MET 335W

Venturi Profiles

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William McClenney

wmccl001@odu.edu

Experiment Title: Venturi Profiles

Purpose:

The purpose of this experiment is to learn the operation of a Venturi flow meter; a device used to measure the velocity of flow in a fluid flow system. Other objectives include obtaining direct measurements of the static head distribution along a Venturi tube, comparison of experimental results with theoretical predictions, and measurement of the meter coefficient of discharge at various flow rates.

Theoretical Considerations:

According to Bernoulli's Principle, an increase in the velocity of a fluid will simultaneously occur with a decrease in pressure. Bernoulli's equation is as follows:

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$$

Fluid flow is expressed as "head" to refer to a height above a reference level.
The above equation represents three heads and their sum (total head):

p/γ is the pressure head;

z is the elevation head;

$v^2/2g$ is the velocity head.

When a pressure head increases, the velocity of the fluid will decrease for a given size area expansion. Likewise, velocity will increase and pressure decrease for any reduction in a given size area.

- Minimum pressure head can be measured at the throat due to the highest velocity found at that location of the venturi.
- Maximum pressure head can be measured at the inlet due to the minimum velocity found at that location of the venturi.
- In the first part of the experiment, pressure heads are measured at every single tube of the venturi, providing an overall profile with a given flow rate.
- In the second part of the experiment, the energy loss and friction loss in the venturi as a function of the Reynolds number are determined only at the inlet (Tube 1) and the throat (Tube 4). The flow rate is adjusted and re-measured 9 times to determine the difference between the inlet and the throat for a different range of flow rates, which can be used to calculate the Reynolds number. These calculations are used to determine the venturi coefficient, which is an expression of the friction in the venturi as a function of the Reynolds number.

Description of Apparatus:

- TecQuipment H5 Venturi meter
- Venturi manometer tubes and scales
- Outlet tubing and clamps
- Upstream valve
- Tank
- Plunger (pipe)

Step-by-Step Procedure:

1. The black power switch located on the pump on/off panel was switched to the on position, starting the pump.
2. The valve controlling the water was opened by rotating the valve counterclockwise, allowing the water to flow inside the venturi meter.
3. The valve was then adjusted so that the flow was just below the overflow tube at the top of the vertical manometer tubes, allowing only excess water to flow through the lower tubing into the tank.
4. Once the upstream valve was adjusted, the water level in each of the 11 individual venturi tubes were recorded onto the data table.
5. The plunger pipe was then seated into the drain of the tank in preparation to measure the time and water flow.
6. A stopwatch was immediately started in order to record the time it takes for the water level to reach 15 liters in the tank.
7. Once the desired 15 liters was achieved, the stopwatch was stopped and the time was recorded on the data sheet.
8. The plunger pipe was removed to allow the water to drain from the tank.
9. The upstream valve was closed slightly by rotating the valve handle clockwise.
10. The water levels in Tube 1 (inlet) and Tube 4 (throat) were observed and recorded in the data sheet.
11. The plunger pipe was again seated into the drain of the tank in preparation to measure the time and water flow.
12. A stopwatch was immediately started in order to record the time it takes for the water level to reach 15 liters in the tank.
13. Once the desired 15 liters was achieved, the stopwatch was stopped and the time was recorded on the data sheet.
14. The plunger pipe was removed to allow the water to drain from the tank.
15. The upstream valve was again closed slightly by rotating the valve handle clockwise.
16. The water levels in Tube 1 (inlet) and Tube 4 (throat) were observed and recorded in the data sheet.
17. The plunger pipe was then seated into the drain of the tank in preparation to measure the time and water flow.
18. A stopwatch was immediately started in order to record the time it takes for the water level to reach 15 liters in the tank.

19. Once the desired 15 liters was achieved, the stopwatch was stopped and the time was recorded on the data sheet.
20. The plunger pipe was removed to allow the water to drain from the tank.
21. The upstream valve was closed slightly by rotating the valve handle clockwise..
22. The water levels in Tube 1 (inlet) and Tube 4 (throat) were observed and recorded in the data sheet.
23. The entire process was repeated until a total of 9 readings were recorded in the data table.
24. This concluded the experiment.

