Birzeit university– faculty of engineering and technology

Department of mechanical engineering

Fluid Mechanic Laboratory

ENME312

Section 1

Experiment No.3

“Flow Through a Venturi-Meter”

Instructors:

Dr. Adel Dweik

Eng. Alanoud Muadi

Group 5:

Majd Raddad 1201196

Qais Samara 1202956

Mohammad Abu Ayyash 1182690

Prepared by: Majd Raddad- 1201196

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Abstract

A venturi flowmeter, which measures fluid flow using differential pressure, is the focus of the experiment designed to explore how the device operates. The experiment involves applying fundamental principles of fluid mechanics, including Bernoulli's theorem and the continuity equation, to determine key fluid flow parameters such as mass flow rate ($\dot{m}$), discharge (Q), and the discharge coefficient (Cd).

The experiment highlights a crucial metric for flowmeter devices, the discharge coefficient (Cd). This coefficient, which signifies the energy losses between specific points, reflects the efficiency of various flow measurement devices. Ideally, the discharge coefficient has a value of 1, indicating no energy loss. For the venturi meter, the Cd is expected to also be around 1, signifying optimal performance.

To calculate the latter, it is necessary to obtain both the theoretical and the experimental flow values. The static head for the theoretical flow should be measured at two primary points along the venturi. By applying the appropriate equation, the theoretical flow can be calculated. The actual flow through the device can be determined by measuring the time it takes for water to fill a volumetric tank.

Analysis involved comparing the ideal pressure distribution with the actual distribution observed along the venturi meter through a plot. While the shapes of the distributions matched, there were slight differences in the values. Additionally, a plot was created to show the relationship between discharge and head, which appeared to be approximately linear and directly proportional.

Objectives

1- Measure the flow in the piping system.

2- Determine the pressure distribution and meter coefficient across various flow rates in a Venturi meter.

Sample calculation:

Table 1: Data given.

Piezometer Tube No. (n)	Diameter of cross section d_n (mm)	Cross-Sectional area a_n (mm^2)
A (1)	26.00	530.9
B	23.20	422.7
C	18.40	265.9
D (2)	16.00	201.1
E	16.80	221.7
F	18.47	268.0
G	20.16	318.8
H	21.84	375.0
J	23.53	435.0
K	25.24	500.8
L	26.00	530.9

- The experiment basically based on two main equations as mentioned before:

  First principle: Bernoulli Equation:

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

Were,

h: Water head at a certain point (m).

V: Velocity of the fluid at a certain point (m/s).

g: Acceleration due to gravity which equals 9.81 (m/s^2).].

Second principle: <u>Continuity equation:</u>

$$Q=a_1V_1= aV_2=a_nV_n \qquad (2)$$

Were:

A: cross sectional area (m^2).

V: velocity of the fluid at a point (m/s).

Q: fluid discharge (m^3/s).

Calculations:

- Mass Flow (ṁ):

$$\dot{m}=\frac{m}{t} \text{ (kg/s)} \qquad (3)$$

were:

ṁ: mass flow rate (kg/s).

m: mass of water (kg).

t: time in seconds(s).

$$\dot{m} =\frac{12}{23}$$

$$\dot{m} = 0.522 \text{ kg/s}$$

$$\dot{m}=\frac{12}{25}$$

$$\dot{m} =0.48 \text{ kg/s}$$

- Discharge flow rate (Q):

$$Q_{Actual} = \frac{\dot{m}}{\rho} (m^3/\text{s}) \qquad (4)$$

Where:

Q: discharge in m^3/s.

$$Q_{Actual} = \frac{0.52}{1000}$$

$$Q_{Actual} = 0.000522\ m^3/\text{s}$$

$$Q_{Actual} = \frac{0.432}{1000}$$

$$Q_{Actual} = 0.00048\ m^3/\text{s}$$

$$Q_{theoritical} = a_2 u_2 = \text{a2}\sqrt{\frac{2g(h1-h2)}{1-(\frac{a2}{a1})^2}}\ (m^3/\text{s}) \qquad (5)$$

