Experimental analysis and comparison using Venturimeter and Orificemeter for estimating coefficient of discharge

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ABSTRACT

The coefficient of discharge (C_d) is also known as the efflux coefficient. To characterize the flow of different fluids using computational fluid dynamics around specific structures Venturimeter and orifice meter are used. C_d analysis of fluids is vital as it is widely employed in various engineering areas, specifically in industries for accurate fluid flow measurement for improving the efficiency of flow measurement methods. The coefficient of discharge observations determined experimentally using Venturimeter and orifice meter. A further graphical comparison was made with respective theoretical values, which are estimated using conventional formulae of the coefficient of discharge. It is observed that the value of the coefficient of discharge calculated using Venturimeter (0.92 to 0.98) is higher than that of Orifice Meter (0.62 to 0.67). Thus Venturimeter provides more accurate critical fluid analysis than orifice meter.

Keywords: coefficient of discharge, Orifice meter, Venture meter

1. INTRODUCTION

The rate of fluid flow is known as discharge. The discharge is the total quantity (volume) of fluid per unit time that passes a given cross-section. Its unit is m3/s and is denoted by Q. The Coefficient of discharge (Cd) is defined as the ratio of actual discharge and the theoretical discharge of flow. The Venturimeter and Orifice Meter are used for measuring the discharge through a pipeline. Orifice and mouthpieces are used for measuring discharge from a reservoir. Weirs and notches are used for measuring discharge in an open channel. Besides these instruments, the Flow Nozzle, Bend meter, Elbow Meter, Ultrasonic flow meters and Electromagnetic, etc. are also used for measuring discharge.

[Jahith, J. Ahamed, et al.] Venturimeter is used for measurement as an efficient instrument. They studied the various features exploring the theory of Venturimeter and data calculated through Bernoulli's equations (1). [Khayat, Omid, and Hossein A farideh] In a three-phase flow, the accurate and stable multiphase flow rate measurement was a big problem in the Oil & Gas industries. They need fewer errors in the required industry. Earlier developed two-phase flow measurement was very complicated and could not be used for three-phase flow measurement. For designing three-phase flow, they need to phase behavior identification in various conditions. (2) [Ramadurg, Karthik, et al.] studied the air Jet impingement for flow characteristics was the most used method for both the heating and cooling surfaces in their research (3). [Wrasse, Aluisio Do N., et al.] developed a flow meter to observe the discharge in gas-liquid flows. A simple algebraic approach added pressure variations of the Venturimeter to calculate the liquid flow rate. (4). [He, Denghui, et al.] researched the cone meter for cryogenic fluid measurement through numerical simulation. When the Reynolds number in the stable region, the pressure loss, coefficient, and discharge coefficient also constant (5). [Osman, Haitham, Khairy Elsayed, and Momtaz Sedrak.] designed an orifice plate's optimal shape to reduce the pressure loss (6). [Dayev, Zh A.] In various industries, differential flow meter was used for flow measurement. So they improve the flow measurement method. (7). [Hutagalung, SutrisnoSalomo] observed the relationship between differential coefficient and Reynolds number based on pressure variations. The discharge-coefficient reduced rapidly when the Reynolds number reached to 1 for the flow of meter. Differential coefficient parameter value could be calculated from the actual discharge ratio to theoretical values. Observation showed that the differential coefficient value was 0.59 (8). [Essien, S., Archibong Archibong-Eso, and Liyun Lao] Experimental research on the discharge coefficient was done for high viscosity fluid by a nozzle (9). [Smajkic, Amer, et al.] Computational Fluid Dynamics (CFD) models were used for the design of high voltage circuit breakers (CB). This type of plan needed specific computer resources. They used enthalpy flow models that did not use space discretization (10). [Mubarok, Mohamad Husni, John E.Cater, and Sadiq J. Zarrouk] used ANSYS for simulation of two-phase geothermal fluid flows by solving Computational fluid dynamics (CFD) models (11). [Stauffer, Taylor.] Venturi flow meter was used for flow measurement in the pipe system for 100 years. There are many kinds of research for improving the Venturi flow meters. In this research, they used multiple taps on the Venturimeter to minimize errors (12). [Hampiholi, Mahesh N., and Ramesh V. Nyamagoud] studied the effect on burning velocity, and flame structure Φ range should be broad (13). [Oh, Sang Taek, et al.] They used multi-nozzle for wide-range measurement, and ASHARE standard applied for this purpose made the meter large, bulky, and difficult in handling (14). [Mubarok, MohamadHusni, Sadiq J. Zarrouk, and John E.Cater] monitored essential parameters of individual goods performance, enthalpy, and mass flow rate (15). [Day, Matthew P., Michael C. Johnson, and Steven L. Barfuss] studied the implementation of six flow meters in 5 diameters and downstream from elbow out of the plane in lab piping fitting. Both meters were fitted on the pipeline and measured their performance against the weight tank. A DEOP was equipped with a flow meter on desired downstream locations. This study was used where accuracy required, and calibration was in the simulated pipe (16)

