



Lebanese American University
Byblos Campus
School of Engineering
Department of Civil Engineering

BERNOULLI EQUATION- VENTURI METER

CIE 321 FLUID MECHANICS- LAB

Laboratory Report prepared for:

Instructor: Talin Tekirian

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Prepared by:

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I. OBJECTIVE:

In this experiment you will be able to analyze the effect of viscosity on pressure loss and also to understand the measurement of discharge from a pipe. As we will be using the Venturi Meter in order to measure flow, the Bernoulli equation is an important relation that can help getting velocities from fluid pressures and vice versa. The purpose of this experiment is also to calculate Q and C_D at different head pressures. Then drawing a relationship between all these properties and head pressure will be discussed in this report.

II. EXPERIMENT: Venturi meter

A. Apparatus

The materials that will be used in this experiment are:

- Venturi Meter¹
- Water Supply
- Flow meter
- Stop watch
- Calculator

B. Procedure

Let us first define the Venturi Meter and the way it works in order to proceed in the experiment:

The apparatus consists of a flow bench from where water can flow to the venturi meter. Inside the flow bench, a tank is connected to one end of a lever arm. The end of the lever arm produces from the side of the flow bench so that the amount of weight on this end of the lever arm may be adjusted. The lever arm has the propriety to measure the actual mass flow

¹ The Venturi meter _invented by Clemens Herschel in 1886_ is the best apparatus used to measure the flow of water in a large pipe having little if any head loss. It is named after the Italian philosopher Giovanni Battista Venturi who created in 1796 a theory saying that water flowing through a pipe diminishing in sectional area, loses lateral pressure as it gains in velocity.

rate of water flowing through the measuring devices. When using the hydraulic bench, placing weight on the lever arm closes the trip valve of the inner tank. When water entering the tank is sufficiently heavy enough to counterbalance the weight on the arm, the arm will rise and the trip valve will open.

But in this experiment, we used another approach to measure water volume: reading it from a meter instead of computing it by placing a weight on the lever arm.

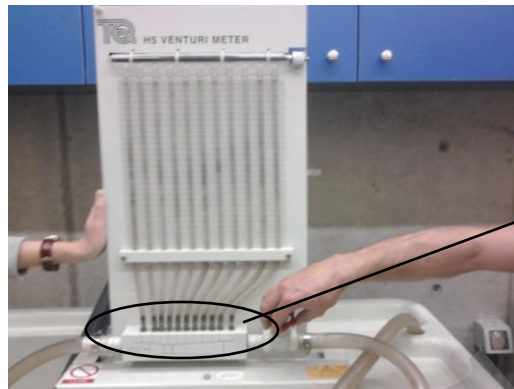


Figure. 1

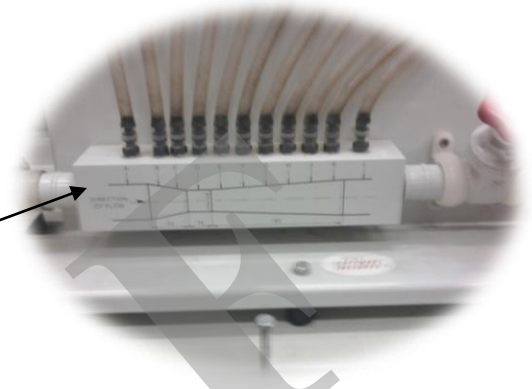


Figure. 2

The experiment will be proceeded as follows:

- a. First, make sure that air purge valve on the upper manifold is tightly closed.
- b. Set both apparatus flow control and bench supply valve to approximately 1/3 their fully open positions.
- c. Start recording time using a stop watch at the moment we opened the flow control valve. Water started to flow in the inner tank. When the meter indicates 5L water volume, stop timing and turn off flow control valve.

- d. Release air purge valve to allow water to rise up to the manometer tubes and form the Hydraulic Grade Line HGL.

PS: You should remove air bubbles from apparatus by tapping manometer tubes.

- e. 5 runs will be done by changing flow rate. Also measure h_1 : height of water in manometer tube A inlet and h_2 in manometer tube D throat. Vary flow rate so that $(h_1 - h_2)$ goes from 60 to 230 mm.

- f. Full flow is obtained at run 5. At this stage, the difference between the Venturi inlet A and throat D is 230 mm.
- g. Compute calculations.