Where:

a1: Cross-section area of venturi inlet (m2).

a2: Cross-section area of venturi throat (m^2).

h1: Water head at venturi inlet (maximum pressure) (m)

h2: Water head at the throat of the venturi (m).

u1: Velocity of the fluid at venturi inlet (m/s).

u_2: Velocity of the fluid at venturi throat (m/s) and can be measured following equation 6 below

u_n: Velocity of the fluid at an arbitrary venturi section (m/s).

g: Acceleration due to gravity which equals 9.81 (m/s^2).

$$Q_{theoritical} = A_2 u_2 = 0.000201 * \sqrt{\frac{2*9.81*(0.22-0.005)}{1-\left(\frac{0.000201}{0.0005311}\right)^2}} = 0.000446\ \frac{m^3}{s}.$$

$$u_2 = \sqrt{\frac{2g(h1-h2)}{1-(\frac{A2}{A1})^2}}\ (\text{m/s}) \qquad (6)$$

$$u_2 = \sqrt{\frac{2*9.81*(0.22-0.005)}{1-\left(\frac{0.000201}{0.0005311}\right)^2}} = 2.22\ \text{m/s}.$$

- Coefficient of discharge (Cd) :

$$\text{Cd} = \frac{Qact.}{Q\ theo.} \qquad (7)$$

Where:

$Q_{theoritical}$: Theoretical discharge through the venturi (m^3/s)

$Q_{act.}$: Actual discharge through the venturi (m^3/s)

$$\text{Cd} = \frac{0.000522}{0.000446} = 1.17$$

$$\sqrt{h1-h2} \quad (m) \qquad (8)$$

$\sqrt{0.22-0.005}$ =0.464 m.

- Coefficient of discharge using the plot of √ΔH Vs. Qact

Slope as the equation suggest = $\frac{1}{Cd*a2*\sqrt{\frac{2g(h1-h2)}{1-(\frac{a2}{a1})^2}}}$ (9).

Slope = 790.42, which by solving the previous equation yield to a value of Cd =0.7902

- Pressure distribution

- Actual pressure Distribution = $\frac{(hn-ha)}{\frac{u2^2}{2g}}$ (Pascal) (10)

Actual Pressure Distribution at point B of run no.1:

Actual Pressure Distribution = $\frac{(0.195-0.215)}{\frac{2.22^2}{2*9.81}}$

Actual Pressure Distribution = -0.0597 Pa.

- Ideal pressure Distribution = $(\frac{a1}{a2})^2$ - $(\frac{a2}{an})^2$ (Pascal) (11)

Ideal pressure Distribution at point B:

Ideal pressure Distribution = $(\frac{0.000201}{0.0005311})^2$ - $(\frac{0.0005311}{0.0005311})^2$

Ideal pressure Distribution = -0.857 Pa.

Results

Table 2: Data and calculations

Run	time	ha	hb	hc	hd	he	hf	hg	hh	hj	hk	hl
1	23	220	205	125	5	25	95	130	155	170	180	185
2	25	210	195	120	9	25	90	125	145	160	170	175
3	27	200	-	-	10	-	-	-	-	-	-	-
4	28	190	-	-	12	-	-	-	-	-	-	-
5	29	180	-	-	14	-	-	-	-	-	-	-
6	32	160	-	-	15	-	-	-	-	-	-	-
7	35	140	-	-	16	-	-	-	-	-	-	-
8	36	120	-	-	17	-	-	-	-	-	-	-
9	41	100	-	-	17	-	-	-	-	-	-	-
10	48	80	-	-	15	-	-	-	-	-	-	-

Table 3 : Calculations od flowrates and discharge coefficients.