2. EXPERIMENTAL WORK

Venturimeter

Venturimeter is used to measure the discharge and works on the principle of Bernoulli's theorem. It consists of three parts.

(a) Convergent section
(b) Throat and
(c) Divergent section

The ratio of the convergent section diameter (D) and the divergent section (d) lies between 3:1 to 4:3. The throat has the minimum diameter. The angle of the convergent section lies in the range of 15-20°. And the angle of the divergent section lays 6-7° only to avoid flow separation.
A manometer is attached with inlet as a first pressure point and the throat as a second pressure point. The coefficient of discharge equation of Venturimeter is:

$$C_d = \frac{Qactual}{Qtheortical}$$

$$Qactual = A_t \times \frac{H_t}{T}$$

$$Qtheortical = \frac{A.\,a\sqrt{2gh}}{\sqrt{A^2 - a^2}}$$

Where Cd, A, a, g, At, Ht and T are the coefficient of discharge, the cross-sectional area of the inlet, the cross-sectional area of the throat, the acceleration due to gravity, the cross-sectional area of the tank, height of the tank and time is second respectively.

$$\frac{H_t}{T} = Height\ of\ the\ tank\ in\ T\ seconds$$

And $h = \frac{x}{s_1}(S_2 - S_1)$

S1 and S2 are the specific gravity of flowing fluid, the specific gravity of manometer fluid, respectively. X is the difference in manometer reading.

The Procedure of the Experiment for Venturimeter

i. Fill the sump tank with water.
ii. Connect the main supply.
iii. Open the valve.
iv. Before note down the reading first, check-in the valve air is completely out of the pipe.
v. Now note down the pressure drop and time is taken i.e. 10 seconds for a level rise in the collective tank.
vi. Repeat the procedure as per the requirement for different discharge rates.
vii. Find the coefficient of discharge with the help of the above formulae.

Constant Parameters for Venturimeter

Area of tank (A_t) = 2000 cm^2
Diameter at inlet D =2.8 cm
Diameter at outlet/Throat = 1.4 cm
Area at inlet (A) = $\frac{\pi}{4}D^2$ = 6.16 cm^2
Area at outlet/Throat (a) = $\frac{\pi}{4}d^2$ = 1.54 cm^2

Orifice Meter

The Orifice Meter is used for measuring the discharge. It also works on the principle of Bernoulli's theorem. The orifice is an opening in the wall or base of a vessel through which the fluid flows. The design of an orifice may be circular, rectangular, square, or triangular. It depends on the requirement and flow of fluid.

A manometer is attached with inlet as a first pressure point and the throat as a second pressure point. The coefficient of discharge equation of Orifice Meter is:

$$C_d = \frac{Qactual}{Qtheortical}$$

$$Qactual = A_t \times \frac{H_t}{T}$$

$$Qtheortical = \frac{A.\,a\sqrt{2gh}}{\sqrt{A^2 - a^2}}$$

Where Cd, A, a, g, At, Ht and T are the coefficient of discharge, the cross-sectional area of the inlet, the cross-sectional area of the throat, the acceleration due to gravity, the cross-sectional area of the tank, height of the tank and time is second respectively.

$$\frac{H_t}{T} = Height\ of\ the\ tank\ in\ T\ seconds$$

And $h = \frac{x}{s_1}(S_2 - S_1)$

S1 and S2 are the specific gravity of flowing fluid, the specific gravity of manometer fluid, respectively. X is the difference in manometer reading.

Constant Parameters for Orifice Meter

The same procedure is being used for finding the comparison parameters in both Orifice Meter and Venturimeter readings. These same parameters are shown below.