C. Data

After recording head pressures at different runs (different flows), we were able to compute the table which contains values of piezometric head in mm for different manometer tubes (from A to H, see figure.2):

	A	B	C	D	E	F	G	H	J	K	L
Run 1	200	198	174	140	148	166	176	182	186	188	190
Run 2	204	200	164	112	126	152.5	168	176.5	184	188	190
Run 3	214	206	152	68	92	132	156	172	182	188	192
Run 4	220	210	141	38.5	70	118	148.5	166.5	180	190	194
Run 5	230	218	124	0	26	92.5	134	160	178	190	196

D. Calculations

As our work will be restricted on the two manometer tubes A and D, we can summarize the steps of equations as follows:

As C_D will be calculated, $Q_{calculated}$ and $Q_{measured}$ must be defined first:

1. $Q_{measured}$ is given by the following relationship:

$$Q_{measured} = \frac{\text{volume}}{\text{time}}$$

We will be using a volume of 5L in the tank. Time is recorded for different flows by manipulating the valve using a stop watch. And then fill the table with the corresponding values:

	Volume (L)	Time (sec)	Measured flow $Q \times 10^{-6} \left(\frac{m^3}{sec}\right)$
Run 1	5	22.75	220
Run 2	5	15.3	327
Run 3	5	13.35	375
Run 4	5	11.75	426
Run 5	5	10.3	485

2. As $Q_{measured}$ is now defined, we can now calculate the “corrected” flow measurement $Q_{calculated}$ using the given formula: $Q = V \times A$, where V is the velocity and A the cross-sectional area. The table below presents area in terms of diameter of cross-sections A and D: $A = \frac{\pi}{4} D^2$

	Diameter (mm)	Area $\times 10^{-6}$ (m ²)
Section A	26	531
Section D	16	201

After calculating the area, we still have to calculate V to define $Q_{calculated}$.

$$Q = V \times A \quad (1)$$

To compute velocity, a long path of steps and calculations must be first defined:

- a. Using the continuity equation for steady incompressible flow, we can determine the relationship between the two velocities at A and D.

$$Q_A = Q_D$$

$$\Leftrightarrow (V_A)(A_A) = (V_D)(A_D)$$

$$\Leftrightarrow V_D = V_A \left(\frac{A_A}{A_D} \right)$$

$$\Leftrightarrow V_D = V_A \left(\frac{531}{201} \right) \quad \Rightarrow \quad V_D = 2.64 V_A \quad (2)$$

- b. Using Bernoulli equation which is based on conservation of energy:

$$z_A + \frac{P_A}{\gamma} + \frac{v_A^2}{2g} = z_D + \frac{P_D}{\gamma} + \frac{v_D^2}{2g} + h$$

$h=0$ because distance between A and D is negligible.

$z_A = z_D$ since both A and D have same centerline.

$$\frac{P_A}{\gamma} + \frac{v_A^2}{2g} = \frac{P_D}{\gamma} + \frac{v_D^2}{2g} \quad \Leftrightarrow \quad h_A - h_D = \frac{1}{2g} (V_D^2 - V_A^2)$$

$$\Rightarrow \quad \boxed{h_A - h_D = 0.304 V_A^2} \quad (3)$$

As we have height of water in both tubes A and B, we replace $(h_A - h_D)$ by their corresponding values for each of the runs in equation (3) to get V_A . Then replace V_A in equation (2) to get V_D . Finally, get $Q_{calculated}$ from equation (1).

	$h_A - h_D$ (mm)	Velocity at A V_A ($\frac{m}{sec}$)	Velocity at D V_D ($\frac{m}{sec}$)	Calculated flow $Q \times 10^{-6}$ ($\frac{m^3}{sec}$)
Run 1	60	0.44	1.17	236
Run 2	92	0.55	1.45	292
Run 3	146	0.69	1.83	368
Run 4	181.5	0.77	2.04	410
Run 5	230	0.87	2.30	462

3. Finally we can compute C_D and then the percentage error which is a crucial calculation to find sources of errors in laboratory experiments.

