

Analysis of Performance of V-CONE meter with experimentally and CFD

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Abstract: The measurement of fluid flow rate is important in many industrial applications like rocket propellant, petroleum industry, hydroelectricity station, water meter. Orifice, venturiers meter, nozzles, venturi cones, venturi nozzles, drag plates are traditional flow rate measuring instruments. But, The V-Cone throttle device has been paid more and more attentions on the measurement of the wet gas flow in recent years. V-Cone flow meter has various advantages over conventional flow meter. Finding out V-Cone Meter characteristics for measuring water flow rate is scope of this dissertation. In this research, beta ratio is considered between 0.55 to 0.85. By using volumetric flow equation, maximum diameter of V-Cone Meter is calculated for 102 mm diameter of pipe. Computational fluid dynamics (CFD) is used to simulate the flow in V-Cone Meter. Front angle and back angle of V-Cone Meter is optimized in ANSYS Fluent. Experimentation is held for different flow rate for finding flow rate constant (Cd). 0.75 is optimized beta ratio for flow rate between 125 m³/hr to 60 m³/hr. experimentally flow rate constant is fluctuating between 0.8 to 0.87 for this V-Cone Meter. Experiments are carried out to validate the CFD predictions. This research is concluded that V-Cone Meter can also use for measuring water flow rate.

Key words- V-Cone Meter, beta ratio, CFD, water flow rate

I. INTRODUCTION

Water flow rate is important in industry like municipal water and wastewater, power, co-generation, mining, pulp-paper industry, industrial manufacturing, food, beverage. The V-Cone Meter provides flow measurement with an accuracy of up to $\pm 0.05\%$ over a turn down ratio of 30:1 [1]. The pressure difference of front and back of the cone is used to realize flow speed measurement. V-Cone Meter expands the flow measurement scope and avoids some limitations of traditional difference flow meter. Velocity depends on the pressure differential that is forcing the fluid through a pipe. Because the pipe's cross-sectional area is known and remains constant, the average velocity is an indication of the flow rate. Other factors that affect liquid flow rate include the liquid's viscosity and density, and the friction of the liquid in contact with the pipe. Measurement of the flow of a fluid, either liquid or gas, is commonly a critical parameter in many processes. In most operations this can be linked to the basic need of the process, knowing that the right fluid is at the right place and the right time. Equally, it can be linked to asset management, keeping the fluid in motion or even simple tank balancing. Some applications, however, require the ability to conduct accurate flow measurements to such an extent that they influence product quality, health and safety, and ultimately can make the difference between making a profit and running at a loss. In Recent years many work is done with help of experimentally, numerically. Szabo, J.L., Winarski, C.P., Hypnar, P.R. [2] has compared the flow rate equations used for the V-Cone Meter with those defined by accepted standards for use with the square-edged orifice meter. Dr. RJW Peters, Dr. R. Steven [3], has reviewed V-Cone Meter experimentally by comparing with orifice meter. F Dong, C Tan, W Li, F S Zhang [4], a series of experiments of oil-water two-phase flows in a 50mm diameter Perspex horizontal pipe, the flow rates were measured with a V-Cone Meter flow meter with 0.65 diameter ratio. Weiguang Liu, Ying Xu, Tao Zhang, Fengfeng Qi [5], has compared V-Cone Meters of three different beta edge types with help of theoretical analysis, numerical simulations and experimental tests. Deng-Hui He, Bo-Feng Bai [6] demonstrate that the introduction of the Two-phase mass flow coefficient of the V-Cone throttle device makes a simple and accurate wet gas measurement correlation feasible. V.K. Singh, T. John Tharakan [7], have studied single- and multi-hole orifice meter over a wide range of Reynolds numbers with help of CFD. The discharge coefficient of multi-hole orifices is larger than that of single-hole orifice over a wide range of Reynold's numbers. It is challenge to find out performance of V-Cone Meter for measuring water flow rate. Whether V-Cone Meter characteristics change as fluid change, it is also a good research. For developing V-Cone Meter, Beta ratio and maximum diameter of V-Cone Meter is calculated by mathematical calculation. After getting fundamental dimension of V-Cone Meter, front and back angle is found by CFD software. Various combination of angles are analyze by keeping other parameter constant (e.g. beta ratio, flow rate, flow rate constant etc.). Ansys Fluent is used for numerical analysis. Various iterations are done to optimize angles. It also

