IOSR Journal of Mechanical & Civil Engineering (IOSRJMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X
PP 32-36
www.iosrjournals.org

Design of V-cone Meter to Measure Water Flow

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***Abstract** : V-cone meter shows good performance than other differential pressure flow meters (like orifice meter, venturi meter). The measurement of flow rate is important in many industrial applications including rocket propellant. V-cone flow meter has varies advantages over conventional flow meter. Flow characteristics of v-cone flow meters are determined both numerically and experimentally over a wide range of Reynolds numbers. 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. As the flow approaches the cone, the flow profile "flattens" toward the shape of a well-developed profile.*

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

I. INTRODUCTION

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. It operates on the same physical principle as other differential pressure-type flowmeters, using the theorem of conservation of energy in fluid flow through a pipe. 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.

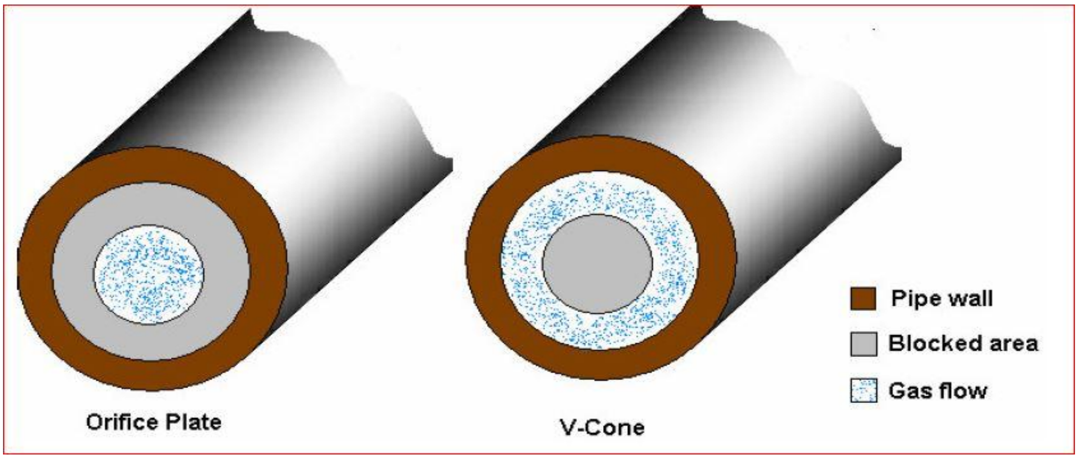

Fig.1.Basic Difference between Orifice Plate and V-cone [8]

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.

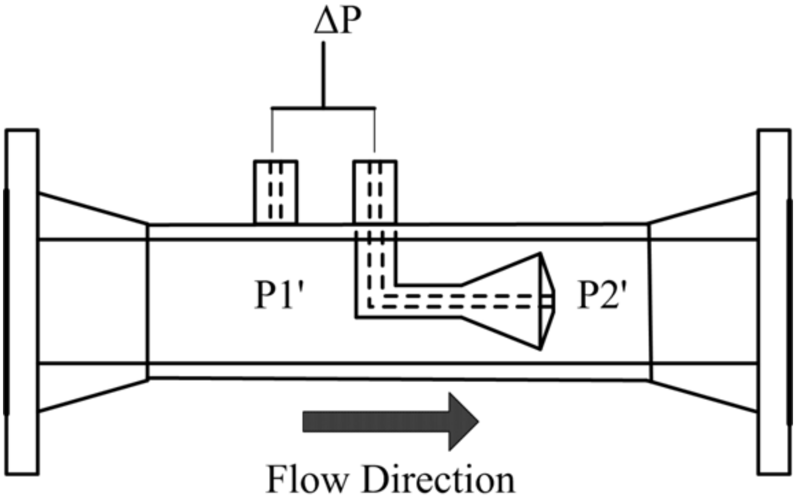

Fig.2. Schematic Diagram of V-cone [13]

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)

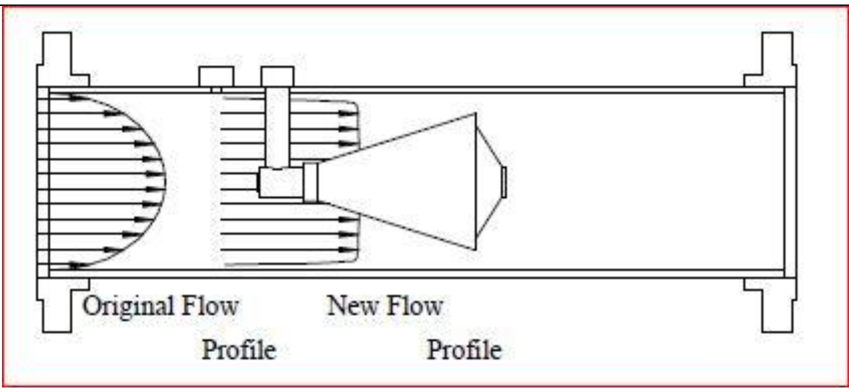

Fig.3 velocity profile for water flowing in a pipe [6]

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) [8] is basic equation to calculate beta ratio of V-cone meter at flowing conditions.