Area of tank (A_t) = 2000 cm^2
Diameter at inlet D =2.8 cm
Diameter at outlet/Throat = 1.4 cm
Area at inlet (A) = $\frac{\pi}{4}D^2$ = 6.16 cm^2
Area at outlet/Throat (a) = $\frac{\pi}{4}d^2$ = 1.54 cm^2

3. RESULTS

Experimental Result of the Venturimeter

The experimental work shows the working of the Venturimeter and Orifice Meter with their formulae for finding the coefficient of discharge. In this study, we discuss the optimization result of the Venturimeter and Orifice Meter for detecting the coefficient of discharge.

First, the Venturimeter result is discussed with the help of observation table 3.1:

Table 3.1 Observation Table of Venturimeter

S.NO	A_t	H_1	H_2	H_t	T	Q actual	X_1	X_2	X	h	A	a	Q th	C_d
1	2000	28	25.2	2.8	10	560	28.6	22.7	5.9	74.34	6.16	1.54	607.4295	0.9219177
2	2000	18	15.1	2.9	10	580	18.5	12.6	5.9	74.34	6.16	1.54	607.4295	0.9548434
3	2000	38	35.4	2.6	10	520	38.2	33.1	5.1	64.26	6.16	1.54	564.7483	0.9207641
4	2000	44	41.4	2.6	10	520	42.1	37.6	4.5	56.7	6.16	1.54	530.4887	0.9802283
5	2000	48	45.6	2.4	10	480	44	39.7	4.3	54.18	6.16	1.54	518.5661	0.9256294

For the experiment, the area of the tank is considered to be fixed 2000 cm^2 for Venturimeter.

Area of tank (A_t) = 2000 cm^2

Now in every 10 seconds time interval, the height of the tank is measured. For example, in the first reading, the height of the tank is 25.2 cm, and after 10 seconds, the height of the tank increases up to 28cm. So the total increase in the height of the tank is calculated.

$$H_t = H_1 - H_2$$

Now we calculate the actual discharge of flowing fluid with the help of given formulae:

$$Qactual = A_t \times \frac{H_t}{T}$$

Therefore after calculating the actual discharge for first reading, the result is obtained:

$$Qactual = 560 \text{ Cm}^3/\text{sec}$$

After finding the actual discharge of flowing fluid, we found the theoretical discharge. For finding the theoretical discharge first, we measured the diameter of the inlet and outlet, which is fixed, and from these diameters, the area can be calculated.

Diameter at inlet D =2.8 cm

Diameter at outlet/Throat = 1.4 cm

Area at inlet (A) = $\frac{\pi}{4}D^2$ = 6.16 cm^2

Area at outlet/Throat (a) = $\frac{\pi}{4}d^2$ = 1.54 cm^2

Now calculate the Difference in manometer reading (X) by differentiating both the manometer reading.

$$X = X_1 - X_2$$

Here the manometer reading (X) is 5.9cm. Now calculate the h. we know that:

$$h = \frac{X}{S_1}(S_2 - S_1)$$

S_1= Specific gravity of flowing fluid

S_2= Specific gravity of manometer fluid

X= Difference in manometer reading

In the Venturimeter experiment, the manometer fluid is mercury, and flowing fluid is water used. So

S_1= Specific gravity of flowing fluid= 1

S_2= Specific gravity of manometer fluid=13.6

So as per first reading h = calculated by this formula:

$$h = \frac{X}{S_1}(S_2 - S_1)$$

$$h = \frac{5.9}{1}(13.6 - 1)$$

h=74.34

Now we have all the values for finding the theoretical discharge. To calculate the theoretical discharge following formulae can be used.

$$Qtheortical = \frac{A.\,a\sqrt{2gh}}{\sqrt{A^2 - a^2}}$$

$$Qtheortical = \frac{6.16 * 1.54\sqrt{2 * 981 * 74.34}}{\sqrt{6.16^2 - 1.54^2}}$$

$$Qtheortical = 607.42\ cm^3/s$$

Now calculate the coefficient discharge:

$$C_d = \frac{Qactual}{Qtheortical}$$

$$C_d = \frac{560}{607.42}$$

$$C_d = 0.92$$

So, further, calculate the coefficient of discharge by repeating the same method. Now all the Venturimeter experiment readings are shown in figure 3.1 by a line diagram.