helps to reduce experimental cost and time. In this paper, V-Cone meter is designed to measure water flow rate in 100 NB pipe. Flow rate constant (C_d) is found out by numerical and experimental method.

II. V-CONE METER

From Fig. 1 [5], it can be seen that the V-Cone Meter upstream tapping is on the wall of the pipe but the downstream tapping is not on the wall of the pipe but on the back face of the cone on the pipe center line. This is a radical departure from the traditional DP meter designs and this design gives some significant performance improvements which will be discussed in chapter two. The different geometry can cause some engineers to wonder if the V-Cone Meter operates according to a different principle than the traditional DP meters but this is not so. The governing flow equation for the V-Cone is identical to that of all other DP meters. From the users point of view all secondary equipment used is exactly the same as would be chosen for any DP meter. That is the same manifolds, DP transmitters and Flow Computers are used as are used with other DP meters (with the flow computer requiring the V-cone equation just as it requires the unique equation for any DP meter). Therefore use of a V-Cone Meter requires no further understanding than that knowledge required to use any other DP meter.

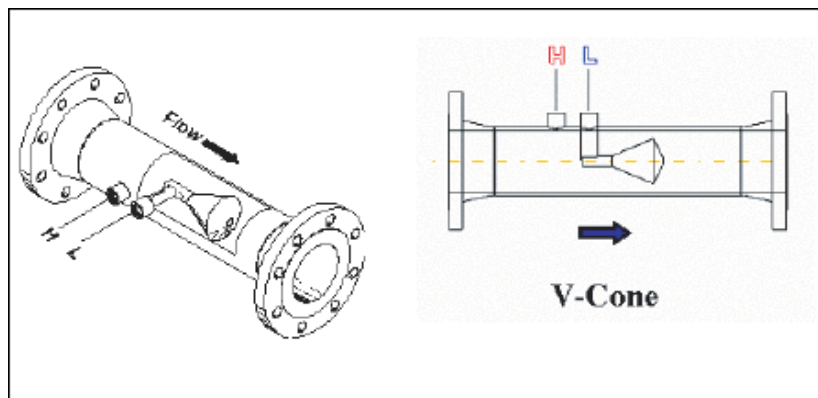


Fig. 1. General V-Cone Meter 3D View and Flow Direction

All DP meters work according to the principles of the conservation of mass and energy. Depending on specific DP meter geometries, some of the parameters are calculated in different ways. In V-Cone Meter, water is flowing along wall of pipe (peripheral side) and in orifice meter, water is flowing from center part of pipe (As shown in Fig 2) [4]. Due to the different geometry the V-Cone Meter beta ratio is calculated by equation 1. Where A is the upstream pipe cross sectional area, d inner diameter of orifice, D is the upstream pipe diameter and d_c is the cone diameter.

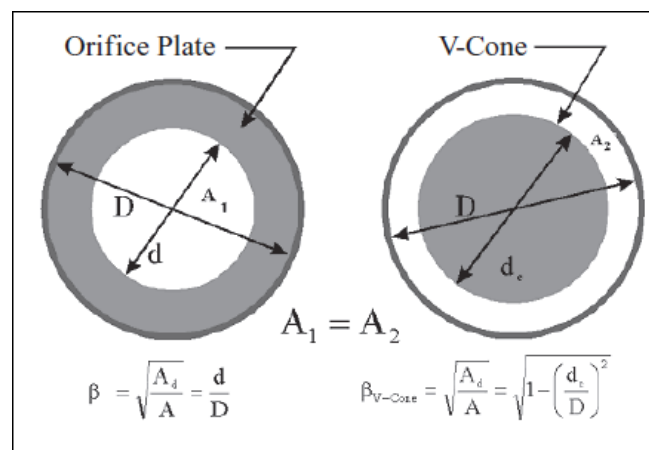


Fig. 2. Schematic Diagram of Orifice Plate and C-cone meter for Beta Ratio Calculation

