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A PERFORMANCE STUDY OF A V-CONE METER IN SWIRLING FLOW

by

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SUMMARY

This report describes a test to evaluate the measurement accuracy of three 150 mm (6 inch) V-Cone meters of different beta ratios in swirling flow. The purpose was to establish the installation effects of this relatively new meter and to compare its performance with the widely-used orifice meters under similar conditions. The test, conducted in Chevron's low pressure air flow system, showed that the V-cone meter was significantly less affected by swirling flow in comparison with the orifice meter. Even in highly swirling flow (swirl angles up to 40 degrees), the flow rate measurements were within 0.5% of the no-swirl baseline measurement. The test at Statoil/K-Lab in natural gas at high pressure (7.5 MPa) confirmed the excellent performance of the V-Cone demonstrated in the Chevron test. Since V-Cone meters are not significantly impacted by swirls, they may be better suited for applications in cramped quarters (e.g. offshore platforms) than orifice meters. The V-Cone meter should be able to measure flow rates with reasonable accuracy even with upstream disturbances (out-of-plane elbows and/or header) locating as close as 10 pipe diameters from the meter without any flow conditioning.

INTRODUCTION

This report describes the results of testing V-Cone meters in swirling flow. Like an orifice meter, V-Cone meter is a differential pressure type meter based on the principle of correlating the observed pressure drop due to an obstruction in the line to the volumetric flow rate. As the name implies, the obstruction is a V-shaped cone hanging in the center of the pipe as shown schematically in Figure 1. This relatively new meter is manufactured and marketed by McCrometer Division of Ketema Inc., Hemet, California.

The meter maunfacturer claims that the performance of V-Cone meters is not affect by non-ideal flow conditions. Reports on previous tests conducted with 50 mm (2 inch) and 100 mm (4 inch) VCone meters with disturbed flows (after a single elbow,close -coupled double elbows out-of-plane and a fully/ half-open valve) appear to support this claim.[1-4] This is in contrast to orifice meters which are known to be sensitive to non-ideal flow conditions that are usually caused by up-stream elbows, valves, and other fittings. Swirl in the flow, typically generated in the piping system by two out-of-plane elbows, is generally considered one of the worst flow conditions in terms of causing inaccurate orifice meter measurements. Thus, the objective of this study was to determine the effects of swirling flow on the measurement accuracy of V-Cone meters. Specifically, the performance of 150 mm (6 inch) V-Cone meters have been evaluated at Chevron Petroleum Technology Company (CPTC) with artificially-generated swirling air flow and at Statoil's K-Lab where the swirls were gcneratcd by a series of elbows out-of-plane in high pressure (7.5 MPa) natural gas flow.

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RESULTS AND DISCUSSION

CPTC test

Baseline Performance

Table 1 lists the three meters' performance at the baseline condition which is taken to be swirl-free with the blade angle set at 0 degree. The reference flow rate was taken to be the sonic nozzle flow rate and the V-Cone meter deviation is defined as:

$$\% \text{ Deviation} = \frac{Q_V - Q_{SN}}{Q_{SN}} \times 100$$

where Q_V = V-Cone meter flow rate
Q_{SN} = Sonic Nozzle flow rate

The baseline performance is essentially a check on vendor's flow coefficient calibration. Except runs conducted on March 24, the observed deviations lie in the range of -0.7% to +0.8% and should be considered quite reasonable in view of uncertainties in the vendor's calibration facility, the air flow system, the expansion factor used in the flow equation, low differential pressure level, and flow distortions caused by the hub of the swirler.