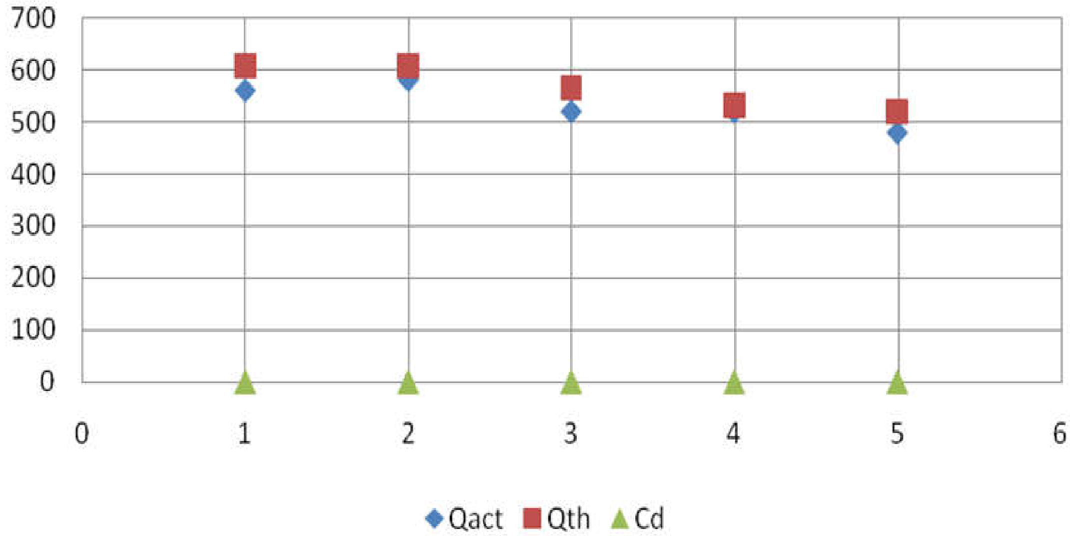

Figure 3.1 A line diagram of the Venturimeter experiment readings

Experimental Result of the Orifice Meter

Now the Orifice Meter result is discussed with the help of observation table 3.2

Table 3.2 Observation Table of Orifice Meter

S.NO.	A_t	H_1	H_2	H_t	T	$Q\ actual$	X_1	X_2	X	h	A	a	$Q\ th$	C_d
1	2000	46.9	45.3	1.6	20	160	13.6	12.6	1	12.6	6.16	1.54	250.0748	0.6398087
2	2000	20.8	19.4	1.4	20	140	13.4	12.6	0.8	10.08	6.16	1.54	223.6737	0.6259119
3	2000	25	23.5	1.5	20	150	13.1	12.2	0.9	11.34	6.16	1.54	237.2417	0.6322665
4	2000	30	28.5	1.5	20	150	16	15.1	0.9	11.34	6.16	1.54	237.2417	0.6322665
5	2000	40	38.6	1.4	20	140	17	16.3	0.7	8.82	6.16	1.54	209.2276	0.6691279

For the experiment, the tank area is considered to be fixed 2000 cm2 for orifice meter.
Area of tank (A_t) = 2000 cm^2

Now every 20 seconds time interval, the height of the tank is measured. For example, in the first reading, the height of the tank is 45.3cm, and after 10 seconds, the height of the tank increases up to 46.9cm. So the total increase in the height of the tank is calculated.

$$H_t = H_1 - H_2$$

Now we calculate the actual discharge of flowing fluid with the help of given formulae:

$$Qactual = A_t \times \frac{H_t}{T}$$

Therefore after calculating the actual discharge for first reading, the result is obtained:

$$Qactual = 160 \text{ cm}^3\text{/sec}$$

After finding the actual discharge of flowing fluid, find out the theoretical discharge. For finding the theoretical discharge first, we measured the diameter of the inlet and outlet, which is fixed, and from these diameters, the area can be calculated.

Diameter at inlet D =2.8 cm
Diameter at outlet/Throat = 1.4 cm
Area at inlet (A) = $\frac{\pi}{4}D^2$ = 6.16 cm^2
Area at outlet/Throat (a) = $\frac{\pi}{4}d^2$ = 1.54 cm^2

Now we calculate the actual discharge of flowing fluid with the help of given formulae:

$$X = X_1 - X_2$$

Here the manometer reading (X) is 1cm.

