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Analyze Performance of V-cone Meter by Experimentally and Theoretically

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Abstract: V-Cone flow meter is an innovative system that takes differential pressure flow measurement to another level. V-cone flow meter has varies advantages over conventional flow meter. Designed for mild to harsh operating environments, and for a wide variety of fluids, this advanced flow meter consistently outperforms traditional DP devices and other flow technologies. Flow characteristics of V-cone flow meters are determined both numerically and experimentally over a wide range of Reynolds numbers. The V-Cone flow offers better accuracy and repeatability, wider range ability, installation flexibility and reduced maintenance. V-cone meter shows good performance than other differential pressure flow meters (like orifice meter, venturi meter). The sharp angle, corner cut and arc are the most common forms of beta edges used in cone flow meters. Trying to measure disturbed flow can create substantial errors for other flowmeter technologies. The V-Cone flow meter overcomes this by reshaping the velocity profile upstream of the cone. This is a benefit derived from the cone's contoured shape and position in the line.

Keywords – V-cone, Beta Edge Ratio, Flow meter, volumetric flow rate

I. Introduction

The key benefit to the V-Cone flow meter's unique design is its ability to provide repeatable accuracy of up to ±0.5% of rate under even the most difficult flow conditions. The V-Cone flow meter has been proven to be accurate over a wide range, from very low to extremely high Reynolds numbers. Whether measuring swirling fluids or low pressure flows, the V-Cone flow meter delivers the accuracy and reliability other devices only achieve under laboratory conditions. The V-Cone flow meter also has low head loss when compared to other DP technologies. V-Cone Flow meter is a technology that accurately measures flow over a wide range of Reynolds numbers, under all kinds of conditions and for a variety of fluids. The V-Cone's remarkable performance characteristics, however, are the result of its unique design. It features a centrally located cone inside the tube. The cone interacts with the fluid flow, reshaping the fluid's velocity profile and creating a region of lower pressure immediately downstream of itself. The pressure difference, exhibited between the static line pressure and the low pressure created downstream of the cone, can be measured via two pressure sensing taps. One tap is placed slightly upstream of the cone, the other is located in the downstream face of the cone itself. The pressure difference can then be incorporated into a derivation of the Bernoulli equation to determine the fluid flow rate. The cone's central position in the line optimizes the velocity profile of the flow at the point of measurement, assuring highly accurate, reliable flow measurement regardless of the condition of the flow upstream of the meter.

Szabo, J.L., Winarski, C.P., Hypnar, P.R. [1], as with the equivalent orifice meter the gas properties are shown to be the most significant sources of input error for the V-Cone meter. This paper demonstrates the requirement for online gas chromatography information for the case history service. Without corrections for compositional changes the case history V-Cone meter could incur a range of flow rate measurement errors of up to 18%. Weiguang Liu, Ying Xu, Tao Zhang, Fengfeng Qi [2], the experiment tested three types of cone flow meters, whose inner tube diameter is 100 mm and β values are 0.45 and 0.65, to verify the prediction accuracy. The experimental results also verified that cone flow meters with S type beta edges have the best mechanical processing consistency. V.K. Singh, T. John Tharakan [3], the computational fluid dynamic simulations for single- and multi-hole orifice meter over a wide range of Reynolds numbers were carried out. The pressure recovery pattern for these orifices were determined and used for the estimation of is charge coefficient. It is shown that pressure recovery for multi-hole orifice meters is larger than that of the single-hole orifice flow meter with an equivalent flow area. Sahand Pirouzpanah, Muhammet Çevik, Gerald L. Morrison [4] in a close coupled slotted orifice plate and swirl flow meter, due to the well-homogenized flow provided by the slotted plate, repeatable GVF measurements with high accuracy are achieved for the range of gas volume fractions from 60% to 95%. The response of the multiphase flow meter is found to be independent of temperature and liquid flow rate. The accuracy of the multiphase flow meter in GVF measurements was obtained to be 70.63%.

II. Theory of V-cone meter

A V-Cone is a type of differential pressure flow meter that uses the same idea as an orifice meter. The main difference is that instead of a hole in the center of the orifice plate, which the water flows through, the V-Cone occupies the center of the pipe forcing water to flow around it.

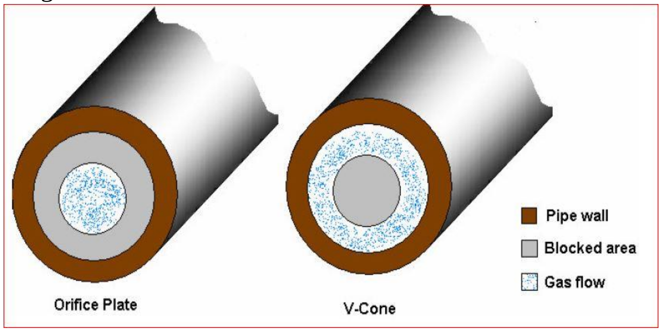


Fig.1.Basic Difference between Orifice Plate and V-cone [7]

The V-cone measures the pressures upstream and downstream. Since velocity and pressure are related (pressure is proportional to velocity squared), the velocity can be calculated from the difference upstream (P1) and downstream (P2) pressures. As the pressure difference increases so does the velocity (the velocity will increase much faster). Different size V-Cones will show a different pressure velocity relationship.

