A REVIEW OF THE V-CONE METER FOR NATURAL GAS FLOWS

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ABSTRACT

Flow rate measurement accuracy of the V-Cone meter is evaluated for a typical low pressure - high volume natural gas installation. Using information provided by the manufacturer of the V-Cone meter a case history flow rate calculation is numerically perturbed for expected errors in input information. This meter is relatively new to the natural gas market and this independent review of the product literature will benefit future users.

The flow rate equations used for the V-Cone meter are compared with those defined by accepted standards for use with the square-edged orifice meter. Through comparing these equations, for a specific test installation, the V-Cone has been shown to have the same characteristics and sensitivities to errors in measured input values (gas composition, temperature, pressure, and differential pressure) as the orifice meter.

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%.

To demonstrate the 10:1 turndown ratio claimed by the meter manufacturer for the test installation Southern California Edison has requested a certified air calibration with each V-Cone meter. The calibration from the first V-Cone meter is reviewed in relation to an equivalently sized orifice meter.

Over the Reynolds number range of interest for the test installation ($5*10^5 < Re < 5*10^6$) the V-Cone meter has been calibrated on air and the discharge coefficient has been shown to vary from 0.8002 to 0.8094 ($\pm$0.57%).

INTRODUCTION

Southern California Edison (SCE), in a proactive response to upcoming changes in the pollution monitoring requirements of the South Coast Air Quality Management District (SCAQMD) has undertaken a review of alternate natural gas flow rate measurement techniques for their steam power generating stations located in the Los Angeles basin. ABB Impell Corporation and Novacorp International Consulting Incorporated formed a joint venture combining electrical power utility and natural gas expertise to assist SCE in this project.

Each of the SCE installations to be affected (see Table 1) was reviewed, through on-site inspection of existing flow conditions and measurement equipment, with the intention of retrofitting newer, more accurate, natural gas flow rate measurement methods. All of the installations examined for this project currently use orifice meter runs to measure the natural gas consumption for the combustion control systems of the boilers.

This paper will present the combinations of required attributes (ie. Increased turndown, low noise sensitivity, and single run capability) that has lead SCE to test a relatively new flow rate measurement instrument, the V-Cone meter, as a replacement for the existing orifice meters. Though the authors of this paper can not introduce independent experimental validation of the performance of the V-Cone meter a case study review, comparing the applicable flow formulas of the V-Cone and orifice meter, is presented along with the calibration results of this case study V-Cone meter.

REQUIRED ATTRIBUTES

A brief description of the flow conditions at the SCE installations reveals the requirement to test such a new meter for this application.

Through contractual commitments, SCE receives natural gas at fixed regulated pressures at the facilities listed (see Table 1). This requires the use of large diameter relatively low pressure piping.

Turndown Ratio

Before evaluating any alternative metering solutions a determination of what operating range will be needed is required. This concept is termed the turndown ratio and is defined as the ratio of the maximum to the minimum actual flow rate the meter can measure with some defined accuracy level. The turndown ratios given in Table 1 are listed for power generation not for fuel consumption. With the lower power generation efficiency at the lower power generation levels these turndown ratios would

Table 1
SCE Steam Generation Power Plants in the SCAQMD District

Station	Power Range Units	Turndown (MWe)	Max Fuel Flow (SCFH/unit)	Meter Run OD (in)	Meter Run Press. (Psig
Alamitos					
1&2	175 - 10	17.5 : 1	1,629,950 (1)	30	62
3&4	320 - 20	16.0 : 1	2,980,480 (1)	30	62
5&6	480 - 30	16.0 : 1	4,601,270	30	72
Huntington					
1&2	215 - 20	10.7 : 1	2,400,000	30	34
3	215 - 90	2.4 : 1	2,002,510 (1)	20	75
4	225 - 20	11.2 : 1	2,095,650 (1)	20	75
Etiwanda					
1&2	132 - 10	13.2 : 1	1,229,448 (1)	12	40
3&4	320 - 20	16.0 : 1	2,980,480 (2)	20 (3)	75
High Grove					
1&2	33 - 7	4.7 : 1	431,400	12.75	17
3&4	45 - 7	6.4 : 1	544,298	14	17
San Bernardino					
1&2	67 - 7	9.6 : 1	624,038 (1)	12	20
Redondo Beach					
5&6	175 - 10	17.5 : 1	1,629,950 (1)	14	28
7&8	510 - 160	3.2 : 1	4,750,140 (1)	30	70
El Segundo					
1&2	175 - 8	21.9 : 1	1,629,950 (1)	18	28
3&4	335 - 20	16.7 : 1	3,120,190 (1)	20 (3)	75