$$\beta_{\text{Traditional}} = \sqrt{\frac{A_d}{A}} = \frac{d}{D} \quad (1)$$

$$\beta_{V-cone} = \sqrt{\frac{A_d}{A}} = \sqrt{1 - \left(\frac{d_c}{D}\right)^2} \quad (2)$$

A. Volumetric Flow Calculation

Volumetric flow rate equation (eq.2) [7] is basic equation to calculate beta ratio of V-Cone Meter at flowing conditions.

$$q_v = N_{vp} \times \frac{C \cdot \beta_{fvcone}^2 \cdot D^2}{\sqrt{1 - \beta_{fvcone}^4}} \times \frac{1}{\sqrt{F_p \cdot \rho_f}} \times \sqrt{\Delta P} \quad (3)$$

Dimensions of pipe from which fluid is flowing change with flowing conditions. Dimensions of pipes are affected by temperature specially (Eq.4).

$$D = [1 + \alpha_p (T - 20)] D_i \quad (4)$$

Beta ratio is very important element of any flow meter. But equation of beta ratio is different for V-Cone Meter is different than orifice and venturi meter. [11]

To summarize V-Cone Meter, finding out its characteristic for specific application.

Water as fluid, Pipe diameter = 100 N, Inner diameter of pipe, Di = 102.26 mm, Beta ratio = 0.75, Operating temperature = 27-35 °C, Density at operating temperature = 996 kg/m³.

From Eq.2, Maximum diameter of V-Cone Meter is 67.6 mm

Table 1. Theoretical Differential Pressure for Different Flow Rate for Cd =0.85

ID	D	qv	Delta P	Delta p	d (fvcone)
Inner Dia. Of pipe	Inner Dia. of pipe operating condition	Volume flow rate	Differential Pressure	Differential Pressure	Max. Dia. Of vcone At flowing condition
mm	mm	m ³ /hr	kPa	mmWC	mm
102.26	102.272	125.49	24.587992	2507.2376	67.6
102.26	102.272	125.33	24.525333	2500.8482	67.6
102.26	102.272	125.31	24.517506	2500.0501	67.6
102.26	102.272	116.03	21.020615	2143.4721	67.6
102.26	102.272	115.33	20.767748	2117.6873	67.6
102.26	102.272	100.09	15.641781	1594.9925	67.6
102.26	102.272	99.76	15.538808	1584.4923	67.6
102.26	102.272	88.73	12.292658	1253.4823	67.6
102.26	102.272	88.66	12.27327	1251.5053	67.6
102.26	102.272	72.74	8.2613577	842.41065	67.6
102.26	102.272	72.55	8.2182560	838.01557	67.6
102.26	102.272	60.12	5.6434252	575.46008	67.6
102.26	102.272	60.1	5.6396711	575.07726	67.6

As shown in Table 1, Differential pressure is directly proportional to flow rate. Practically, differential pressure is measured in millimeter water column (mmWC) in this experimental set up. So at the time of experimentation DP value in mmWC are required. Conversion is 1kPa=101.971 mmWC.

III. NUMERICAL ANALYSIS OF V-CONE METER WITH ANSYS FLUENT 14.0

From beta ratio equation (1), max. Diameter of V-Cone Meter is 67.6 mm. Solid model of V-Cone Meter is prepared in CATIA software (As shown in Fig. 3). As shown in Fig. 4, all important dimensions of V-Cone Meter are displayed. Angle ϕ_1 and Angle ϕ_2 are unknown parameters which are finding out by number of iterations in CFD.