Recorded Data Table:

Measured Volume of Water for Flow Rate: 15 L

Part 1: Table 1; Pressure Head at Multiple Venturi Locations

Venturi Location	Recorded height of water column in tube (mm) $\left(\frac{P}{\gamma}\right)$
A(1)	278
B(2)	270
C(3)	170
D(4)	7.5
E(5)	45
F(6)	125
G (7)	170
H(8)	200
J(9)	215
K(10)	238
L(11)	245
Volume Flow Time (seconds)	43.21

Part 2: Table 2; Pressure Head at Inlet and Throat with Varying Flow Rates

Venturi Location	Recorded height of water column in tube (mm) $\left(\frac{P}{\gamma}\right)$								
A (1) (inlet)	288	250	208	176	148	124	100	75	55
D(4) (throat)	18	12	8	14	10	14	8	8	14
Volume Flow Time (seconds)	45.6	46.2	54.3	58.2	64.0	91.2	94.9	98.6	150.9

Calculations:

Measured Volume of Water for Flow Rate: 15 L

The velocity at any location (N) can be calculated using the measured volumetric flow rate (Q) and the cross section area (A) at each location: $V_N = \frac{Q}{A_N}$

Given the volume = 15 L and the volume flow time = 43.21 s, then volumetric flow rate (Q) can be calculated as 3.471 x 10^{-4} m^3/s

$$V_A = \frac{Q}{A_A} = \frac{3.471 \times 10^{-4} m^3/s}{5.31 \times 10^{-4} m^2} = 0.65 \text{ m/s}$$

Sample Calculations:

1. Actual Volumetric Flow Rate using the measured Volumetric Flow time

$$Q = \frac{15 \text{ L}}{45.6 \text{ s}} = 0.000328 \text{ m/s}$$

2. Theoretical Volumetric Flow, Q if friction is neglected:

$$Q = A_4 \sqrt{2g \frac{(P_1/\gamma) - (P_4/\gamma)}{1 - (D_4/D_1)^4}} = (2.01 \text{ E}^{-04} \text{ m}^2) \sqrt{2g \frac{(0.288-0.018) \text{ m}}{1 - (0.016 \text{ m}/0.026 \text{ m})^4}}$$

$$= (2.01\text{E}^{-04}) \sqrt{2g \frac{(0.270)}{1 - 0.143}} = (2.01\text{E}^{-04}) \sqrt{2g \frac{270}{0.857}} = (2.01\text{E}^{-04} \text{ m}^2) \sqrt{2g (315.1)}$$

$$= 4.998 \text{ E}^{-04} \text{ m}^3/\text{s}$$

3. Velocity Calculation using the actual flow rate, Q:

$$\text{Velocity} = \frac{Q_{actual}}{A_1} = \frac{(3.28 \text{ E}^{-04} \text{ m}^3/\text{s})}{(5.309 \text{ E}^{-04} \text{ m}^2)} = 0.618 \text{ m/s}$$

4. Reynolds number at the venturi inlet, $(P_1/\gamma) - (P_4/\gamma$ (location 1)):

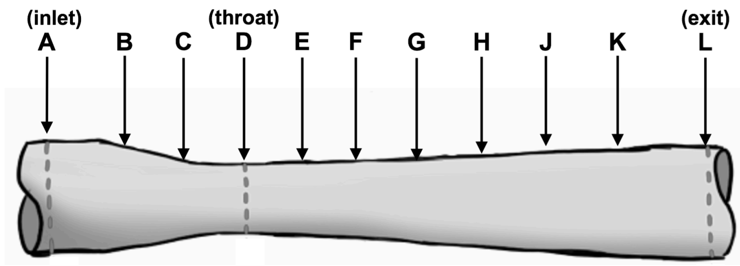
$$N_{R1} = \frac{\rho V_1 D_1}{\mu} = \frac{[0.618 \text{ m/s}]\,[0.026 \text{ m}]}{0.00000093 \text{ m}^3/\text{s}} = 17277 \text{ (turbulent flow)}$$

5. Venturi coefficient at the inlet:

$$C_v = \frac{Q_{actual}}{Q_{theoretical}} = \frac{0.000328 \text{ m}^3/\text{s}}{0.0004998 \text{ m}_3/\text{s}} = 0.656$$

Calculated Data Tables:

Table 3: Venturi Dimensions



Venturi Location	Diameter (mm)	Radius (mm) $\left(\frac{D}{2}\right)$	Area (mm^2) ($A=\pi r^2$)	Area (m^2) (x 10^{-4})
A (1)	26.00	13.00	530.93	5.31
B (2)	23.20	11.60	422.73	4.23
C (3)	18.40	9.20	265.90	2.66
D (4)	16.00	8.00	201.06	2.01
E (5)	16.80	8.40	221.67	2.22
F (6)	18.47	9.24	267.90	2.68
G (7)	20.16	10.08	319.21	3.19
H (8)	21.84	10.92	374.62	3.75
J (9)	23.53	11.76	434.47	4.34
K (10)	25.24	12.62	500.34	5.00
L (11)	26.00	13.00	530.93	5.31