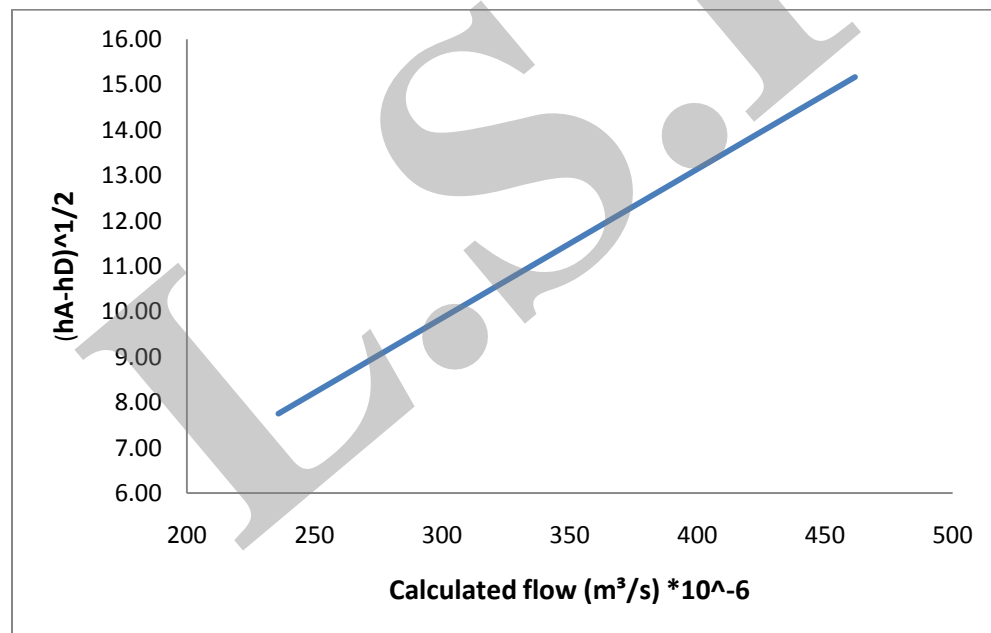
$$C_D = \frac{Q_{measured}}{Q_{calculated}} \quad ; \quad \% \text{ error} = \frac{|Q_{measured} - Q_{calculated}|}{Q_{measured}} \times 100$$

The table below summarizes all calculated values.

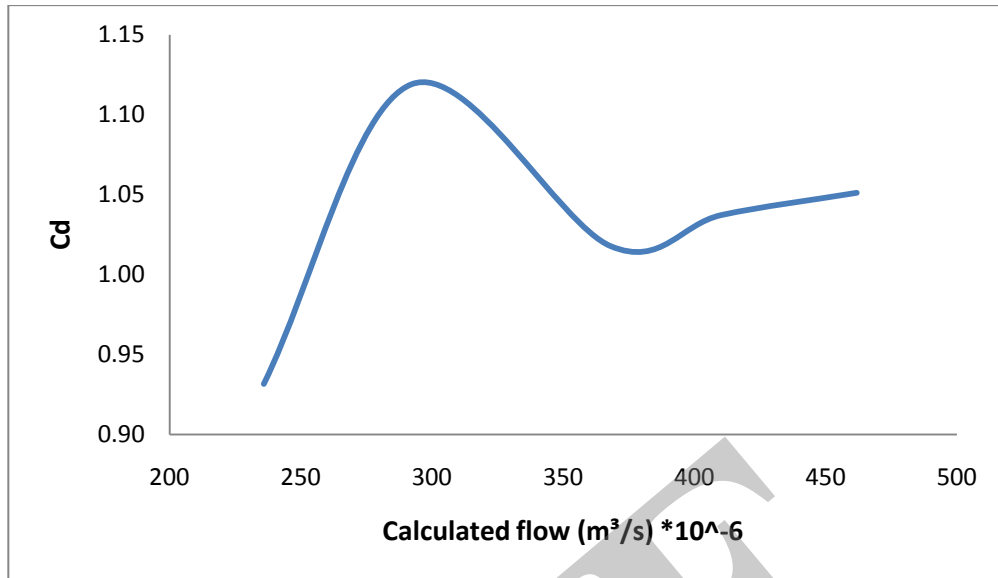
	Measured flow $Q \times 10^{-6} \left(\frac{m^3}{sec}\right)$	Calculated flow $Q \times 10^{-6} \left(\frac{m^3}{sec}\right)$	C_D	ERROR (%)
Run 1	220	236	0.93	7.32
Run 2	327	292	1.12	10.63
Run 3	375	368	1.02	1.76
Run 4	426	410	1.04	3.59
Run 5	485	462	1.05	4.87