h1-h2 (m)	√2*g*(h1-h2)(m	(a2/a1)^2	Qtheo	Qact	Cd	u2(m/sec)	(u2^2/2g)
0.215	2.05	0.93	0.000446	0.000522	1.17	2.22	0.25
0.201	1.99	0.93	0.000431	0.00048	1.11	2.14	0.23
0.19	1.93	0.93	0.000419	0.000444	1.06	2.08	0.22
0.178	1.87	0.93	0.000406	0.000429	1.06	2.02	0.21
0.166	1.80	0.93	0.000392	0.000414	1.06	1.95	0.19
0.145	1.69	0.93	0.000366	0.000375	1.02	1.82	0.17
0.124	1.56	0.93	0.000339	0.000343	1.01	1.68	0.14
0.103	1.42	0.93	0.000309	0.000333	1.08	1.54	0.12
0.083	1.28	0.93	0.000277	0.000293	1.06	1.38	0.10
0.065	1.13	0.93	0.000245	0.00025	1.02	1.22	0.08

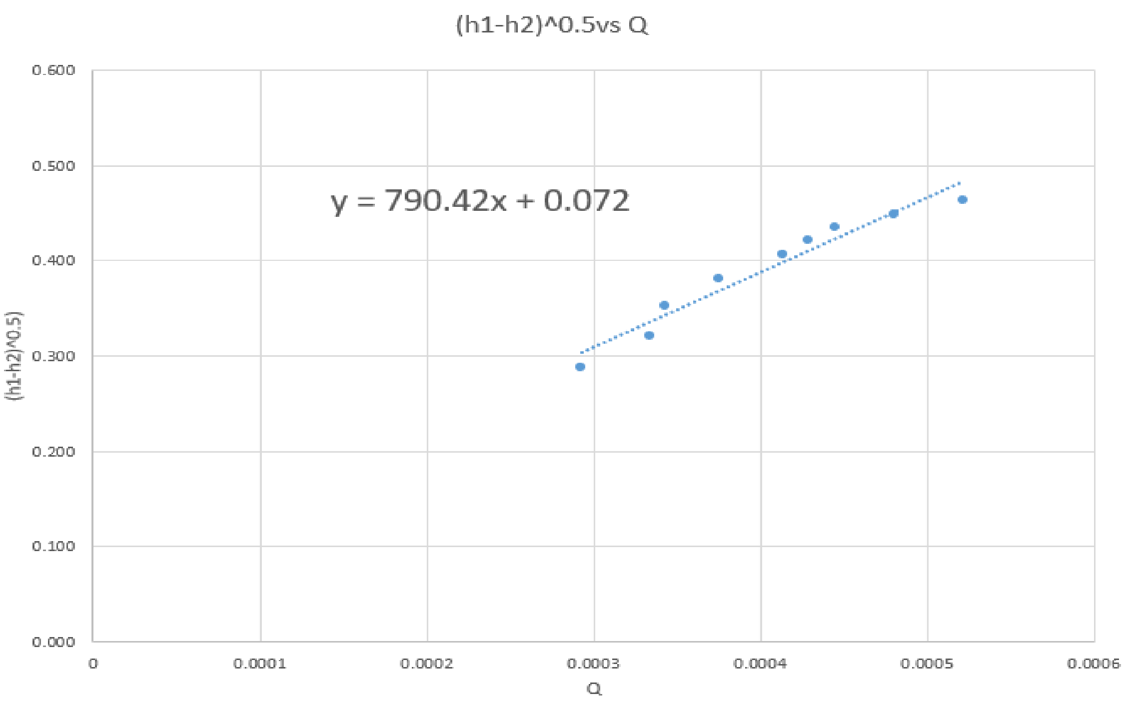


Figure 1: Relationship between ($\sqrt{\Delta H}$) and the flow rate.