(1) Gas flow values are approximated for units where no data was available based on 9,314 SCFH/Net MWe
(Flows not annotated are taken from plant logs or design manuals)
(2) Actual measured value at 317 MWe of 2,965,000 SCFH
(3) Dual orifice runs per unit

provide overly conservative design criteria for fuel metering. SCE chose a turndown ratio of 10:1 with an accuracy of better than ±0.75% as an appropriate metering selection criterion for this evaluation of measurement methods.

The existing installations have the typical 3:1 flow turndown ration of a single orifice meter run. The common solution to increase this turndown ratio, multiple orifice meter runs, is not a viable solution for this application. At many of these SCE sites space for additional piping is extremely limited and the weight of the automated switching valves would require extensive structural modifications. SCE control engineers are also concerned that the flow instabilities which occur during run switching would have a detrimental impact on the stability of the combustion control systems.

Installation Effects

The influences on measurement accuracy of elbow or valve-induced asymmetric velocity profiles, flow swirl induced by multiple elbows, instrumentation gauge line resonance, and flow pulsations generated by valves or resonant side branches, are grouped together under the title “installation effects”.

Multiple Elbows

At each of these SCE sites there are multiple 90 degree elbows in various planes upstream of each of the existing orifice meters, and no straightening vanes to remove the swirl these elbows would introduce. However, there is sufficient length of straight pipe upstream and downstream of each orifice meter to comply with code requirements.

Flow Noise

At each of these SCE sites, the control of the amount of natural gas to enter the burners is regulated just downstream of the orifice meter runs. The flow of gas through these control valves does create noise. To limit this radiated noise some SCE installations have placed these valves within sound dampening enclosures and coated the gas lines with sound absorbing material.

Since this level of noise abatement is needed, flow pulsations within the line must be considered a possible threat to accurate flow rate measurements.

Other Impacts of Measurement Upgrade

Any upgrade to measurement of the natural gas flow would affect other systems at the SCE plants. In order to optimize the use of these resources the combustion control systems and plant efficiency monitoring systems would need to be integrated with any new fuel measurement system.

This combinations of required attributes; increased turndown, low noise sensitivity, and single run capability, has lead us to recommend testing a relatively new flow rate measurement instrument, the V-Cone meter. For this application, where the legal transfer of natural gas is not the purpose of the measurement, the fact that the V-Cone meter is not yet a certified custody transfer standard does not need to come into the instrument selection process. V-Cone meters can be installed into the existing orifice meter runs and be used to provide flow rate measurements to the combustion control system, plant efficiency monitoring system, and meet the SCAQMD monitoring requirements.

The V-Cone Meter

The V-Cone meter, produced by McCrometer, is being marketed as a new differential pressure flow meter. The manufacturer claims this meter has a number of advantages over conventional measurement methods [1]:

- accuracy of better than 0.5% of rate,
- single run flow rate turndown ratio of up 30 to 1,
- cone specifically designed to dampen the amplitude of oscillation of the measured pressure field,
- no moving parts,
- contoured shape of the cone directs flow away from the critical edge with a resultant decrease in wear,
- very short installation runs required (two diameters upstream and five diameters downstream) with no flow conditioning requirements.

This improved performance is attributed to positioning the contoured shape of the cone in the center of the "high velocity core flow"[1]. The manufacturer claims that positioning the V-Cone in this manner reshapes the velocity profile upstream of the differential pressure sensing points (see Figure 1) stabilizing the readings over a much broader flow range than typical dP meters.

The flow rate through the meter is calculated from a measurement of the differential pressure between the sidewall of the unobstructed pipe and the stagnation pressure on the downstream side of the cone.

SCE requested a calibration certificate, from an independent laboratory with a primary standard air facility (eg. Colorado Engineering Experimental Station, Inc. CEESI[2]), be provided with each meter. This certification is to confirm that the single run V-Cone meter does provide the required turndown ratio of 10:1 with accuracies of at least ±0.75%.