Table 1 The Baseline Performance of V-Cone Meters

Run Date	Run No.	Beta Ratio	V-Cone Meter Static Pressure (kPa)	V-Cone Meter Differential Pressure (kPa)	Sonic Nozzle Flow Rate (SCMH)	V-Cone Meter Deviation from Nozzles Flow (%)
3/19/95	0	0.65	70.7	0.43	803.2	0.645
3/19/95	1	0.65	70.2	0.43	800.1	0.837
3/24/95	7	0.65	60.3	0.41	747.3	1.843
3/27/95	0	0.45	67.6	1.89	771.1	-0.719
3/28/95	0	0.45	65.2	1.86	757.8	-0.692
3/28/95	14	0.45	63.6	1.84	748.2	-0.704
3/28/95	15	0.45	64.2	1.02	544.2	-0.231
4/2/95	0	0.55	60.3	0.81	744.0	-0.645
4/2/95	11	0.55	59.6	0.81	737.1	-0.526

The vendor recommends an optimum operating differential pressure of 12.5 kPa (50 inches of water) for V-Cone meters. The recorded V-Cone meter differential pressures in this test were substantially below that level because one of the two blowers in the air flow system was out of service, resulting in only one-half of the usual throughput for the system. This low differential pressure level contributed the most uncertainty in this test. The large fluctuation in the 0.65 beta case can easily be attributed to the extremely low differential pressure (less than 0.5 kPa or 2 inches of water). Given the low flow rate, a measurement error of 24.9 Pa (0.1 inch of water) by the differential pressure transducer can cause up to 3% error in the flow rate for the β=0.65 meter, 1.5% error for the β=0.55 meter, and 0.7% for the β=0.45 meter. Thus, even a deviation of 1.8% in the β=0.65 case is still within the expected performance bound

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The impact of this study lies in offshore gas metering applications[4]. On an offshore platform, a flow meter that is significantly less affected by installation effects may prove to be very beneficial. The cramped platform deck area precludes long straight pipes to condition the gas flow before being measured by the traditional orifice meters. Thus, V-Cone meters may find application on platforms if their accuracy is not compromised by short pipe lengths between the disturbances (elbows, valves, etc.) and the meter. With shorter pipes, the space and weight requirement of a metering system can be reduced which is a very important consideration for offshore platform construction and maintenance.

EXPERIMENTAL SYSTEM AND PROCEDURES

The test at CPTC was conducted in the low pressure air flow system located in Murphy Coyote Lease in La Habra, California. Figure 2 is a schematic of the experimental setup for this test. Two air blowers, each rated at 1475 SCM/H (1.25 MMSCF/D) at 103 kPa (15 psig), were used to supply the air flow. However, one of the blowers was down for this test, resulting in only half of the total flow rate capacity. A fin-fan cooler was installed downstream of the blowers to maintain compressed air temperature at approximately 3°C above the ambient temperature. A pressure control valve was placed in the bypass line to discharge the excess air from the blowers. The test section consists of flange sections for the V-cone meter, orifice meter, and a dual sonic nozzle bank. Sonic nozzles were selected as the flow reference device for the air flow system. The nozzles were calibrated near the operating conditions at the Colorado Engineering Experimental Station, Inc. (CEESI) with ±0.10% uncertainty.

For this swirling flow test, the 150 mm (6 inch) V-Cone meter was installed approximately 21 pipe diameters downstream of an axial vane swirler. The swirl generator was the same one that was used in a similar test for orifice meters.[5] Swirls of different intensities in the line could be generated easily and efficiently by turning the angle of 10 externally adjustable blades attached to the hub of the swirler. Details of the swirler construction is described in Reference 5.

At K-Lab the test was conducted in the 6" high pressure natural gas line, at the Statoil operated gas terminal at Kårstø, Norway. Figure 2A shows a schematic of the set up the test. The gas is circulated around in the closed test loop by means of a centrifugal compressor which has a maximum flowrate of 2000 ACM/H (70 000 ACF/H). The reference flowrate at K-Lab is measured by means of a series of sonic nozzles which have been calibrated in K-Lab's own primary calibration rig (Figure 2B). The swirling tests which are reported were obtained at 7.5 MPa (75 bar) and at gas temperatur of approximately 37°C.

At K-Lab the V-Cone meter was installed 100 D downstream a series of 90° elbows out-of-plane to assess the baseline performance and at 0 D, i.e. imediately at the outlet of the last elbow (Figure 2A) to look at the influence of swirls.

The manufacturer supplied three V-Cone meters of 0.65, 0.55, and 0.45 beta ratios for this evaluation.

