



Birzeit university– faculty of engineering and technology

Department of mechanical engineering

Fluid Mechanic Laboratory

ENME312

Section 1

Experiment No.4

“Discharge through an orifice-meter”

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Abstract

Understanding the movement of fluids is crucial and warrants detailed examination. It serves as a key indicator for various fluid properties and provides insights into how fluids interact with their environment. This comprehension is essential for drawing conclusions relevant to system design and scientific inquiry.

The purpose of the experiment is to study how an orifice meter operates. This device includes a sharp-edged, circular opening through which fluids pass. As fluids move through this point, known as the vena contracta, their velocity increases upon exiting the device. Attached to the vena contracta is a manometer that measures the static head. Using the principles of Bernoulli and continuity, the flow rate (Q) is determined. The experiment also aims to explore parameters such as the discharge coefficient (C_d), coefficient of contraction (C_c), and coefficient of velocity (C_u).

The experiment is based on two key assumptions: that the pressure head and the velocity of the fluid at the water tank's surface are zero. This necessitates measuring the static head at the vena contracta point. Additionally, as will be discussed later in the sample, it is necessary to use a pitot tube to take head measurements, along with readings when overflow occurs.

The coefficients of velocity (C_u), contraction (C_c), and discharge were measured as 0.9735, 0.756, and 0.679 respectively, all values being less than 1. Additionally, the discharge coefficient was calculated using three different methods, yielding results of 0.679, 0.511, and 0.672. These results are satisfactory and validate the methods used to approximate the discharge coefficient.

A plot was made for the relation between the discharge and the square root of the head, the results suggest a linear trend with a slope of 0.0003 that was used to calculate one of the previously mentioned values.

Objectives

- Observing the flow measurements in piping systems.
- Determining the discharge, velocity, and contraction coefficients at various flow rates.

Sample calculation.

Sample calculation for run No.1

The ideal flow velocity is related to (H_0) by this equation:

$$\frac{u_0^2}{2g} = H_0 \quad (1)$$

Where:

H_0 : height of water when overflow is reached (mm).

(g): gravitational constant (m/s^2).

u_0 : the ideal velocity (mm/s).

$$\frac{u_0^2}{2 * 9810} = 382$$

$$u_0 = 2737.67 \text{ mm/s}$$

The equation 2 expresses the actual velocity:

$$\frac{u_c^2}{2g} = H_c \quad (2)$$

Where:

H_c : height of water by the pitot tube (mm)

(g): gravitational constant (m/s^2).

(u_c) : the actual velocity (mm/s)

$$\frac{u_c^2}{2 * 9810} = 362$$

$$u_c = 2665.04 \text{ mm/s}$$

The coefficient of velocity (C_u) can be determined by:

$$c_u = \frac{u_c}{u_0} = \sqrt{\frac{H_c}{H_0}} \quad (3)$$

$$c_u = \frac{2665.04}{2737.67}$$

$$c_u = 0.9735$$

To calculate cross-section area of the vena contract a_c to the cross-section of the orifice a_o

$$a_{c,0} = \frac{\mu}{4} * d^2 \quad (4)$$

$$a_c = 94.985 \text{ mm}^2$$

$$a_o = 132.665 \text{ mm}^2$$

the coefficient of contraction (C_c) can be calculated by:

$$Cc = \frac{a_c}{a_0} \quad (5)$$

$$Cc = \frac{94.985}{132.665}$$

$$Cc = 0.71598$$

1. First method to calculate Cd:

$$Q_{act} = \frac{m}{\rho t} \quad (6)$$

Q_{act} : the actual discharge (m^3/S)

m: mass of flowing water kg

ρ : the density of water ($\frac{kg}{m^3}$)

t: time (S)

$$Q_{act} = \frac{12}{1000 * 49.2}$$

$$Q_{act} = 2.44 \times 10^{-4} m^3/s$$

On the contrary, to calculate the theoretical flow rate.

$$Q_0 = a_0 \sqrt{2gH_0} \quad (7)$$

Q_0 : theoretical value of discharge (m^3/S)

H_0 : the height of the water in glass tank(mm).

$$Q_0 = 132.665 \sqrt{2 * 9810 * 384} = 3.632 \times 10^{-4} (m^3/S)$$

The discharge coefficient:

$$C_d = \frac{Q_{act}}{Q_0} \quad (8)$$

$$C_d = \frac{2.6467 \times 10^{-4}}{3.641 \times 10^{-4}}$$

$$\mathbf{Cd = 0.6716}$$

2. Second method to calculate.

$$C_d = C_u * C_c \quad (9)$$

$$C_d = 0.96825 * 0.71598$$

$$\mathbf{C_d = 0.697}$$

3. Third method to calculate C_d is by plot Q Vs. $\sqrt{H}$ by using slope of the fit line and this equation:

$$C_d = \frac{\text{slope}}{(\sqrt{2 \times g})a_0} \quad (10)$$

Slope from graph (figure 1)

a_0 : the cross-sectional area of the orifice (m^2)

g : gravitational constant (m/S^2).

$$C_d = \frac{0.0003}{\sqrt{2 \times 9.81} \times 1.32665 \times 10^{-4}}$$

$$\mathbf{C_d = 0.511}$$

Results

Table (1): calculated characteristics of flow pass through an orifice at different flow rates.