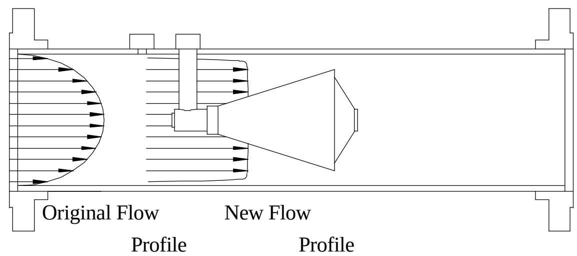

Figure 1 V-Cone Meter

V-Cone Sizing Calculations

The following calculations are required to estimate the flow rate through a given V-Cone meter and have been provided by McCrometer.

To calculate flow rate for the V-Cone Flow Meter:

$$Q = \frac{x}{4} \bullet \left[\frac{2g_c}{p}\right]^{1/2} \bullet D^2 \bullet \left[\frac{b\vee^2}{1 - b\vee^4}\right] \bullet \Delta P^{1/2} \bullet CD$$

To modify for steam or gas flow: $R = 1 - \Delta P/P$

$$Y = \left[\frac{\left(1 - b\vee^4\right) \bullet \left(k / \left(k-1\right)\right) \bullet R^{2/k} \bullet \left(1 - R^{\left(\left(k-1\right)/k\right)}\right)}{\left(1 - \left(b\vee^4 \bullet R^{2/k}\right)\right) \bullet \left(1 - R\right)}\right]^{1/2}$$

$$q^1 = Q \bullet Y \bullet \left[35.374 \bullet \frac{Zb}{Zf} \bullet \frac{\left(P / 144\right)}{T} \bullet 60\right]$$

To calculate beta ratio $(b\vee)$ and cone diameter:

$$b\vee = \frac{\left(D^2 - d^2\right)^{1/2}}{D} \qquad d = D \bullet (1 - \beta\nu^2)^{1/2}$$

To calculate linear velocity and Reynolds number:

$$V = \frac{Q}{x \bullet D^2 / 4} \qquad \mathrm{Re} = V \bullet D / m$$

where:

- Q = the incompressible flow rate (ACFS).
- q^1 = the flow rate of gas (SCFM).
- g_c = gravitational constant (ft/s^2).
- ρ = the density of the gas (lb/ft^3).
- D = the inside diameter of the meter (ft).
- d = outside diameter of the cone (ft).
- β_v = the beta ratio of the V-Cone meter.
- ΔP = is the differential pressure across the V-Cone (PSF).
- P = the line pressure (PSF absolute).
- CD = is the meter's discharge coefficient.
- k = the isentropic exponent of the fluid.
- Y = the derived expansion factor.
- V = the linear velocity (ft/s).
- Re = the Reynolds number.
- μ = the fluid viscosity (ft^2/s).
- T = the fluid temperature in (degrees Rankine).
- Zb = the gas compressibility factor at base conditions.
- Zf = the gas compressibility factor at flowing conditions.

$$\mathrm{CD} = 1 - \left[1 - \frac{1}{(\mathrm{D}+1)}\right] b_v + \left[2.5 - \frac{6.45}{(\mathrm{D}+2.5)}\right] b_v^{\,2} - \left(2.15 - \frac{9.108}{(\mathrm{D}+4.7)}\right) b_v^{\,3}$$

where:

D = the meter inside diameter (in).

The accuracy of this estimator depends on haw extreme the beta ratio and line sizes are (highest confidence are 0.4 <βν<0.85 and 1" < D < 16"). A rough figure would be estimated as ± 2% to ± 5% of actual CD.

The manufacturer states that these equations can be used to describe the performance of a V-Cone meter provided the pipe Reynolds number is greater than $8*10^3$ and the derived expansion factor (Y) is greater than 0.96. Note that the discharge coefficient (CD) is independent of Reynolds number or gas properties and is defined on the basis of geometry only.