E. Results

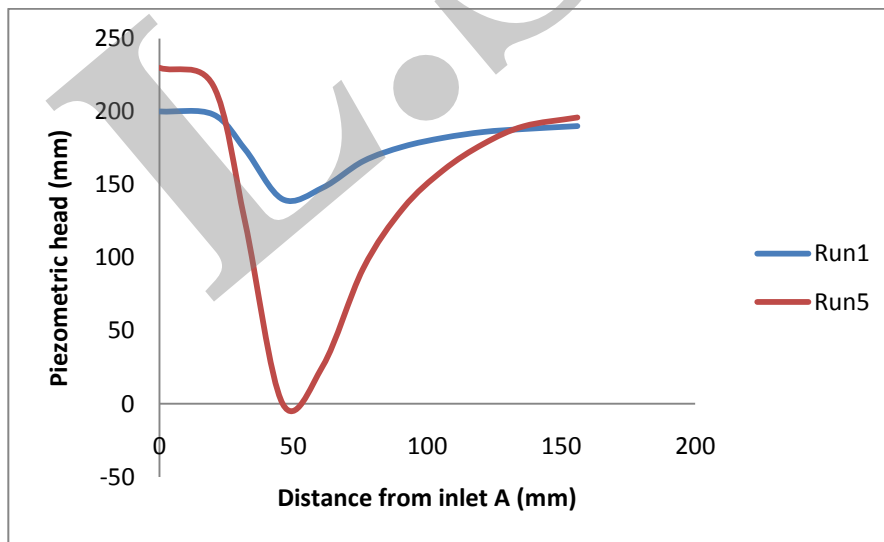
- ✓ Average of discharge coefficient $C_D = 1.03$, which is not between 0.90 and 0.99.
- ✓ Graph of $(h_A - h_D)^{1/2}$ versus $Q_{calculated}$ for the venturi meter :



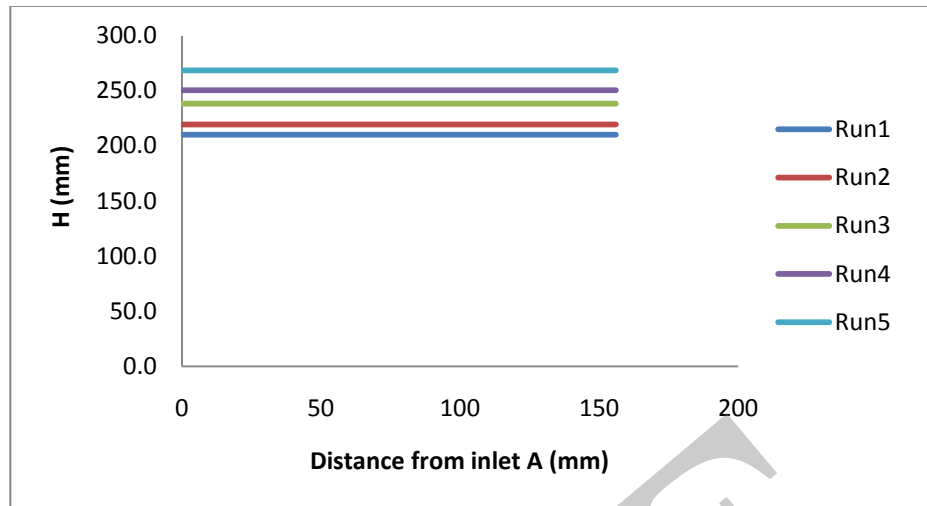
✓ Graph of C_D versus $Q_{calculated}$ for the venturi meter :



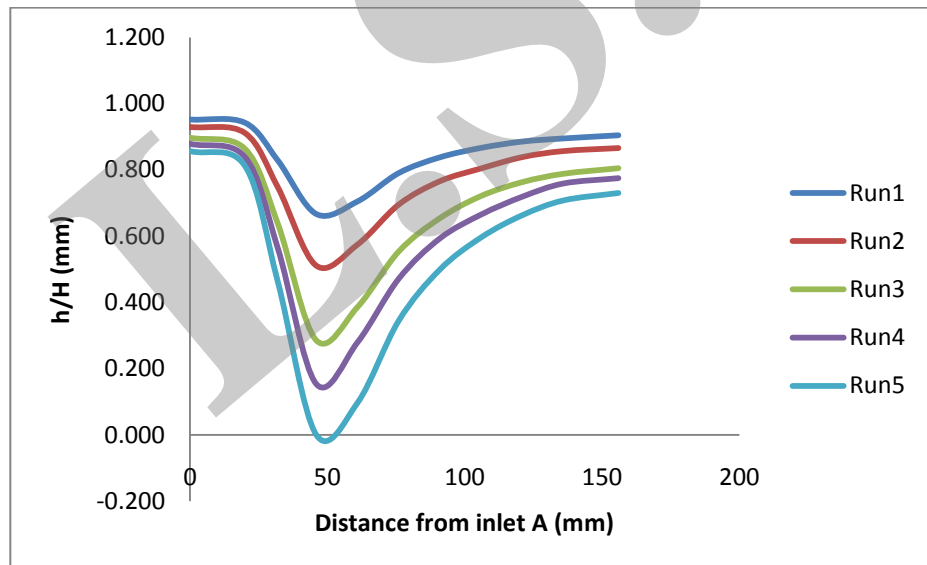
✓ Graph of the piezometric head (h) with respect to the distance along the conduit only for runs 1 & 5 :