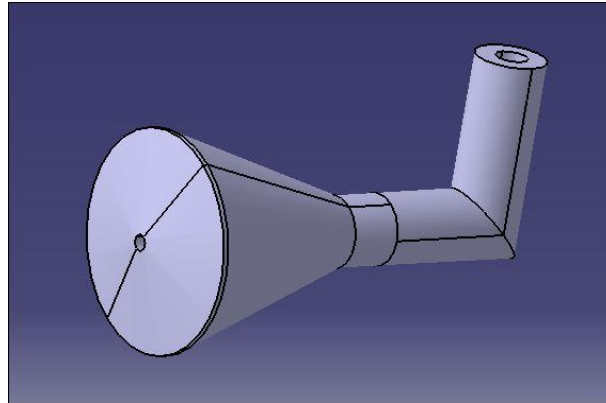


Fig. 3. CAD Model of V-Cone Meter in CATIA V5

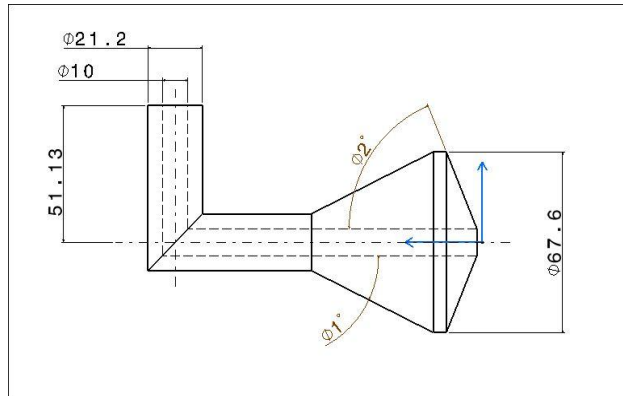


Fig 4. Important Dimensions of V-Cone Meter (all dimensions in mm)

Behavior of water flow is analyzed by Computational fluid dynamics (CFD) in ANSYS FLUENT 14.0. Pressure based solver and Realizable $k-\epsilon$ (RKE) model is suitable for V-Cone Meter analysis. With Boolean operation water domain is prepared in ANSYS. All water domain is meshed with TETRA elements (number of elements 386526). After applying all boundary conditions and initial values, differential pressure (DP) are got for different flow rate. As mentioned in Table 2, differential pressure is decrease as flow rate is decrease. As shown in Table 3, angles of V-Cone Meter is make impact on DP. As angle changes, behavior of V-Cone Meter is also changed. After comparing Numerical DP with theoretical DP, DP of V-Cone Meter with angle 20° and 80° are more close to theoretical value. So, angle 20° and 80° are selected for further calculations.

Table 2. DP value for actual flow rate value From CFD software.

Flow Rate	Flow Rate	Velocity	Numerical (CFD) DP
m ³ /hr	kg/s	m/s	Pascal
125.49	34.72	4.24	20665.56
125.33	34.67	4.24	20452.56
125.31	34.67	4.24	20500.96
116.03	32.10	3.92	17551.80
115.33	31.91	3.90	17368.10
100.09	27.69	3.38	13700.16
99.76	27.60	3.37	13281.59
88.73	24.55	3.00	10552.81
88.66	24.53	3.00	10536.83
72.74	20.12	2.46	7271.60
72.55	20.07	2.45	7249.60
60.12	16.63	2.03	5214.10
60.1	16.63	2.03	5214.30

Table 3. Effect of V-Cone Meter Angle on DP

Flow rate in m ³ /hr		115	100	90
Angle ϕ_1	Angle ϕ_2	Differential Pressure (DP) in CFD (Pa)		
25	75	17205	12708	10317
15	75	8611	6430	5265
26	67.5	15675	12046	9550
20	80	17739	13414	10821
Theoretical Differential Pressure (DP) (Pa)		20650	15613	12647