These V-Cone equations can be reformulated so that the mass flow rate through the meter can be calculated using the typical units (3) defined below;

$$q_{mv} = \frac{x}{4} \mathrm{CD} \left[\frac{b_v^{\,2}}{1 - b_v^{\,4}}\right] \mathrm{Y} \mathrm{D}^2 \left[2 g_c r_{t,} \; r \Delta \mathrm{P}\right]^{1/2}$$

$$= N_1 CD \left[\frac{b_u^{\,2}}{1 - b_u^{\,4}}\right] Y D^2 \left[r_{t,} \; r \Delta \mathrm{P}\right]^{1/2}$$

<u>Orifice Flow Rate Equations</u>

In this paper the V-Cone formulas given above will be compared to the Concentric, Square-Edged Orifice Meter equations [3];

$$q_{mo} = \frac{x}{4} C_d E_v Y_1 d^2 \left[2 g_c r_t r \Delta \mathrm{P}\right]^{1/2}$$

$$= N_1 C_d E_v Y_1 d^2 \left[r_{t,} \; r \Delta \mathrm{P}\right]^{1/2}$$

where for a flange tapped orifice with the static pressure measured on the upstream tap:

$$E_v = 1 / \left(1 - b^4\right)^{1/2} \qquad \beta = d/D$$

$$Y_1 = 1 - \left(0.41 + 0.35 b^4\right) \frac{\Delta \mathrm{P}}{k N_3 P}$$

$$C_d = C_i + 0.000511 \left[\frac{10^6 b}{\mathrm{Re}_D}\right]^{0.7} + \left(0.0210 + 0.0049 A\right) b^4 C$$

$$C_i = C_i\left(CT\right) + Upstm + Dnstm$$

$$C_i\left(CT\right) = 0.5961 + 0.0291 b^2 - 0.0291 b^8 + 0.003\left(1 - b\right) M_1$$

$$Upstrm = \left[0.0433 + 0.0712 e^{-8.5 L_1} - 0.1145 e^{-6.0 L_1}\right]\left(1 - 0.23 A\right) B$$

$$Dnstm = -0.0116\left[M_2 - 0.52 M_2^{\,1.3}\right] b^{1.1} \left(1 - 0.14 A\right)$$

$$B = b^4 / \left(1 - b^4\right)$$

$$M_1 = \max\left(2.8 - D / N_4, 0.0\right) \quad M_2 = 2 L_2 / \left(1 - b\right)$$

$$L_1 = L_2 = N_4 / D$$

$$A = \left[\frac{19{,}000 b}{\mathrm{Re}_D}\right]^{0.8} \qquad C = \left[\frac{10^6 b}{\mathrm{Re}_D}\right]^{0.35}$$

$$\mathrm{Re}_D = \frac{N_2 q_m}{m D}$$

These orifice equations can be used for; 0.1<β<0.75, and $4*10^3 < \mathrm{Re}_D < 3.6*10^7$, provided the ratio of absolute pressures (downstream over upstream tap) is greater than 0.8.

Typical combine numerical and unit conversion constants for these equations are [3]:

	U.S. Units	IP Units	SI Units
g_c	32.1740 [lbm-ft/lb.f.-s^2]	32.1740 [lbm-ft/lbf-s^2]	1.0 [kg m/N s^2]
d,D	Inches	Feet	Meters
P	psia	lbf/ft^2	Pa
ΔP	in H_2O (60°F)	lbf/ft^2	Pa
q_m	lbm/s	lbm/s	kg/s
μ	Poise	lbm/ft-s	kg/m s
ρ	lbm/ft^3	lbm/ft^3	kg/m^3
N_1	0.0997424	6.30025	1.11072
N_2	227.375	1.27324	1.27324
N_3	27.7070	1.0	1.0
N_4	1.0	1.0	0.0254

Case Study Meter

At the Alamitos site (see Table1) Units 5&6 share an isolated custody transfer metering station. SCE has chosen this site for the test installation so the inservice flow rate measurements of the V-Cone meter can be compared to the values measured at the multiple run utility company meter station.

McCrometer was provided with the site information and have sized a V-Cone meter with an internal diameter of 29.376 [in] and a cone diameter of 27.160 [in] with a guaranteed 10:1 turndown ratio for this application. This sizing results in a V-Cone beta ratio (β_v) of .0381 and an estimated discharge coefficient (CD) of 0.8606.

Given a natural has composition typical of that provide to this site by SoCal Natural Gas Company (see Table 2), the regulated supply pressure of 72 psig, and an operating temperature of 60°F, a flow of 4.75 MMSCFH would result in a pipe Reynolds number of $4.3*10^6$ and produce an estimated differential pressure of 117.61 inches water column at this V-Cone Meter.

An orifice meter sized to produce the same differential pressure under the same flow conditions would have a bore of 13.318 [in] for this same internal diameter of 29.376 [in].