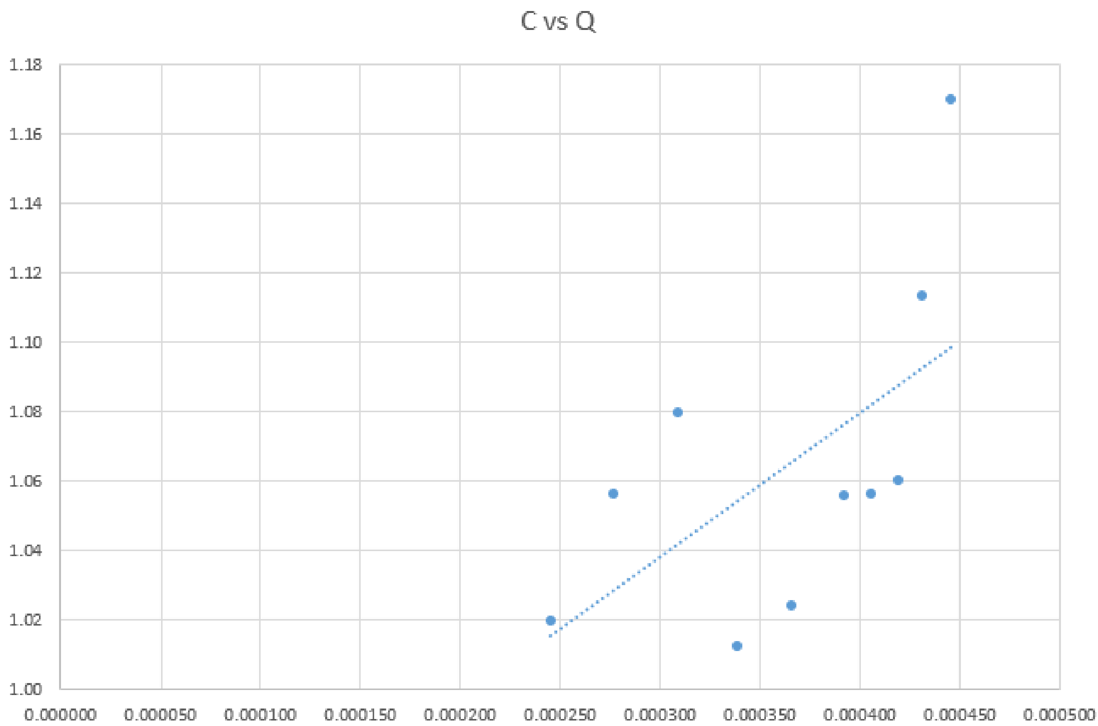


Figure 2: Relationship between (Cd) and the actual flow rate.

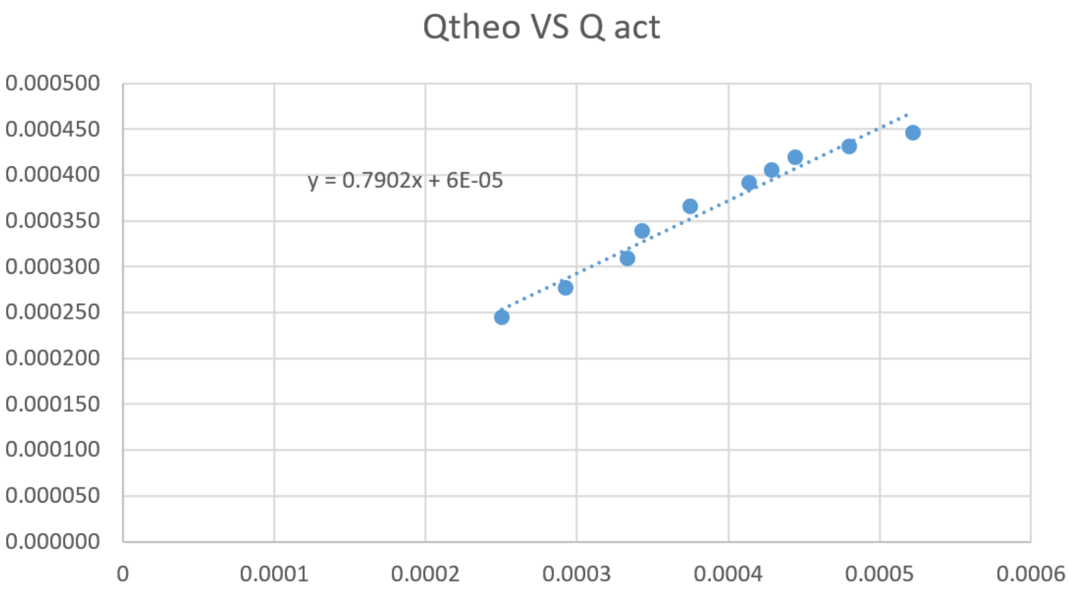


Figure 3: Relationship between theoretical flow rate VS actual flow rate.