Table 4: Velocities at Multiple Venturi Locations

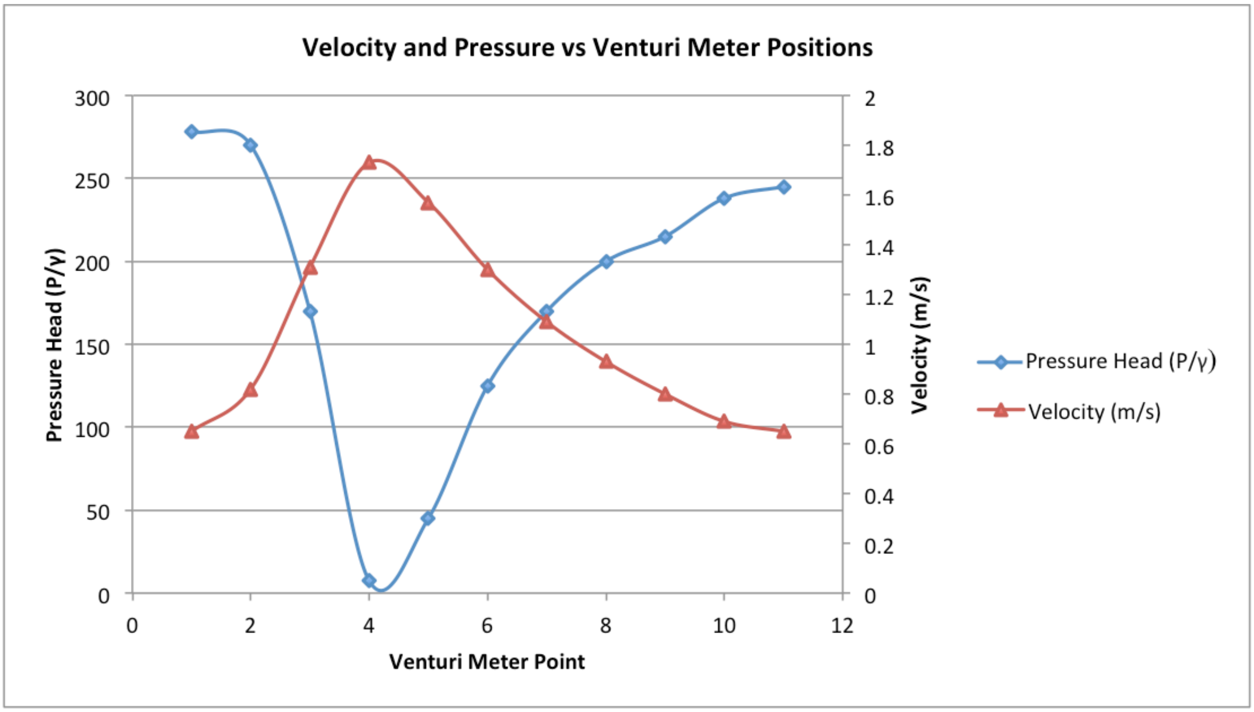
Venturi Location	Recorded height of water column in tube (mm) $\left(\frac{P}{\gamma}\right)$	Velocity (m/s)
A(1)	278	0.65
B(2)	270	0.82
C(3)	170	1.31
D(4)	7.5	1.73
E(5)	45	1.57
F(6)	125	1.30
G (7)	170	1.09
H(8)	200	0.93
J(9)	215	0.80
K(10)	238	0.69
L(11)	245	0.65
Volume Flow Time (seconds)	43.21	Given