As can be seen in Figure 2 the flow equations for the V-Cone and Orifice meters demonstrate their common heritage, the Bernoulli equation, by having precisely the same pressure drop versus Reynolds Number characteristics.

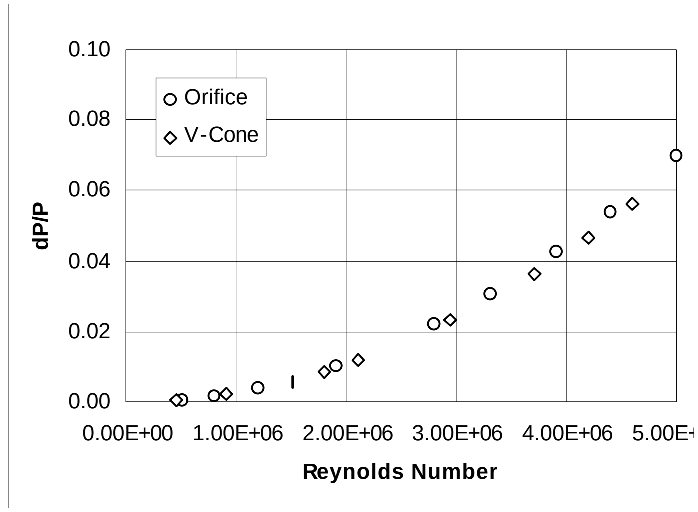

Figure 2
V-Cone versus Orifice meter Performance

V-Cone Computation = Error Sensitivity

In each of the computations of this section the maximum flow rate describing for the Case Study Meter is perturbed by the expected level of measurement accuracy to demonstrate error sensitivity. Note that since most of these errors are related to percentage of full transducer span the percentage error would be proportionally higher at lower flow rates.

This is not an uncertainty analysis for the metering installation but rather an investigation into the sensitivity of the governing flow rate equation to errors in the various measured inputs. Without access to the experimental data used to develop the flow equations or a clear statement of the uncertainties in the empirically derived discharge coefficient the authors are unable to make any definite statement of the overall measurement uncertainty involved with a V-Cone meter installation.

Range of Gas Composition

Many of the power stations owned and operated by SCE have more than one natural gas pipeline servicing the site. In addition, the utility companies SCE buys natural gas from are supplied by various sources depending on current market commitments. Natural gas chemical compositions typical of the various sources SCE uses are given in Table 2.

The physical properties for these various gas compositions have been calculated using the BWRS equation of state. These calculated properties have then been used to calculate the expected flow rate through both the V-Cone and the orifice meters for the conditions described above.

It is apparent that the V-Cone meter demonstrates the same flow rate measurement sensitivity to gas composition as the orifice meter. As such, online gas chromatography will be used to provide updated information of the composition of the natural gas to the V-Cone meter flow computer. This

Table 2
Various Natural Gas Compositions Supplied to SCE

	Typical Alberta	Triton Natural	SoCal Natural	Kelt Natural	Mobil Off
Methane	96.18%	66.30%	91.51%	84.05%	61.57%
Ethane	1.95%	1.49%	3.51%	2.20%	17.49%
Propane	0.33%	0.75%	0.79%	1.39%	3.59%
i-Butane	0.07%	0.21%	0.07%	0.18%	1.59%
n-Butane	0.07%	0.35%	0.17%	0.54%	2.86%
i-Pentane	0.02%	0.14%	0.05%	0.26%	1.03%
n-Pentane	0.03%	0.09%	0.00%	0.24%	6.14%
Nitrogen	0.38%	15.00%	3.27%	0.95%	4.21%
CO_2	0.91%	15.26%	0.51%	9.24%	1.02%
At 14.696 (psia) and 59°F					
ρ_b (lbm/ft^3)	0.044408	0.060387	0.046035	0.052585	0.069291
Z_b	0.99776	0.99766	0.99771	0.99740	0.99454
At 86.7 (psia) and 60°F					
ρ(lbm/ft^3)	0.26437	0.35967	0.27411	0.31361	0.41938
Z	0.98688	0.98629	0.98663	0.98475	0.96756
ν (lb/ft s)	7.2587e-6	8.5202e-6	7.3695e-6	7.5530e-6	6.7368e-6
k	1.3060	1.3092	1.3027	1.2949	1.2029
V-Cone Flow = 29.376”ID, 27.16”d, 60°F, 86.7 psia, 117.61 in H_2O dP					
Q(MMSCFH)	4.836	4.149	4.750	4.447	3.894
Deviation (%)	+1.81	-12.65	0.0	-6.38	-18.02
V-Cone Flow = 29.376”ID, 13.313”d, 60°F, 86.7 psia, 117.61 in H_2O dP					
Q(MMSCFH)	4.836	4.149	4.750	4.448	3.898
Deviation (%)	+1.80	-12.65	0.0	-6.36	-17.94