✓ Graph of the energy line EL ($H = h + \frac{v^2}{2g}$) with respect to the distance along the conduit :



✓ Graph of $\frac{h}{H}$ with respect to the distance along the conduit :



F. Discussion

- The average value of the discharge coefficient is equal to 1.03 which is beyond the recommended limits (0.90-0.99). This is due to the error in the processing of this experience; the percentage of error has altered from 1.76% to 10.63%. This considerable error cannot be ignored thus it has influenced the results among which the invalid value of C_D . Sources of errors are many. Discrepancies however were strictly seen when reading the pressure heads and specially the stopwatch is considered to be the precursor of error results. Plus, the fluid is not ideal, as we considered in the calculations.

- In the first graph, $(h_A - h_D)^{1/2}$ is a linear increasing curve with respect to $Q_{calculated}$ meaning that the square root of the difference in piezometric heads is directly proportional to the calculated flow proving the following equation:

$$Q_{calculated} = A_D \left[\frac{2g(h_A - h_D)}{1 - \left(\frac{A_D}{A_A}\right)^2} \right]^{1/2}$$

- Since $C_D = \frac{Q_{measured}}{Q_{calculated}}$, it is obvious that the second graph _which plots the discharge coefficient versus the calculated flow_ will be somehow a slowly increasing curve (small positive slope).
- The third graph represents the piezometric heads at runs 1 & 5 along the distance. That will result into two curves similar to the shape formed by the water surfaces in the manometer tubes (Hydraulic Grade line). In addition, the curve will increase its downward slope (differences between piezometric heads) when the flow increases (Run5: full flow).
- From the fourth graph, we can deduce that $H \left(h + \frac{v^2}{2g} \right)$ representing the energy line is a constant line that does not change with distance but does decrease when the flow increase (from run1 till run5).
- Finally, the last graph is a plot of the ratio between h (the hydraulic grade line) and H (the energy line) with respect to the distant along the conduit.

- The existence of energy loss is due to viscosity effects on flow of water in the Venturi meter. As we considered the fluid as an ideal one, viscosity was neglected in calculations. This is shown in the data related to the same cross-section for the same run (same flow).
- The Bernoulli equation for this experiment is given by: $\frac{P_A}{\gamma} + \frac{v_A^2}{2g} = \frac{P_D}{\gamma} + \frac{v_D^2}{2g}$ and is composed of two main components: the pressure head $\frac{P}{\gamma}$ which is directly read from the manometer tubes and the velocity head $\frac{v^2}{2g}$. These two components vary along the length of the Venturi section. The bigger the diameter of a cross-section, the higher the pressure head ($\frac{P}{\gamma} = h$) and the lower the velocity at this cross-section due to the consistency of $\frac{P}{\gamma} + \frac{v^2}{2g}$. The points of maximum velocity and minimum pressure have the smallest diameter which are found at cross-section D (16.00 mm).
- Pressure distribution at cross-sections A and L should have been the same, because the flow was considered as steady, incompressible and frictionless. But pressure distribution altered from A to L since the actual fluid is not ideal.

III. Conclusion

The Venturi meter helped us understand measurement of discharge from a pipe and to define relationships between different properties of fluid: effect of viscosity on pressure losses, variation of pressure and velocity on different cross-sections...

This experiment gave us a real understand of how to apply both Bernoulli equation and Continuity equation and to study the Hydraulic Grade Line (HGL) and Energy Line (EL) by plotting these results.

Objectives were all achieved but many errors were encountered during the experiment and thus affected results.

IV. References

- Elementary Fluid Mechanics, by R. Street, G. Watters, and J. Vennard, John Wiley and Sons, Inc.
- <http://www.google.co.uk/search?q=history+of+the+venturi+meter&hl=en&sa=X&biw=1350&bih=526&tbs=tl:1,tll:1886,tlh:1886&ei=GuLSTKy7DMvi4AaVusjiDw&ved=0CDYQzQEwAg>
- http://www.google.co.uk/search?q=history+of+the+venturi+meter&hl=en&biw=1350&bih=526&tbs=tl:1&tbo=u&ei=_eDSTJe2A4fo4Aay_-SDDw&sa=X&oi=timeline_result&ct=title&resnum=11&ved=0CD8Q5wIwCg

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