Run	time(sec)	Hc(mm)	Ho(mm)	Qact(m ³ /sec)	Qtheo(m ³ /sec)	u ₀ (m/s)	Cd	Cu	$\sqrt{(H_0)}$ (mm)
1	49.2	362	382	0.0002439	0.0003632	2.73767	0.67155	0.9735	19.545
2	51.8	362	355	0.0002317	0.0003501	2.63915	0.66165	1.0098	18.841
3	52.1	362	340	0.0002303	0.0003426	2.58279	0.6722	1.0318	18.439
4	53.2	362	325	0.0002256	0.0003350	2.52517	0.67332	1.0554	18.028
5	54.3	362	313	0.0002210	0.0003288	2.47812	0.67221	1.0754	17.692
6	55.6	362	300	0.0002158	0.0003219	2.42611	0.67056	1.0985	17.321
7	56.2	362	290	0.0002135	0.0003164	2.38533	0.67475	1.1173	17.029
8	59.9	362	245	0.0002003	0.0002909	2.19246	0.68876	1.2155	15.652

Table (2): Calculated Values

D ₀ (mm)	13	Cu	0.9735
D _c (mm)	11	C _c	0.71598
a ₀ (mm ²)	132.665	C _d (Cu*C _c)	0.697
a _c (mm ²)	94.985	C _d (from the plotting slope)	0.511
Q _{act} (m ³ /sec)	0.0002439	C _d	0.672
Q _{theo} (m ³ /sec)	0.0003632	u _c (m/s)	2665.04