Table 5: Volumetric Flow Rate, Reynolds Number, and Venturi Coefficient

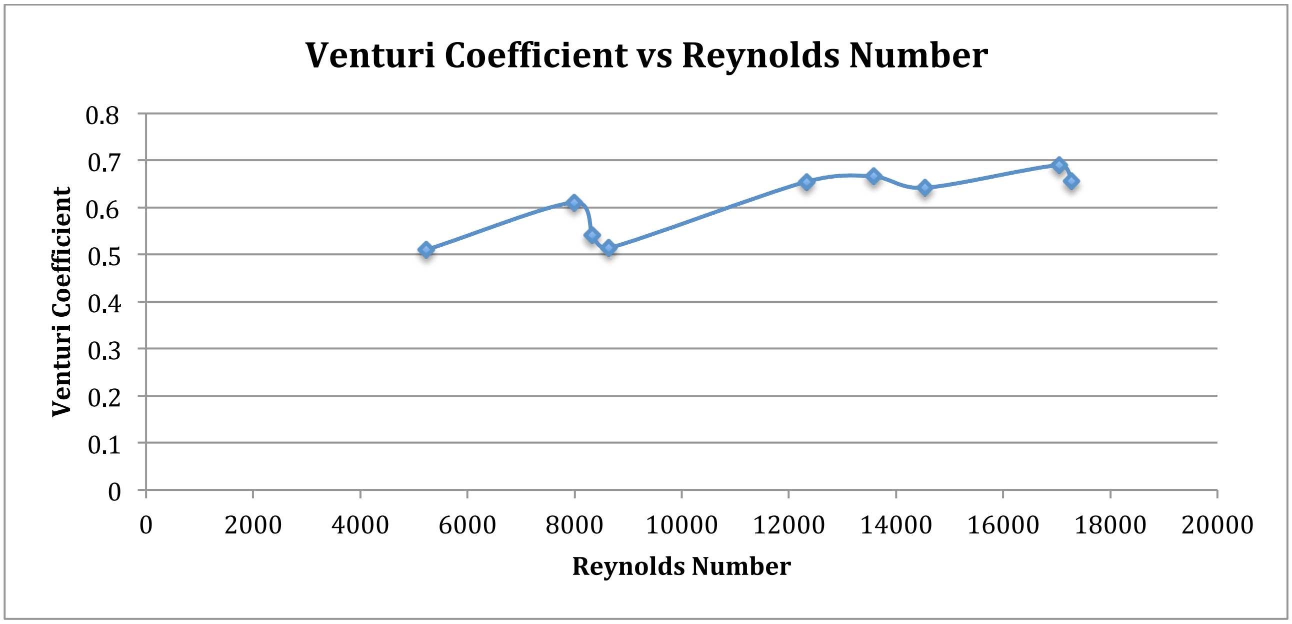
Venturi Reading Number	Volumetric Flow Rate, Q actual (m^3/s) E^{-04}	P1/γ - P4/γ, (mm)	Q Theoretical (m^3/s) E^{-04}	Error (%)	Velocity (m/s)	Reynolds Number, N	Venturi, C_v
1	3.28	270	4.998	34.4	0.618	17277	0.656
2	3.24	238	4.693	31.0	0.610	17053	0.690
3	2.76	200	4.302	35.8	0.520	14538	0.642
4	2.58	162	3.872	33.4	0.486	13587	0.666
5	2.34	138	3.574	34.5	0.441	12329	0.655
6	1.64	110	3.190	48.6	0.309	8639	0.514
7	1.58	92	2.918	45.8	0.298	8331	0.541
8	1.52	67	2.489	38.9	0.286	7996	0.611
9	0.994	41	1.948	48.9	0.187	5228	0.510

Graphs:

Graph 1: Velocity and Pressure vs. Venturi Meter Positions



Graph 2: Venturi Coefficient vs. Reynolds Number



Discussion of Results and Conclusions:

A horizontal pipe with steady, incompressible flow was utilized. Demonstration of the validity of Bernoulli's equation was seen in Graph One: Velocity and Pressure versus the Venturi Meter Positions. Measurement of static pressure heads, along a pipe with various cross sections and constricted flow rates showed that the velocity head increased simultaneously while the pressure head decreased.

Per the velocity profile for steady flow through a Venturi meter, the Venturi throat reached a maximum velocity of 1.73 m/s. Portions of the pipe with greater cross-sectional areas had decreasing velocity.

In Part Two of this lab, data was obtained to determine the theoretical and actual pressure heads through a Venturi meter, along with the loss coefficient, and how it varied with the Reynolds number. The Reynolds number was greater than 4000, an indication of turbulent flow. The Venturi coefficient was less than one, which means that there was a degree of friction in the pipe. Furthermore, even though the horizontal Venturi inlet and exit diameters were identical (26.00 mm) and the flow was incompressible and steady, due to friction losses the pressure head was reduced while the velocity head remained the same.

High error rate in the theoretical and actual results were seen. Certain correction factors in the calculations for the theoretical did not include energy loss. However there were energy losses, such as could be derived from friction in the pipe and water columns. In addition, several calibration issues of pump and timer should be considered for preventative maintenance issues. Leakage of tubes should also be checked, considering the many that are inherent to the Venturi meter system. Full evacuation of fluids before the start of successive runs could also improve accuracy and precision.