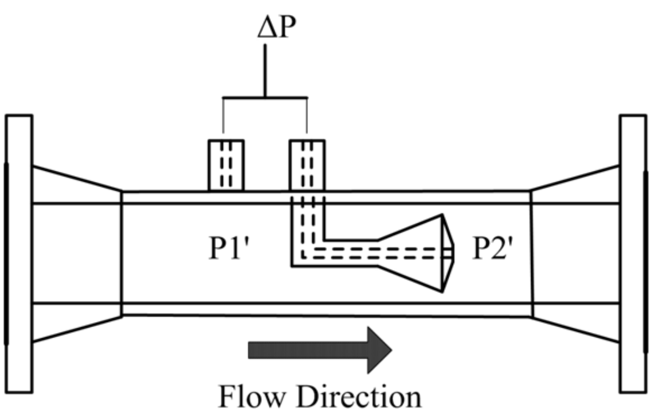


Fig.2. Schematic Diagram of V-cone [13]

The V-cone is shaped, as it is to get a more accurate velocity measurement by measuring the maximum velocity in the pipe. In a pipe where the flow has not been obstructed or disturbed, the flow will become "well-developed". During well-developed flow, the velocity at each point will be different. The velocity would be zero at the wall of the pipe, maximum at the center of the pipe and zero at the wall again. A velocity profile for water flowing in a pipe (Fig.3)

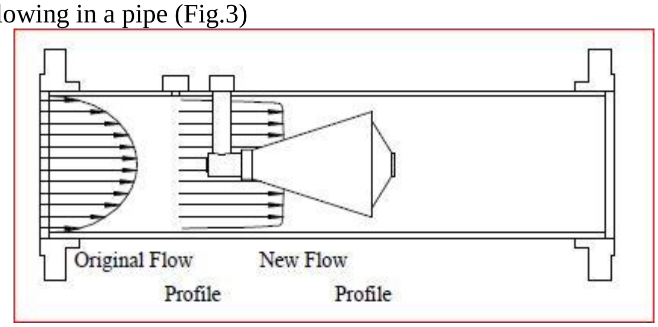


Fig.3 velocity profile for water flowing in a pipe [6]

This is due to friction at the pipe wall that slows down the fluid as it passes. Since the cone is suspended in the center of the pipe, it interacts directly with the high velocity region in two ways:

Most piping changes (pumps, tees, elbows, etc.) can disturb well-developed flow. A V-cone overcomes this by reshaping the velocity profile upstream of the cone by using its contoured shape. As the flow approaches the cone, the flow profile changes to become a well-developed profile. The pressure sensor is located in the center of the pipe to provide the highest velocity measurement.

III. Calculations of Volumetric Flow Rate at Flow Condition

Volumetric flow rate equation (eq.1) [7] is basic equation to calculate beta ratio of V-cone meter at flowing conditions.

$$q_v = N_{vp} x \frac{C.\beta_{fvcone}^2 .D^2}{\sqrt{1-\beta_{fvcone}^4}} x \frac{1}{\sqrt{F_p .\rho_f}} x\sqrt{\Delta P} \; \ldots..(1)$$

$N_{vp} = N\ factor\ fpr\ flowing\ volume\ with\ density\ determination$

$\beta_{fvcone} = Beta\ ratio\ for\ V-cone\ at\ flowing\ conditiond$ in mm

$D = Internal\ pipe\ diameter\ \ at\ flowing\ conditions\ in\ mm$

$C = Meter\ constant$

$F_p = Correction\ for\ liquid\ compressibility$

$\rho_f = Density\ of\ fluid\ at\ flowing\ conditions\ in\ kg/m^3$

$\Delta P = Differential\ pressure\ (DP)\ in\ KPa$

$q_v = Volumeteric\ flow\ rate\ at\ flowing\ conditions\ in\ m^3/hr$

Dimensions of pipe from which fluid is flowing change with flowing conditions. Dimensions of pipes are affected by temperature specially (eq.2).

$D = \left[1 + \ \alpha_p\ (T-20)\right] D_i \ldots..(2)$

$D_i = ID\ of\ pipe\ at\ STP\ in\ mm$

$T = Temperature\ of\ fluid\ in$ ℃

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.