automated procedure is needed in order to achieve the required level of measurement accuracy and the expected once per minute communication of natural gas flow rate to the offices of the SCAQMD.

Sensitivity to Measured Temperature

Typically, temperature measurements made in field applications are assumed to have an accuracy of approximately ±1%. To a some extent this error stems from the need to use thermowells. The thermal conductivity of the wells connects the temperature being sensed by the transmitter to that of the outside pipe temperature.

Assuming that a one percent error of calibrated span is possible and that a 110°F span is used then a temperature measurement of 60.0°F could be an actual temperature of anything between 59.0°F and 61.0°F (see Table 3). This range of temperatures has an impact on the physical properties of the natural gas being measured.

Summarizing these results, a ±1% error in temperature measurement may result in a ±0.10% error in the flow rate calculated from both the V-Cone and orifice flow meters.

Table 3
Variations in Flow Temperatures

T (°F)	59.0	60.0	61.0
SoCal Natural Gas at 86.7 psia			
ρ(lbm/ft^3)	0.27466	0.27411	0.27356
Z	0.98655	0.98663	0.98672
ν(lb/ft s)	7.37e-6	7.37e-6	7.37e-6
k	1.3030	1.3027	1.3023
V-Cone Flow = 29.376”ID, 27.16”d, 86.7 psia, 117.61 in H_2O dP			
Q(MMSCFH)	4.755	4.750	4.745
Deviation (%)	+0.10	0.00	-0.10
Orifice Flow = 29.376”ID, 13.313”d, 86.7 psia, 117.61 in H_2O dP			
Q(MMSCFH)	4.755	4.750	4.745
Deviation (%)	+0.10	0.00	-0.10

Sensitivity to Measured Static Pressure

The class of static pressure transducers recommended for this application [4] can be special ordered to have an application accuracy of ±0.1% of calibrated span (see Table 4).

Assuming a ±0.1 percent error of a 100 psia calibration span, a measured pressure of 86.7 psia could be from an actual pressure anywhere between 86.6 and 86.8 psia. This pressure range also has an impact on the values of the gas properties.

Table 4
Variations in Static Pressure

P (psia)	86.6	86.7	86.8
SoCal Natural Gas at 60°F			
ρ(lbm/ft^3)	0.26437	0.27411	0.27443
Z	0.98688	0.98663	0.98662
v(lb/ft s)	7.37e-6	7.37e-6	7.37e-6
k	1.3027	1.3027	1.3027
V-Cone Flow = 29.376”ID, 27.16”d, 60°F, 117.61 in H_2O dP			
Q(MMSCFH)	4.747	4.750	4.753
Deviation (%)	-0.06	0.0	+0.06
Orifice Flow = 29.376”ID, 13.313”d, 60°F, 117.61 in H_2O dP			
Q(MMSCFH)	4.747	4.750	4.753
Deviation (%)	-0.06	0.0	+0.06

Summarizing these results a ±0.1% error in static pressure measurement may result in a ±0.06% error in the flow rate calculated from both the V-Cone and orifice flow meters.

Sensitivity to Measured Differential Pressure

The class of differential pressure transducers recommended for this application [5] can have a field application accuracy of approximately ±0.1% of calibrated span.

Assuming a ±0.1 percent error of a 120 inch water column calibration span, a measured differential pressure reading of 117.61 inches water column could result from an actual differential pressure anywhere between 117.49 and 117.73 inches water column. The differential pressure across the meter has no impact on the values of the gas properties required (see Table 5).

Summarizing these results, a ±0.1% error in differential pressure measurement may result in a ±0.4% error in the flow rate calculated from the V-Cone meter, virtually the same sensitivity of the orifice meter.