Now calculate the h. we know that:

$$h = \frac{X}{S_1}(S_2 - S_1)$$

S_1= Specific gravity of flowing fluid

S_2= Specific gravity of manometer fluid

X= Difference in manometer reading

In the Venturimeter experiment, the manometer fluid is mercury, and flowing fluid is water used. So

S_1= Specific gravity of flowing fluid= 1

S_2= Specific gravity of manometer fluid=13.6

So as per first reading h = calculated by this formula:

$$h = \frac{X}{S_1}(S_2 - S_1)$$

$$h = \frac{1}{1}(13.6 - 1)$$

$$h=12.6$$

Now we have all the value for finding the theoretical discharge. To calculate the theoretical discharge with the help of the below formulae:

$$Qtheortical = \frac{A.\,a\,\sqrt{2gh}}{\sqrt{A^2 - a^2}}$$

$$Qtheortical = \frac{6.16 * 1.54 \sqrt{2 * 981 * 12.6}}{\sqrt{6.16^2 - 1.54^2}}$$

$$Qtheortical = 250.07\ cm^3/s$$

Now calculate the coefficient discharge:

$$C_d = \frac{Qactual}{Qtheortical}$$

$$C_d = \frac{160}{250.07}$$

$$C_d = 0.639 = 0.64$$

So, further, we calculate the coefficient of discharge by repeating the same method.

Now all the Orifice Meter experiment readings are shown in figure 3.2 by a line diagram.

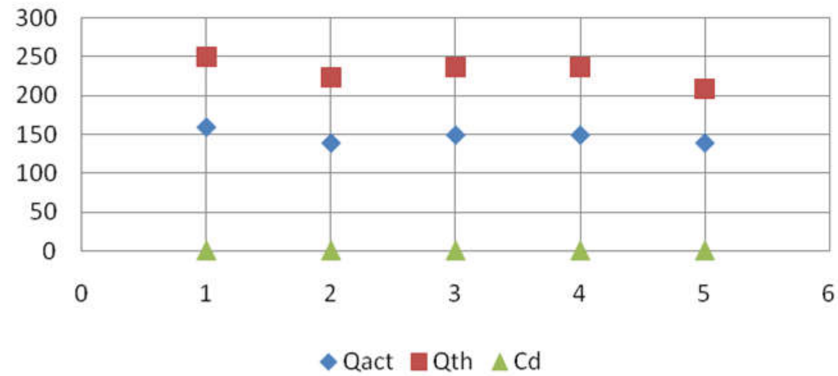

Figure 3.2 A line diagram of the Orifice Meter experiment readings

Comparison of the coefficient of discharge

Now from the result of observation table 3.1 and 3.2, the coefficient of discharge by both the instrument Venturimeter and Orifice Meter is given in table 3.3; VC_d indicates the coefficient of discharge of Venturimeter, and OC_d indicates the coefficient of discharge of Orifice Meter. Now compare both the coefficient of discharge of Venturimeter and orifice meter. Comparison in terms of bar chart can be seen for both the coefficient of discharge of Venturimeter and Orifice Meter in figure 3.3. By this figure and Comparison, it is clear that the discharge of Venturimeter is always higher than the discharge orifice meter's coefficient. The value of the VC_d for the Venturimeter is always lying in the range of 0.92 to 0.98. And OC_d for Orifice Meter lies in the range of 0.62 to 0.67.

Table 3.3 coefficient of discharge of Venturimeter and Orifice Meter

VC_d	OC_d
0.9219177	0.6398087
0.9548434	0.6259119
0.9207641	0.6322665
0.9802283	0.6322665
0.9256294	0.6691279