For orifice and venturi meter

$\beta = \frac{d}{D} \ldots\ldots..(3)$

For V-cone meter

$\beta = \frac{d_e}{D} = \beta_{fvcone} = \frac{\sqrt{D^2 - d_{fvcone}^2}}{D} \ldots.(4)$

$\beta = Beta\ ratio\ for\ flow\ mere\ (any)$

$d = Max.diameter\ of\ flow\ merer$

$d_e = Equivalent\ diameter\ of\ v-cone\ meter$

$d_{fvcone} = Max.diameter\ of\ v-cone\ meter$

To summarize V-cone meter, finding out its characteristic for specific application.

Fluid = Water

Pipe = 100 NB
D_i = 102.26 mm
Beta ratio = 0.76
Operating temp. = 27-35 °C
Density at op. temp. = 996 kg/m^3

IV. Experimental Set Up

Experimental set up is compulsory in every differential pressure flow meter to calculate flow meter constant. Because every V-cone meter may have different flow meter constant (C_d). Some parameters are captured from experimental set up with help of various instruments.

Table I
Instruments to monitor parameters

No.	Parameters	Instruments	Unit
1	Inlet Pressure	Pressure Gauge	Bar
2	Temperature	Thermocouple	Degree Celsius
3	Differential pressure	Digital DP	Pascal
4	Time	Digital timer	Second
5	Mass of water	Digital Mass meter	Kilogram

A. Process for Experiments

1. Install V-cone in pipe line with all instruments.
2. Start water flow with 1.44 bar pressure. After 1 minute, flow will get steady.
3. Start timer and digital weight machine.
4. After some time (approximately 30-40 seconds) stop water flow.
5. Digital display shows all monitored parameters, like Temperature, mass of water, time, inlet pressure, differential pressure.

B. Calculation for flow rate

1. Calculation of actual flow rate (Q_a)

$$Q_a = \frac{M*3600}{\rho * t} \quad ....(5)$$

Q_a is in m^3/hr
M= Mass of water flow through pipe , Kg
t= time, second

2. Calculation of theoretical flow (Q_t)

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

A= Area through which water is flowing, m^2

3. V-cone flow meter constant (C_d)

$$C_d = \frac{Q_a}{Q_t} \quad ....(7)$$

V. Result

By comparing theoretical calculation and experimental results, we conclude that V-cone meter design is correct. Flow meter constant is between 0.88 to 0.84 (Table 2). We get almost same differential pressure value for same flow rate (Table 3). Error is 2 to 7 %.

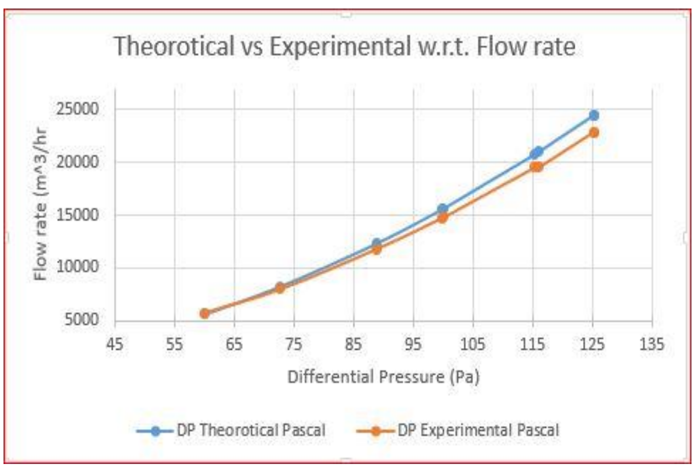
Table II
Experimental Reading of V-cone

Mass of Water	Time	DP	Actual Flow	Theoretical Flow	Flow meter Constant
Kg	Sec	Pascal	m^3/hr	m^3/hr	
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	44.3	7994.	72.55	83.78	0.866

	73	27			
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

Table III
Comparison of Theoretical DP and Experimental DP for same flow rate

Flow Rate	**Differential Pressure**		**% Error**
	Theoretical	**Experimental**	
m3/hr	Pascal	Pascal	
125.31	24518.33	22905.96	7.04
125.24	24490.95	22923.35	6.83
125.19	24471.39	22907.5	6.82
116.03	21021.32	19577.8	7.37
115.33	20768.45	19531.44	6.33
100.09	15642.13	14816.81	5.57
99.76	15539.33	14737.11	5.44
88.73	12293.07	11781.9	4.33
72.74	8261.65	8014.66	3.08
60.1	5639.86	5773.22	-2.30



GRAPH 1. THEORETICAL DP AND EXPERIMENTAL DP W.R.T FLOW RATE

From results, Flow meter constant is vary from 0.883 to 0.844. It must be constant up to 2 digits (e.g. 0.87 or 0.85) for specific V-cone. It is future scope that find out error and constant flow meter constant.

VI. CONCLUSIONS

1. V-cone meter shows good results for measuring gas and two phase fluid flow and also for measuring water flow.
2. Theoretical differential pressure and experimental differential pressure (DP) are matching farely well, some error (2-7%) is due to frictional losses and measuring instruments error.
3. For V-cone meter, flow meter constant (Cd) for is constant and within range (0.77 to 0.88).

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