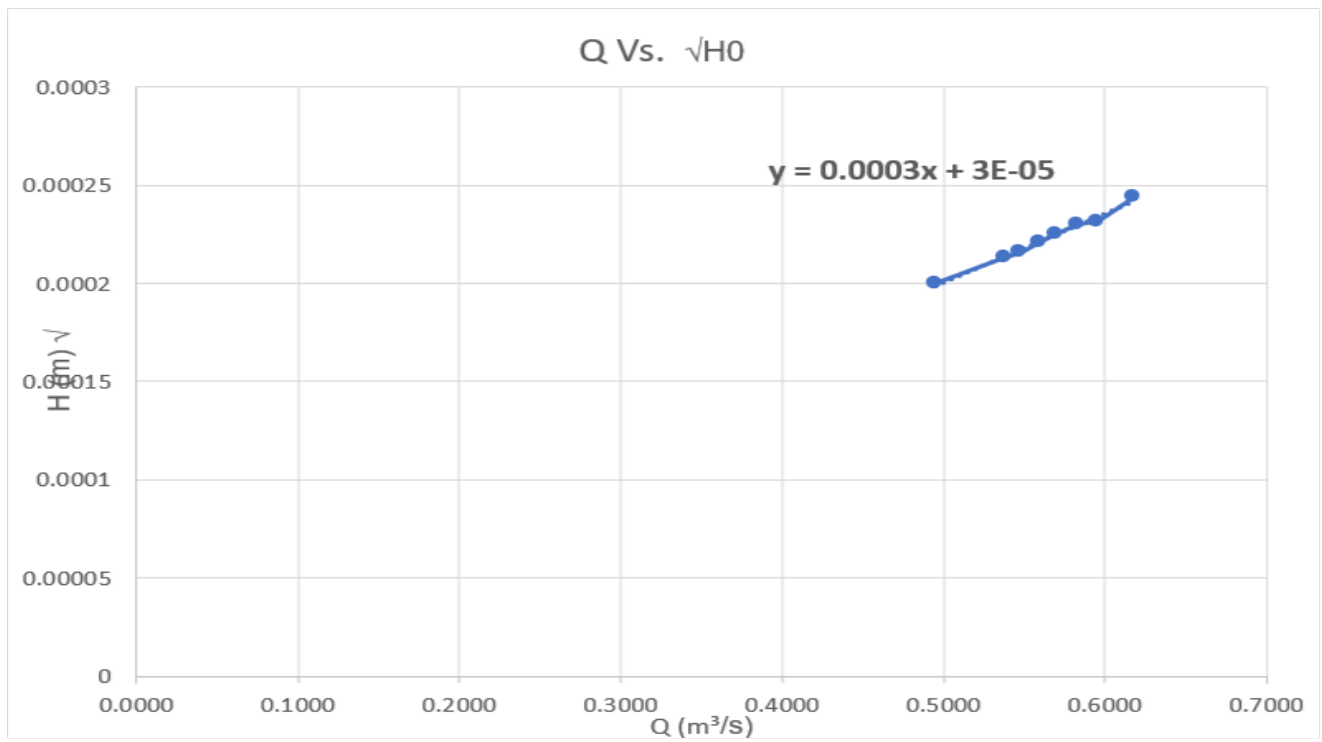


Figure (1): Variation of Q Vs. $\sqrt{H}$

Discussion of results

The goal of the experiment was to examine how the orifice meter functions by introducing key parameters such as the coefficients of contraction, velocity, and discharge (C_c , C_u , C_d). By relying on certain assumptions, the principles of Bernoulli and continuity were applied to determine the discharge value (Q). The experiment successfully met its objective by calculating these parameters, providing insight into the accuracy and effectiveness of the device.

Table (1) summarizes the results from each test run, including theoretical velocity and flow, actual flow, and the calculated discharge coefficient. The discharge coefficient has been calculated to be 0.697, 0.511 and 0.672 as was shown in table (2), indicating significant head losses in the orifice meter. These losses are due to factors like the sharpness of the orifice plate causing energy dissipation, the abrupt change in cross-section at the plate causing water turbulence, and other factors contributing to energy loss, all of which affect the discharge coefficient value.

A plot was generated from Figure (1), correlating discharge (Q) with the square root of the head difference ($\sqrt{H}$). The trend displayed a linear fit with a slope of 0.0003, suggesting a direct proportional relationship between these parameters, as anticipated by Bernoulli's equation.

Furthermore, the three methods employed to determine the value of C_d yielded identical results with minor discrepancies, thus confirming the validity of all three approaches for calculating the discharge coefficient.

The coefficient of contraction (C_c), coefficient of velocity (C_u), and coefficient of discharge (C_d) were utilized to approximate the true discharge values, as they consider the influence of the surroundings on flow and its deviation from the ideal discharge value.

A comparison between venturi meters and orifice meters shows that venturi meters are more accurate. This is evident from their higher discharge coefficients (C_d). The design of venturi meters, featuring multiple sections with varied cross-sectional areas, ensures smoother flow transitions and less energy loss than orifice meters.

Conclusions

Based on the results obtained, it can be concluded that the behavior of fluid flow is influenced by the cross-sectional area of the pipe. This alteration in cross-sectional area affects both velocity and pressure within the flow.

During the experiment, in addition to measuring the specified parameters, another aspect observed was the efficiency of the orifice in flow measurement. It became evident that the orifice induces significant head losses primarily due to its shape and sharpness, as well as the volume of fluid passing through the device.

Ratios of parameters such as C_u , C_c , and C_d were computed, all yielding positive values below one. These expected results signify the actual values relative to the ideal ones, crucial for estimating real flow values as they reflect the impact of real-life fluid surroundings.

During the experiment, various water heights were measured along with recorded time intervals. However, the manual process of placing weights, timekeeping, and observing the hydraulic bench lever may have led to less accurate results than desired.

Enhancing the experiment's accuracy could be improved by using a more advanced device capable of automatically recording water heights and flow times, thereby reducing reliance on manual measurements and potentially improving precision.

References

- Fluid mechanics laboratory manual (2022, march).
- White, F. M. (1999, January 1). Fluid Mechanics.
- Engineering, O. (2023, May 27). *What is an Orifice Plate Flow Meter?* <https://www.omega.com/en-us/resources/orifice-plate-flow-meter#:~:text=The%20orifice%20plate%20flow%20meter,and%20stream%20mass%20flow%20measurement>.

Appendices

Fluid Mechanics Lab.		
ME312		
Exp. No. 4		
Discharge Through an Orifice-meter		
<u>Sharp Orifice</u>		
<u>Part 1</u>		
<u>H₀ constant</u>		
H ₀ = <u>382</u> mm	d ₀ = <u>13</u> mm	Weight = <u>12</u> kg
H _c = <u>362</u> mm	d _c = <u>10.4</u> mm	Time = <u>49.2</u> sec

<u>Part 2</u>		
Weight = <u>12</u> kg		
Run	Time (sec)	H ₀ (mm)
1	49.2	382
2	48 51.8	365 355
3	52.1	340
4	53.2	325
5	54.3	313
6	55.6	300
7	56.2	290
8	59.9	245

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