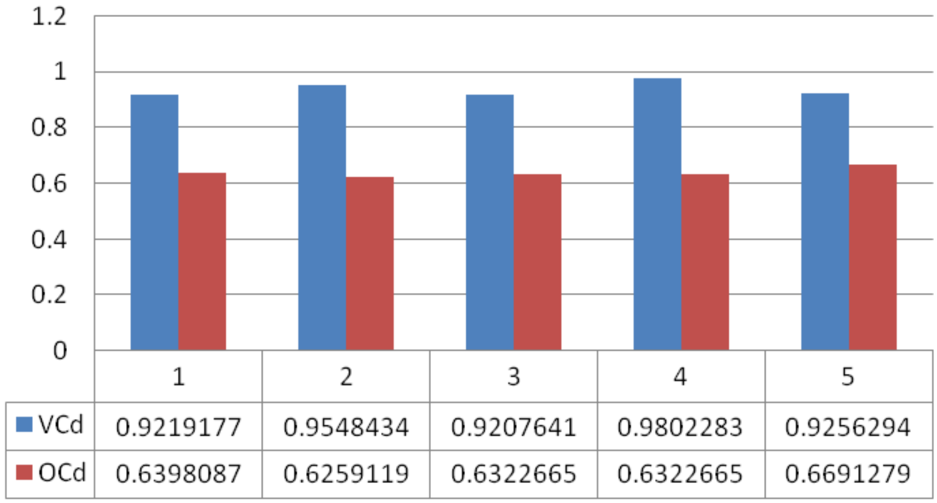

Figure 3.3 Comparison of the coefficient of discharge

Table 3.4 Comparison of the actual discharge, theoretical discharge and the coefficient of discharge of Orifice Meter and Venturimeter

Orifice Meter			Venturimeter		
OQ_{actual}	OQ_{th}	OC_d	VQ_{actual}	VQ_{th}	VC_d
160	250.0748	0.6398087	560	607.4295	0.9219177
140	223.6737	0.6259119	580	607.4295	0.9548434
150	237.2417	0.6322665	520	564.7483	0.9207641
150	237.2417	0.6322665	520	530.4887	0.9802283
140	209.2276	0.6691279	480	518.5661	0.9256294

Where, OQ_{actual}, OQ_{th}, and OC_d are the actual discharge, theoretical discharge, and coefficient of discharge of Orifice Meter, respectively. Similarly, VQ_{actual}, VQ_{th}, and VC_d are the actual discharge, theoretical discharge, and coefficient of discharge of Venturimeter respectively.

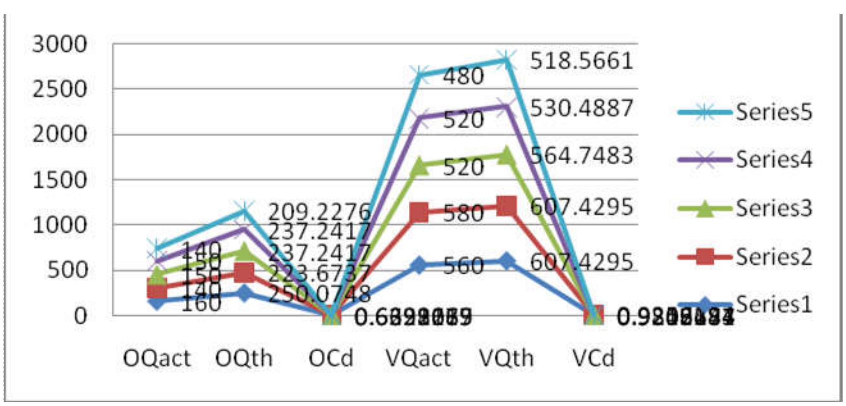

Figure 3.4 Line diagram of the actual discharge, theoretical discharge and the coefficient of discharge of Orifice Meter and Venturimeter

4. CONCLUSION

It is experimentally proved that the coefficient of discharge by both the instrument Venturimeter and Orifice Meter is always less than 1. In this research, it is experimentally found the coefficient of discharge for the Venturimeter and Orifice Meter simultaneously by the five readings of each instrument's experiment and always find the result is less than one. Results concluded that VC_d and OC_d for Venturimeter and Orifice Meter are less than 1. Table 3.4 showed the Comparison of the actual discharge of Orifice Meter (OQ_{act}), theoretical discharge of Orifice Meter (OQ_{th}) and the coefficient of discharge of Orifice Meter (O QC_d) and the actual discharge of Venturimeter (VQ_{act}), theoretical discharge of Venturimeter (VQ_{th}) and the coefficient of discharge of Venturimeter (VQC_d). Line diagram (figure 3.4) showed the actual discharge, theoretical discharge, and the coefficient of discharge of Orifice Meter and Venturimeter. Finally, the coefficient of discharge is in the range of 0.92 to 0.98 for the Venturimeter, and 0.62 -0.67 for the Orifice Meter.

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