Table 5
Variations in Differential Pressure

ΔP (in H_2O)	117.49	117.61	117.73
V-Cone Flow = 29.376”ID, 27.16”d, 60°F, 86.7 psia			
Q(MMSCFH)	4.748	4.750	4.752
Deviation (%)	-0.04	0.0	+0.04
V-Cone Flow = 29.376”ID, 13.313”d, 60°F, 86.7 psia			
Q(MMSCFH)	4.748	4.750	4.753
Deviation (%)	-0.04	0.0	+0.06

Initial Calibration Results

Calibration measurements using reference sonic nozzles were performed on the test installation V-Cone meter at the facilities of the Colorado Engineering Experimental Station, Inc. (CEESI) [2] in February of 1992.

Figure 3 shows the measured value of the V-Cone discharge coefficient during these calibrations. For pipe Reynolds numbers form 4.538*10^6 to 2.083*10^6 the static line pressure upstream of the

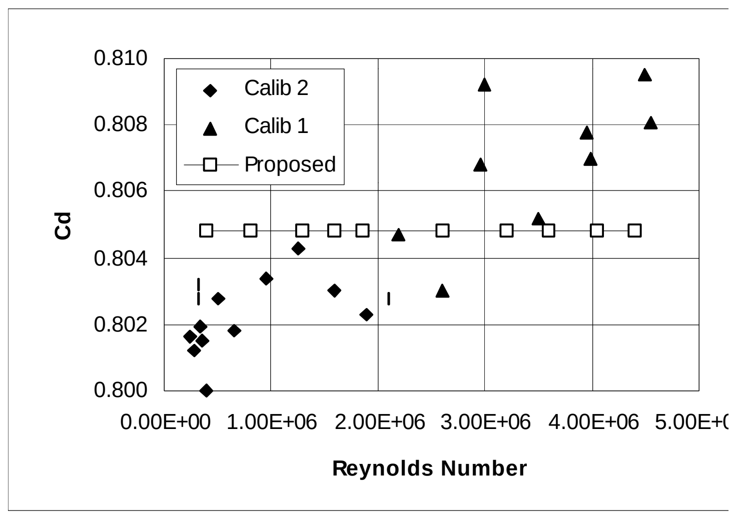

Figure 3
CD vs Re Calibration for the V-Cone Meter

V-Cone meter was held relatively constant at 80 ±2 psia (Calib 1). To expedite the calibration, for pipe Reynolds numbers from 2.083*10^6 to 2.886*10^5 the static line pressure upstream of the V-Cone meter was allowed to drop (Calib 2). Superimposed on this data is the constant value of discharge coefficient McCrometer is recommending SCE use for this V-Cone meter.

This mean value of measured discharge coefficient (CD=0.80476, Proposed) indicates that the discharge coefficient estimating formula is 6.9% high at these large line sizes (CD=0.8606, Estimated).

Over this same Reynolds number range the discharge coefficient calculated for the comparable orifice meter (see Figure 2) varied from 0.6019 to 0.6025.

The consequence of changing the calibration methodology in the middle of the tests is shown in Figure 4. The differential pressures measured at the V-Cone during the calibrations have been non-dimensionalized (dividing them by the value of the absolute static pressure upstream of the meter)

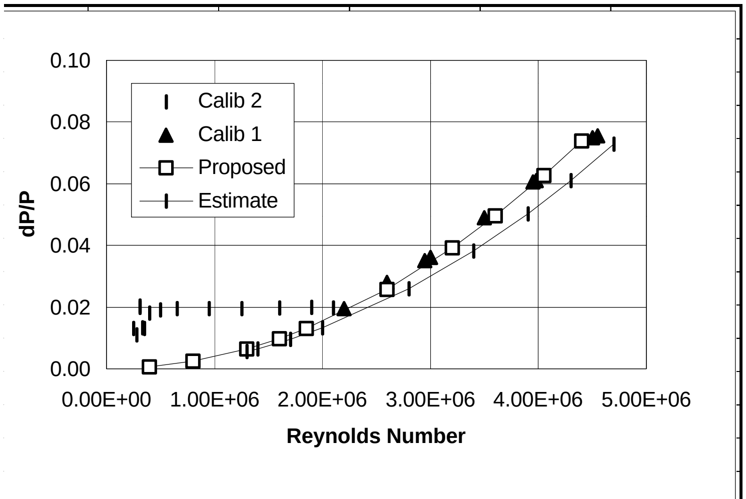

Figure 4
Dimensions dP vs Re for the V-Cone Meter

and are plotted against the pipe Reynolds numbers. Superimposed on these data points are curves of the expected 10:1 turndown ratio V-Cone performance based on the discharge coefficient from the estimating formula (Estimate) and the mean measured value (Proposed) for an air flow at the Mean “Calib1” conditions.