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

$N_{vp} = N\ factor\ fpr\ flowing\ volume\ with\ density\ determination$
$\beta_{fvcone} = Beta\ ratio\ for\ V-cone\ at\ flowing\ conditiond$ in mm
$D = Internal\ pipe\ diameter\ \ at\ flowing\ conditions\ in\ mm$
$C = Meter\ constant$
$F_p = Correction\ for\ liquid\ compresibility$
$\rho_f = Density\ of\ fluid\ at\ flowing\ conditions\ in\ kg/m^3$
$\Delta P = Differential\ pressure\ in\ KPa$
$q_v = Volumeteric\ flow\ rate\ at\ flowing\ conditions\ in\ m^3/hr$
Dimensions of pipe from which fluid is flowing change with flowing conditions. Dimensions of pipes are affected by temperature specially (eq.2).

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

$\alpha_p = Coeficient\ of\ thermal\ expantion$
$D_i = ID\ of\ pipe\ at\ STP\ in\ mm$
$T = Temperature\ of\ fuid\ in\ {}^\circ C$
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, let's finding out its characteristic for specific application.
Fluid = Water
Pipe = 100NB
D_i = 102.6 mm
Max. Flow rate = 100 m^3/hr
Beta ratio = 0.45, 0.55, 0.65, 0.75, 0.85
Operating temp. = 50□ C
Max. Operating pressure = 20.5 kg/cm^2
Viscosity at operating temp. = 0.6134 cp
Density at op. temp. = 991 kg/m^3

IV. RESULT

From given data and with the help of basic equations (eq. 1 to eq. 4), we get differential pressure (DP) and maximum diameter of v-cone meter for different beta ratio (β). Differential pressure range is 0.474 KPa to 5.756 KPa, which is very wide. Maximum diameter range is 54.06 mm to 91.65 mm.

Table 1

Sr. No.	Beta Ratio (β)	Differential Pressure (△P) (KPa)	Max. Dia. Of Vcone (D) (mm)
1	0.45	5.756	91.65
2	0.55	2.44	85.72
3	0.65	1.1327	77.99
4	0.75	0.53	67.88
5	0.85	0.474	54.06

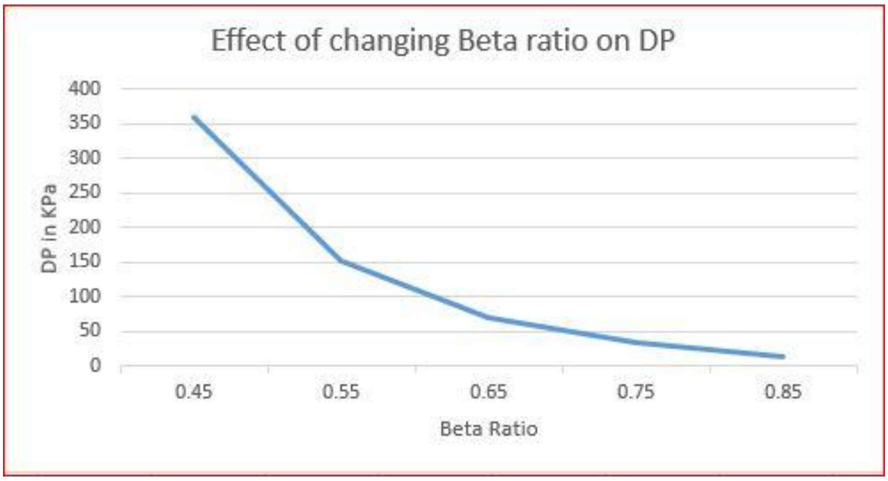

Fig.4 velocity profile for water flowing in a pipe

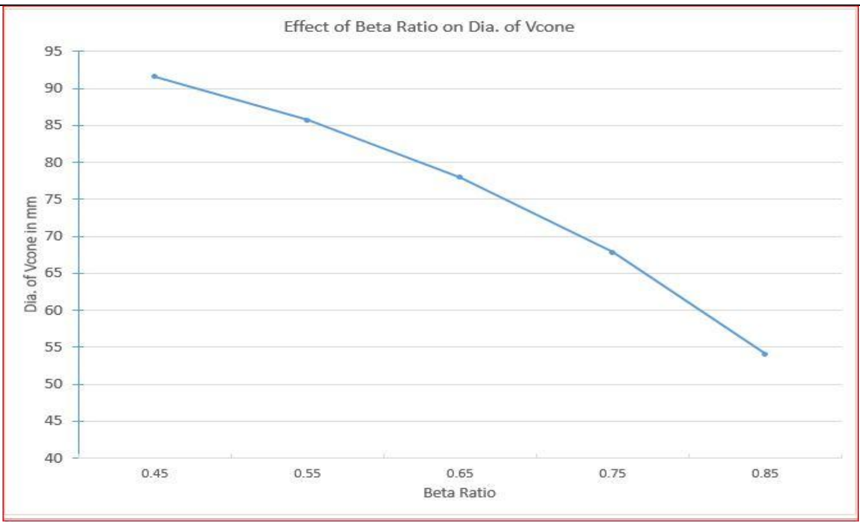

Fig.5 velocity profile for water flowing in a pipe

V. CONCLUSION

As change in beta ratio, we get drastic change in differential pressure value. As beta ratio increase, differential pressure value decrease. ($\beta \propto \Delta P$). More DP gives less least count, which gives more accuracy. Small change in flow gives max. deflection in DP. It means 0.45 beta ratio is best for measuring small change in flow if we consider only differential pressure value. If water column is used for measure DP then big water column is require (5.757 KPa for 0.45 beta ratio). i.e. 0.45 is not optimized beta ratio, because we did not consider pressure loss, costing, accuracy etc. factors. Finding optimized beta ratio by considering other factors is future scope for is research work.

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