Discussion of results

The aim of the experiment was to examine a venturi meter by focusing on key parameters such as the discharge coefficient (Cd), mass flow rate ($\dot{m}$), and the pressure distribution along the device. These values were derived by applying Bernoulli's principles and the continuity equation. The experiment successfully met its goals by calculating these parameters, which helped identify the main challenges encountered during the experiment and allowed for an estimation of the venturi meter's efficiency.

Table (3) presents data on mass flow rate, theoretical velocity, theoretical flow, and actual flow, utilized to determine the discharge coefficient (Cd). Expectations for Cd, ideally around 1 or less for the venturi meter, were not met; obtained values varied and exceeded expectations. Cd reflects head losses, anticipated to be minimal due to smooth transitions within the device. Values greater than 1 suggest measurement inaccuracies, hinting at experimental errors. Inconsistent execution, such as improper valve adjustments and significant openings between runs, contributed to these errors, leading to unreliable results. Figure (2) illustrates the relationship between Cd and flow, ideally forming a nearly horizontal line intersecting the y-axis at 1.

Figure (1) displays a plot of the square root of the head difference versus the actual discharge. Although the discharge values are not reliable, the trend fits an approximately straight line, indicating a linear and directly proportional relationship between these parameters. This behavior is anticipated and aligns with Bernoulli's equation. The slope of this plot was used to calculate the discharge coefficient (Cd), which yielded a value of 0.7902. This value is consistent with those obtained in the earliest runs of the experiment.

Conclusions

The obtained values for Cd from all runs did not converge to a specific value, making it impossible to determine a definitive result from the experiment. This lack of convergence is unsatisfactory, given that the expected values of Cd are around 1, none of which were observed in any of the runs.

One objective of the experiment was to examine the pressure distribution along the venturi meter, as depicted in Fig (3). The observed pattern was anticipated, as static pressure readings during the experiment followed the same trend. This suggests a direct relationship between pressure distribution and the cross-sectional area of the venturi meter. Moreover, an inversely proportional relationship can be inferred between velocity (u) and pressure distribution.

In general, the value of the discharge coefficient (Cd) could signify the real-life influence of surrounding fluid on flow measurement accuracy. An expected Cd of 1 for a venturi meter reflects the device's efficiency in flow measurement. Despite the experiment's failure to achieve this ideal result, it's noteworthy that a venturi meter generally offers higher precision in flow measurement compared to alternatives like the orifice meter.