Conclusion

The V-Cone meter produced by McCrometer is being marketed as a new differential pressure flow meter with a number of advantages over conventional measurement methods. The turndown ratios published [1] for this meter, up to 30 to 1, and the claims of low sensitivity to pulsating flows were of particular interest to the authors.

This paper 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. In comparing these equations for a specific test installation, the V-Cone has been shown to have the same characteristics and sensitivities to errors in measured unput values (gas composition, temperature, pressure, and differential pressure) as the orifice meter.

The core hypothesis to the V-Cone meter is that the “flatter” velocity profile produced upstream of the central contoured shape provides a more consistent and stable differential pressure signal. This restructuring of the velocity profile is used to support the V-Cone claims of insensitivity to installation effects, high turndown ratio, and low pulsation sensitivity. McCrometer has furnished experimental validation of the short installation runs required for the V-Cone meter. These are primarily from the installations of the Utah Water Research Laboratory, Logan, Utah. The air calibration reported in this paper, however, was conducted in such a way that even the limited turndown ratio required, 10:1, was not conclusively demonstrated for the fixed upstream pressure particular to this SCE application and no experimental evidence regarding the sensitivity of the V-Cone meter to pulsations in compressible flows was made available to the authors.

The V-Cone manufacturers are pursuing custody transfer certification for their meter and are using the data from these initial calibration results to reformulate their equations for these larger meters in compressible flows.

For the Reynolds number range of interest for the test installation ($5*10^5<Re<5*10^6$) the V-Cone meter has been calibrated on air and the discharge coefficient has been shown to vary form 0.8002 to 0.8094 (±0.57%). Over this Reynolds number range the discharge coefficient calculated for the comparable orifice meter varies form 0.6019 to 0.6025 (±0.5%). This suggests the V-Cone meter would benefit from the use of a curve fit of the discharge coefficient versus Reynolds number. Since these are the first experimental results of compressible flow through a V-Cone of this size (internal Diameter of 29.376 [in] and a cone diameter of 27.160 [in]) the manufacturer has recommended SCE use the mean discharge coefficient form this calibration. The value of this average measured discharge coefficient (CD = 0.80476) indicates that the current V-Cone meter discharge coefficient estimating formula is 6.9% high at these large line sizes (CD = 0.8606, Estimated).

Further independent experimental investigations of the properties of the V-Cone meter have been conducted in oil, steam, and gas flows by SIRA [6]. McCrometer will be making the report from this work public as soon as it is completed.

Southern California Edison is continuing the test of the V-Cone meter and has selected a test site precisely downstream of a multi-run custody transfer meter station. This installation at the Alamitos Unit 6 steam generation power plant is expected to provide an experimental evaluation of the turndown advantages claimed for this new differential pressure flow meter in natural gas service.

[1] "Technical Brief: V-Cone Primary Element", McCrometer, 3255 West Stetson Avenue, Hemet, CA 92545, USA, VT-100

[2] "Laboratory Calibration of Transmission Gas Flowmetering Systems", Seidl, W.F., Caldwell, S.H., American Gas Association Operating Section Distribution/Transmission Conference, Boston, Massachusetts, May 1985.

[3] "Manual of Petroleum Measurement Standards Chapter 14 - Natural Gas Fluids Measurement, Section 3 - Concentric, Square-Edged Orifice Meters, Part 1 - General Equations and Uncertainty Guidelines", American Gas Association, Report No. 3, Part 1, 1990.

[4] Gould Electronic & Electrical Products "Gage and Absolute Pressure Transmitters - Model PG3000/PA3000 Series", Bulletin 1001/1011 - 11/81, Gould Inc. Measurement Systems Division, Oxnard, California

[5] Gould Electronic & Electrical Products "Differential Pressure Transmitters - Model PD3000 Series", Bulletin 104 9/81, Gould Inc. Measurement Systems Division, Oxnard, California

[6] SIRA, South Hill, Chislehurst, Kent, BR7 SEH, U.K.