IV. EXPERIMENTAL ANALYSIS OF V-CONE METER

To find out actual effect of V-Cone Meter on DP, experimental analysis is done under actual conditions. Components of experimental set up (Fig.5) [16]:

1. Constant Head Tank (20 m3)
2. Butterfly Valve
3. Pressure Transmitter
4. Temperature Transmitter
5. Conditioning Flow Meter
6. Flow Meter To Be Calibrated
7. DP Transmitter
8. Control (Butterfly) Valve
9. Diverter
10. Weigh Tank (5000kg)
11. Weigh Bridge
12. Water Reservoir
13. Overflow Return Line
14. Low Pressure Pump (3 nos.)

Calculation for flow rate after experimentation.

1. Calculation of actual flow rate (Q_a)

$$Q_a = \frac{M * 3600}{\rho * t} \tag{5}$$

Q_a is in m³/hr

M= Mass of water flow through pipe in t sec, Kg

t= time, second

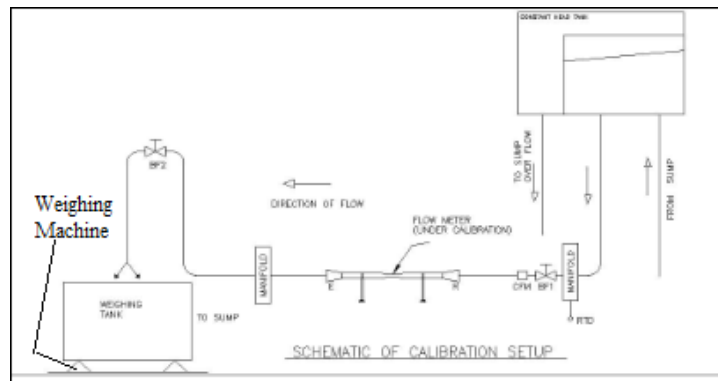


Fig. 5. Water Flow Direction in Testing Setup

2. Calculation of theoretical flow (Q_t)

$$Q_t = A * \sqrt{\frac{2 * \Delta P}{(1 - \beta^4) * \rho}} \tag{6}$$

A= Area through which water is flowing, m²

3. V-cone flow meter constant (C_d)

$$C_d = \frac{Q_a}{Q_t} \tag{7}$$

Table 4. Experimental Differential Pressure (DP) Value

Mass of Water Kg	Time Sec	DP Pascal	Actual Flow m ³ /hr	Theoretical Flow m ³ /hr	Flow meter Constant
1314	37.901	22905.96	125.31	141.815	0.883
1305	37.66	22923.35	125.24	141.87	0.882
1350	38.99	22907.5	125.19	141.82	0.882
1396	40.207	22888.97	125.49	141.76	0.885
1398	40.181	22901.944	125.23	141.8	0.883

1393	37.293	22929.75	125.33	141.89	0.883
1190	35.726	19531.44	115.33	130.95	0.88
1140	38.856	19577.8	116.03	131.5	0.882
1072.5	39.199	14737.11	99.76	113.75	0.877
1085	42.85	14816.81	100.09	114.05	0.877
1052	38.971	11781.9	88.73	101.70	0.872
956	44.634	11763.37	88.66	101.62	0.872
896	44.373	7994.27	72.55	83.78	0.866
893	42.754	8014.66	72.74	83.88	0.867
860	42.754	7955.33	72.7	83.57	0.869
777	46.722	5773.22	60.1	71.19	0.844
829	49.869	5773.19	60.12	71.19	0.844

From equations 4, 5, 6 and experimental readings, flow rate constant is calculated. As in table 3, there is difference in actual DP and theoretical DP. Flow meter constant value (C_d) is approximately 0.85 for this V-Cone Meter.