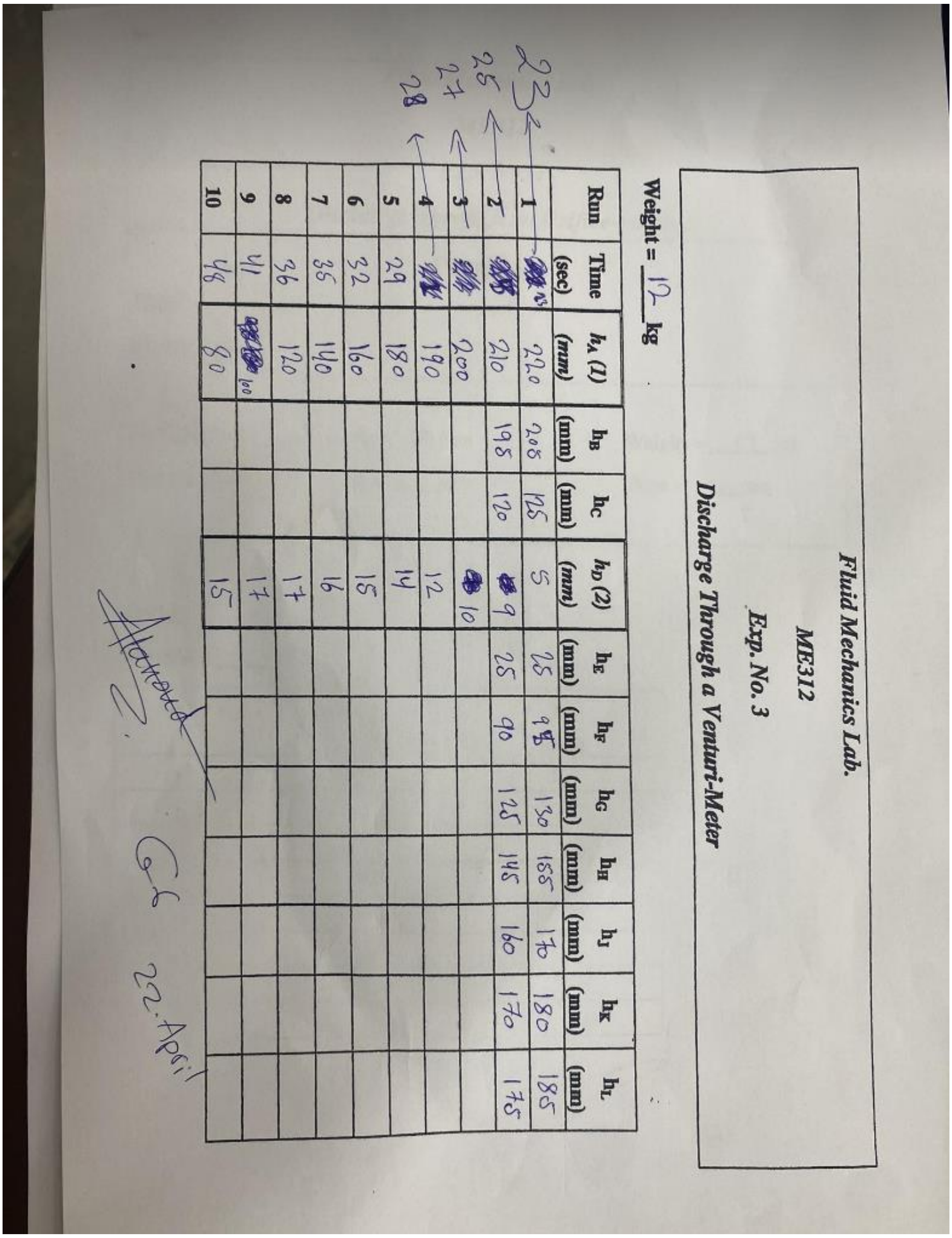
To improve results, stricter adherence to instructions is essential, along with conducting multiple runs. Implementing an automated timer linked to the lever arm managing weight would enhance precision. Furthermore, replacing the manometers attached to the venturi meter is advisable, as obtaining accurate water height readings proved challenging.

References

- Fluid mechanics laboratory manual (2022, march).

- White, F. M. (1999, January 1). Fluid Mechanics.

Appendices



Fluid Mechanics Lab.

ME312

Exp. No. 3

Discharge Through a Venturi-Meter

Weight = 12 kg

	Run	Time (sec)	h_A (1) (mm)	h_B (mm)	h_C (mm)	h_D (2) (mm)	h_E (mm)	h_F (mm)	h_G (mm)	h_H (mm)	h_J (mm)	h_K (mm)	h_L (mm)
23	1	23	220	208	125	5	25	95	130	155	170	180	185
25	2	[illegible]	210	198	120	9	25	90	125	145	160	170	175
27	3	[illegible]	200			10							
28	4	[illegible]	190			12							
	5	29	180			14							
	6	32	160			15							
	7	35	140			16							
	8	36	120			17							
	9	41	100			17							
	10	48	80			15							

Ahmad 22. April