
|  | 0.75 | 0.54 |
|  | 0.5 | 0.545 |
|  | 0.25 | 0.565 |
|  | 0.15 | 0.59 |
|  | 0.1 | 0.62 |
|  | 0.075 | 0.66 |
|  | 0.05 | 0.67 |
|  | 0.025 | 0.67 |
|  | 0 | 0.67 |

Table .6 Flow 5 Pressure Profile

### Station 3

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Pressure taps from left (closest to orfice) to right (in. of water) | | | | | | |
| Flow | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| 1 (slow open) | 0.60 | 0.40 | 0.35 | 0.31 | 0.30 | 0.30 | 0.30 |
| 2 (fast closed) | 4.15 | 2.95 | 2.60 | 2.50 | 2.40 | 2.35 | 2.35 |
| 3 (fast open) | 0.80 | 0.55 | 0.50 | 0.47 | 0.45 | 0.45 | 0.45 |
| 4 (fast half open) | 1.35 | 0.95 | 0.87 | 0.80 | 0.78 | 0.78 | 0.78 |
| 5 (slow closed) | 2.95 | 2.10 | 1.90 | 1.78 | 1.70 | 1.70 | 1.70 |

Table .7 Pressure Tap Values Over Time

|  |  |
| --- | --- |
| Orifice Diameters (in) | |
| 1 | 1.252 |
| 2 | 1.251 |
| 3 | 1.251 |

Table .8 Orifice Diameters

## Reduced Data

### Station 1

|  |  |  |  |
| --- | --- | --- | --- |
| Flow | Discharge Coefficient From Chart | Discharge Coefficient Calculated | Discharge Coefficient Actual |
| 1 | 0.6200 | 0.9311 | 0.9200 |
| 2 | 0.6200 | 0.9311 | 0.9200 |
| 3 | 0.6200 | 0.9311 | 0.9200 |
| 4 | 0.6200 | 0.9311 | 0.9200 |
| 5 | 0.6200 | 0.9311 | 0.9200 |

Table .9 Orifice Discharge Coefficients

|  |  |  |
| --- | --- | --- |
| Flow | Discharge Coefficient Calculated | Discharge Coefficient Actual |
| 1 | 0.9660 | 0.9205 |
| 2 | 0.9781 | 0.9205 |
| 3 | 0.9689 | 0.9205 |
| 4 | 0.9724 | 0.9205 |
| 5 | 0.9764 | 0.9205 |

Table .10 Venturi Discharge Coefficients

### Station 2

|  |  |  |
| --- | --- | --- |
| Flow 1 |  |  |
|  | Position [m] | Velocity compared to V inf [m/s] |
|  | 0.0254 | 4.1764 |
|  | 0.02286 | 4.1764 |
|  | 0.02032 | 4.1764 |
|  | 0.01524 | 4.1764 |
|  | 0.0127 | 4.1764 |
|  | 0.01016 | 4.1764 |
|  | 0.00762 | 2.5979 |
|  | 0.00508 | 1.9440 |
|  | 0.00254 | 1.0193 |
|  | 0.001905 | 0.6467 |
|  | 0.00127 | 0.3098 |
|  | 0.000635 | 0.0000 |
|  | 0 | 0.0000 |

Figure .1 Flow Profile (Flow 1)

|  |  |  |
| --- | --- | --- |
| Flow 2 |  |  |
|  | Position [m] | Velocity compared to V inf [m/s] |
|  | 0.0254 | 9.7307 |
|  | 0.01905 | 7.4983 |
|  | 0.0127 | 6.5736 |
|  | 0.00635 | 4.9951 |
|  | 0.00381 | 3.8244 |
|  | 0.00254 | 2.3267 |
|  | 0.001905 | 1.3779 |
|  | 0.00127 | 0.2595 |
|  | 0.000635 | 0.1289 |
|  | 0 | 0.0000 |

Figure .2 Flow Profile (Flow 2)

|  |  |  |
| --- | --- | --- |
| Flow 3 |  |  |
|  | Position [m] | Velocity compared to V inf [m/s] |
|  | 0.0254 | 4.7356 |
|  | 0.01905 | 4.7356 |
|  | 0.0127 | 3.1570 |
|  | 0.00635 | 2.5032 |
|  | 0.00381 | 1.5785 |
|  | 0.00254 | 1.2059 |
|  | 0.001905 | 0.5592 |
|  | 0.00127 | 0.2708 |
|  | 0.000635 | 0.0000 |
|  | 0 | 0.0000 |

Figure .3 Flow Profile (Flow 3)

|  |  |  |
| --- | --- | --- |
| Flow 4 |  |  |
|  | Position [m] | Velocity compared to V inf [m/s] |
|  | 0.0254 | 5.9063 |
|  | 0.01905 | 4.3278 |
|  | 0.0127 | 3.6739 |
|  | 0.00635 | 2.7492 |
|  | 0.00381 | 2.0397 |
|  | 0.00254 | 1.1707 |
|  | 0.001905 | 0.2148 |
|  | 0.00127 | 0.2148 |
|  | 0.000635 | 0.0000 |
|  | 0 | 0.0000 |

Figure .4 Flow Profile (Flow 4)

|  |  |  |
| --- | --- | --- |
| Flow 5 |  |  |
|  | Position [m] | Velocity compared to V inf [m/s] |
|  | 0.0254 | 8.0489 |
|  | 0.01905 | 8.0489 |
|  | 0.0127 | 6.4704 |
|  | 0.00635 | 4.5192 |
|  | 0.00381 | 3.0572 |
|  | 0.00254 | 1.7348 |
|  | 0.001905 | 0.3158 |
|  | 0.00127 | 0.0000 |
|  | 0.000635 | 0.0000 |
|  | 0 | 0.0000 |

Figure .5 Flow Profile (Flow 5)

### Station 3

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Velocities from the Dynamic Head taken in Pressure taps [m/s] against Tap Position [m] | | | | | | |
| Flow | **0** | **0.055** | **0.026** | **0.026** | **0.039** | **0.039** | **0.207** |
| 1 (slow open) | 17.2919 | 14.1188 | 13.2069 | 12.4293 | 12.2272 | 12.2272 | 12.2272 |
| 2 (fast closed) | 45.4769 | 38.3422 | 35.9959 | 35.2969 | 34.5837 | 34.2216 | 34.2216 |
| 3 (fast open) | 19.9669 | 16.5557 | 15.7852 | 15.3044 | 14.9752 | 14.9752 | 14.9752 |
| 4 (fast half open) | 25.9378 | 21.7585 | 20.8222 | 19.9669 | 19.7158 | 19.7158 | 19.7158 |
| 5 (slow closed) | 38.3422 | 32.3501 | 30.7711 | 29.7835 | 29.1066 | 29.1066 | 29.1066 |

Table .11 Flow Velocity in Station 3

## Sample Calculations

### Pressure from Pressure Column Height

### Velocity from Pressure Drops

### Reynold’s Number

### Orifice Discharge Coefficient (Calculated)

### Venturi Discharge Coefficient (Calculated)

### Orifice Discharge Coefficient (Actual)

### Venturi Discharge Coefficient (Actual)