V. RESULTS

V-Cone Meter is analyzed by theoretical, numerical (CFD) and experimental methods. Differential pressure (DP) is determined for different flow rates in three different way (as shown in Table 5). Flow rate is changed from 130 m³/hr to 60 m³/hr range. After all calculations and testing, theoretical results are considered as datum. CFD simulation shows lower values than other analysis. Theoretical DP is higher at same flow rate. (As shown in Fig.6).

Table 5. Comparison of Theoretical, Numerical, Experimental DP

Flow Rate	Flow Rate	Theoretical DP	Numerical (CFD) DP	Experimental DP	Numerical (CFD) Error	Experimental Error
m ³ /hr	kg/s	Pascal			% w.r.t. Theoretical DP	
125.49	34.72	24587.99	20665.56	22905.65	15.95	6.84
125.33	34.67	24525.33	20452.56	22923.35	16.61	6.53
125.31	34.67	24517.51	20500.96	22907.51	16.38	6.57
116.03	32.10	21020.62	17551.80	20010.45	16.50	4.81
115.33	31.91	20767.74	17368.10	19531.44	16.37	5.95
100.09	27.69	15641.78	13700.16	14816.83	12.41	5.27
99.76	27.60	15538.80	13281.59	14737.11	14.53	5.16
88.73	24.55	12292.65	10552.81	11763.90	14.15	4.30
88.66	24.53	12273.27	10536.83	11763.37	14.15	4.15
72.74	20.12	8261.35	7271.60	7994.27	11.98	3.23
72.55	20.07	8218.25	7249.60	7955.33	11.79	3.20
60.12	16.63	5643.42	5214.10	5773.22	7.61	-2.30
60.1	16.63	5639.67	5214.30	5773.19	7.54	-2.37

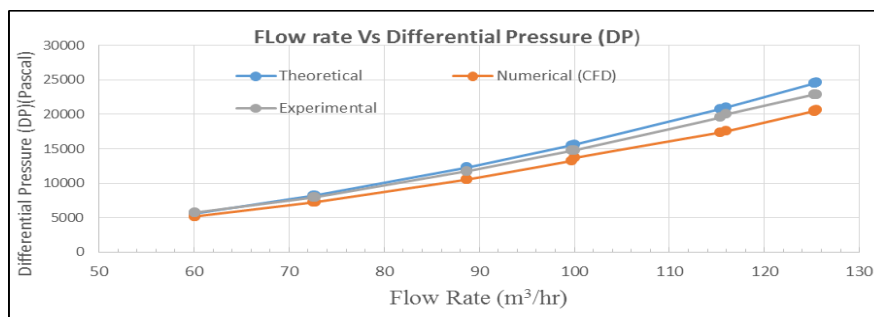


Fig. 6. Flow Rate Vs Differential Pressure (DP)

Theoretical differential pressure, Numerical (CFD) differential pressure and experimental differential pressure (DP) are close for given flow rate.

VI. CONCLUSIONS

Optimized geometry of V-Cone Meter is developed to measure water flow. With help of ANSYS FLUENT (CFD) optimized cone angles are found. i.e. $\theta_1=20^\circ$ and $\theta_2 = 80^\circ$. V-Cone Meter shows considerable changes in differential pressure (DP) according to change in water flow. Optimized beta ratio of V-Cone Meter is 0.75 for given requirements (100 NB pipe diameter, 1.44 bar input pressure, 130 m³/hr -90 m³/hr water flow). V-Cone Meter shows good results for measuring water flow rate. Theoretical differential pressure, Numerical (CFD) differential pressure and experimental differential pressure (DP) are matching fairly well, some error is due to frictional losses and measuring instruments error. For V-Cone Meter, flow meter constant (Cd) for is constant. From above conclusions, V-Cone Meter can replace traditional DP flow meter (like orifice meter, venturi meter etc.) for measuring water flow rate.

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