

**Faculty of Engineering and Technology**

**Mechanical Engineering Department**

**Fluid Mechanics laboratory**

**ENME312**

**Experiment #6**

**Flow Measuring apparatus**

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 **Date of performing the experiment: 18.4.2022**

 **Date of submitting the experiment: 19.4.2022**

**Abstract**

 Various water flow measuring devices are being used nowadays, apparatus and principles used varies among devices. So, efficiency for those devices need to be determined in order to compare between them and decide which one to use. In order to do so, three different devices (Venturi-Meter, Orifice-Meter, and Rotameter) are supplied with mutual water flow to determine the efficiency of each.

 As in previous experiments, a Hydraulic Bench was used to supply us with water and measure the experimental mass flow rate. The pumped water flows through a Venturi-Meter containing a throat, then passes through an orifice to end up at a 90 degrees elbow to reach the Rotameter as shown in Figure (1).

 The **Aim** of this experiment was to measure the efficiency of each device and determine the most accurate. This can be done through comparing Theoretical values of each device with the experimental mass flow rate found by the hydraulic bench.

 Multiple **Principles** were applied in the experiment. The first is Bernoulli, all three devices are based on Bernoulli’s principle of the sum of energies. Also, the Venturi-Meter and the Orifice-Meter are Based on the Continuity Equation. On the other hand, the Rotameter has Calibration Curve derived from its linear relation that helps us to find the flow rate values.

As a **Result**, Efficiency values for each device were obtained and can be compared to determine the most accurate. Average of the Cd values for each one can be used or the slope of the curve. So, our final decision will be **Rotameter (1.1476) > Venturi (1.1249) > Orifice (0.7133).**



Figure (1): Devices connections and Manometers locations.

**Objectives**

To Measure:

* Mass of the pieces put to hold up the water tank and the arm length at the hydraulic bench.
* The time for water to equalize the (mass \* arm length).
* The manometer readings at key points on the tube.
* Rotameter Readings.

To Analyze:

* How the manometer readings change with the change of flow rate.
* How the time needed to fill the tank changes as flow rate changes.
* Different arm length gives different time reading.
* The behavior of Discharge Coefficient against Flow Rate.
* Which device flow rate values were more efficient.

To Determine:

* Cross-Sectional Areas at key points.
* Experimental Mass Flow Rate by the Hydraulic Bench.
* Theoretical Mass Flow Rate from each device apart.
* The Slopes of Qexp vs Qth graphs (Discharge Coefficients).
* An approximated Calibration Curve for the Rotameter.

**Sample Calculations**

As previously mentioned, Bernoulli and Continuity equations should be used. So:

$\frac{V1^{2}}{2g}+h1= \frac{V2^{2}}{2g}+h2= \frac{Vn^{2}}{2g}+h$ (1)

* h: Water head at a certain point [m].
* u: Velocity of the fluid at a certain point [m/s].
* g: Acceleration due to gravity which equals 9.81 [m/s2].

$Q=A1V1=A2V2=AnVn$ (2)

* *a1*: Cross-section area of a certain point [m2].

 By combining (1) and (2) we get the following formula for Theoretical Values of mass flow rate for the Venturi and Orifice at their points (shown in figure [1]) as follows:

$\dot{m}\_{Venturi}= a\_{B}\sqrt{\frac{2g\left(hA-hB\right)}{1-\left(\frac{aB}{aA}\right)^{2}}}$ (3)

$\dot{m}\_{Orifice}= a\_{F}\sqrt{\frac{2g\left(hE-hF\right)}{1-\left(\frac{aF}{aE}\right)^{2}}}$ (4)

Areas needed for the previous equations can be obtained from Table (1).

Table (1): Diameters and Areas (m2) for the key points on the tube.

|  |
| --- |
| Areas of Points |
| Point | diameter (m) | Area (m2) |
| A | 0.026 | 0.00053 |
| B | 0.016 | 0.00020 |
| E | 0.051 | 0.00204 |
| F | 0.020 | 0.00031 |

For the Rotameter, mass flow rate calculations can be done by referring to the calibration curve shown in Figure (2).



Figure (2): Given Rotameter Calibration Curve to find Mass Flow Rate in (kg/s).

Also, the discharge coefficient (Cd) can be calculated for each device, regarding that the theoretical values varies, by:

$Cd=\frac{m\_{exp}}{m\_{th}}$ (5)

Finally, Experimental value of mass flow rate can be found by:

$\dot{m}=\frac{Mass \left(kg\right) × 3}{Time (s)}$ (6)

*Sample Calculations*

Taking Run #2 as our sample,

Measured data was:

|  |  |
| --- | --- |
| **Quantity** | **Value** |
| Mass at the Hydraulic Bench (kg) | 3 x 4 = 12 kg |
| Time to left the tank (seconds) | 23.87 s |
| Manometer reading at A: hA (mm) | 394 |
| hB (mm) | 115 |
| hE (mm) | 336 |
| hF (mm) | 78 |
| Rotameter Reading (cm) | 20.8 |

So, From eq. (3): $\dot{m}\_{Venturi}= 0.00053\sqrt{\frac{2g\left(394-115\right)}{1-\left(\frac{0.00053}{0.00020}\right)^{2}}}=0.47$ kg/s

And From eq. (4) $\dot{m}\_{Orifice}= 0.00031\sqrt{\frac{2g\left(336-87\right)}{1-\left(\frac{0.00031}{0.00204}\right)^{2}}}=0.71 kg/s$

From Figure (2) $\dot{m}\_{Rotameter}=0.44 kg/s$

From eq. (6) $\dot{m}\_{exp}=\frac{4 × 3}{23.87}=0.5 kg/s$

In Conclusion, from applying eq. (5) on all devices we get:

$Cd\_{vent}=\frac{0.5}{0.47}=1.08$$Cd\_{ori}=\frac{0.5}{0.71}=0.7$$Cd\_{rota}=\frac{0.5}{0.44}=1.14$

**Results**

Table (2): Manometer Readings, Time, and Rotameter readings for all Runs.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Run | hA (mm) | hB (mm) | hE (mm) | hF (mm) | Time (s) | Rotameter reading (cm) |
| 1 | 371 | 110 | 359 | 65 | 21.97 | 21.9 |
| 2 | 349 | 115 | 336 | 78 | 23.87 | 20.8 |
| 3 | 320 | 125 | 310 | 94 | 26.72 | 19.1 |
| 4 | 293 | 132 | 281 | 108 | 28.63 | 17.2 |
| 5 | 278 | 139 | 267 | 116 | 31.94 | 16 |
| 6 | 256 | 145 | 246 | 129 | 35.75 | 14.15 |
| 7 | 240 | 153 | 229 | 140 | 40.43 | 11.7 |
| 8 | 225 | 155 | 218 | 144 | 44.59 | 10.5 |
| 9 | 211 | 160 | 205 | 151 | 52.44 | 8.6 |
| 10 | 200 | 163 | 196 | 156 | 62.22 | 7 |

Table (3): Mass Flow Rate “m”, and Discharge Coefficient Calculations for all runs.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| m Rotameter (kg/s) | m actual (kg/s) | m Venturi (kg/s) | m Orifice (kg/s) | Cd vent | Cd ori | Cd rota. |
| 0.47 | 0.55 | 0.49 | 0.76 | 1.11 | 0.72 | 1.16 |
| 0.44 | 0.50 | 0.47 | 0.71 | 1.08 | 0.70 | 1.14 |
| 0.4 | 0.45 | 0.42 | 0.65 | 1.06 | 0.69 | 1.12 |
| 0.38 | 0.42 | 0.39 | 0.59 | 1.09 | 0.72 | 1.10 |
| 0.35 | 0.38 | 0.36 | 0.55 | 1.05 | 0.69 | 1.07 |
| 0.31 | 0.34 | 0.32 | 0.48 | 1.05 | 0.70 | 1.08 |
| 0.27 | 0.30 | 0.28 | 0.42 | 1.05 | 0.71 | 1.10 |
| 0.23 | 0.27 | 0.25 | 0.38 | 1.06 | 0.70 | 1.17 |
| 0.2 | 0.23 | 0.22 | 0.33 | 1.05 | 0.70 | 1.14 |
| 0.175 | 0.19 | 0.19 | 0.28 | 1.04 | 0.69 | 1.10 |

Figure (3): Cd values for all devices as a graph and equation.

Figure (4): Calibration Curve for Rotameter through actual mass rate

**Discussion of Results**

 The main purpose from the Flow Measurements experiment was to compare the three popular devices (Venturi-Meter, Orifice-Meter and Rotameter) by calculating the mass flow rates (m) Experimentally and Theoretically, and Discharge Coefficients. So, monometer measurements at key points, Rotameter Reading and areas had to be recorded to work out the Theoretical Value. Meanwhile, Mass and Time were recorded to find the Experimental value through the Hydraulic Bench. For accuracy, multiple runs were conducted at different water flow rates.

 As our sample calculation has showed, we substituted our measurements in equations derived from the main principles each device was based on in order to find our final values. And for Run #2 that we took we got the following discharge values (1.08 - 0.7 - 1.14 ‘unitless’). Which can be used for our main goal to compare them.

 It was clear that all mass flow rate values shown in Table (4) had a direct **Relationship** with the same parameter since they all decreased as we decreased our flow rate. Also, some **trends** we observed through graphs. Figure (3) show that we have a constant slope line generated by each device, the slope value is approximately equal to the mean of the Discharge Coefficient Readings.

 An approximate Calibration Curve for the Rotameter was drawn in figure (4) by graphing the actual mass flow rate versus the Rotameter Readings.

 Afterall, the final results we got are pretty logical and related to what we assumed by start. So, they can be used to meet our objective of finding the most accurate water flow rate measuring device. However, some values had some errors that shouldn’t be present theoretically like getting discharge coefficients larger than 1. These errors could be from different sources such as:

* The tube had impurities and algae sticking to its surface and floating in the Rotameter vertical section.
* Inaccurate Manometer readings due to Surface Tension.
* Inaccurate Time measurements due to using manual stopwatch.
* Inaccurate Rotameter readings due to water fluctuations.
* Operator errors.
* Loss of significant figures.
* Instrumental errors in the devices it self.

**Conclusion**

 As a result, we got three final representative values from each device which enables us to compare them in terms of accuracy. Although we had illogical coefficients of values larger than 1, but our results can still be considered acceptable since the order of devices is the same expected order before conducting the experiment (Rotameter (1.1476) > Venturi (1.1249) > Orifice (0.7133). To get better Results, the procedure could be repeated while trying to eliminate other possible sources of error especially cleaning the tube surface.

**Applications**

 This experiment can be utilized to classify the flow rate measuring devices in terms of accuracy relatively to the actual value. Since the Discharge Coefficient indicates the efficiency of each device. However, each device has its own applications in different fields and industries as demonstrated previously for the Venturi and the Orifice devices.

 For The Rotameter, it also not less important or popular than its competitors. The device is used in Laboratories, Process and oil industries, and where there is a quality air supply is required. It also can be used where low pressure is necessary.