- ¤ CPTC tested β : 0.65 - 0.55 - 0.45
- ¤ K-Lab tested β : 0.65 - 0.45

The beta ratio for V-Cone meters is defined to match the same pipe opening areas as in orifice meters. The flow rate equation follows the form for orifice meter flow calculations. However, based on gravimetric water flow calibration, the vendor supplies a meter flow coefficient to use in the V-Cone meter flow equation. The average flow coefficients supplied for the three meters were 0.843, 0.858, and 0.879, respectively. All applicable equations for V-Cone meter flow calculations are shown in Appendix A.

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given the test condition.

The repeatability of the V-Cone meters is also quite good. The differences between repeated runs of same flow rate in Table 1 ranges from 0.027% for the β=0.45 meter to 0.192% for the β=0.65 meter. Again, repeatability appears to improve with higher differential pressure level.

Effects of Swirl

The swirler blades were generally set between -40 to +40 degrees to generate swirling flows of various intensities. Velocity profile surveys conducted in a previous study[6] using the same swirler have shown that the swirl generated was the solid body rotation type similar to flow passing through two close couple elbows and the observed swirl angle was close to the pre-set blade angle. In the field, swirls of 20 degrees is typically generated by double elbows and up to 40 degrees is possible when the flow exits certain header configurations. Figures 3-6 present the V-Cone meter performances at various swirl angles. There appears to be no pronounced effects of swirl intensity on V-Cone metering accuracy. The deviations generally fluctuate by less than ±0.5% from the swirl-free baseline performance. For meters of β=0.45 and β=0.55 in Figures 3-5 , there appears to be certain faint periodicity with the swirl angle, but the patterns seem to be too weak to draw firm conclusions. When the swirl angles exceed 50 degrees in Figure 6, the flow deviations then become significant. However, flows of such swirl intensity are not found in field piping systems.

This lack of swirling flow effects in V-Cone meters is in sharp contrast to orifice meters. A previous test has shown that swirls significantly depress orifice meter measurements.[6] The effects were pronounced and symmetrical as the swirler blade angles varied. Figure 7 depicts the effects of swirls on an orifice meter at β=0.5. Orifice meter undermeasured the flow rate by approximately 4% in 20° swirling flow and by about 10% in 40° swirls.

The fluid dynamics involved in the meter configuration account for the performance difference of these two meters in swirling flow. In orifice meters, the flow is forced through a hole in the center of the pipe where the vortex structure may be preserved or even enhanced due to a tighter spin imposed by the restriction. This hypothesis is supported by experimental data of more pronounced swirling flow effects in smaller beta ratio orifice meters.[7] In V-Cone meters, the flow is forced through the narrow annular space between the central cone and the pipe surface. The upstream vortices tend to be pushed toward and confined near the pipe wall region in the ensuing jet exiting the gap. The low pressure port, located at the downstream face of the cone itself, apparently is not sensitive to remaining swirls in this wake region behind a buff body.

K-Lab test

Baseline Performance

The baseline performance was assessed for 7.5 MPa respectively for beta ratios 0.65 and 0.45 and at 37°C approximately. The flowrate was varied between approximately 170 Am^3/h and 1500 Am^3/h corresponding to a max. differential pressure over the V-Cone of about 162.8 KPa (1628 10^{-3} Bar) .

Tables 2 and 4 show the performance of the 2 V-Cone (0.65 and 0.45 beta ratios) at 100 D downstream of the 90° bend. The flowrate through the V-Cone is compared to the reference flowrate through the sonic nozzles. The flowrate through the V-Cone was calculated using the C_d determined in water at low Reynolds number compared to what was obtained at K-Lab.

The deviations (%) between the V-Cone flowrates at 100D (baseline) calculated with the vendor's flow coefficient and the reference flowrate given by the sonic nozzles (SN) vary between 3% and 4%

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for $\beta = 0.65$ and $\beta = 0.45$.

The pipe Reynolds number which was obtained during the test varied from 2.10^6 to 20.10^6 which is respectively 20 times and 200 times higher than the highest Re-number obtained at CPTC.

Effect of swirls

The swirl out of the series of elbows could not be varied as during the CPTC test because the installation at K-Lab is a permanent installation which can only be modified by reconfiguration of the piping arrangement. This was not undertaken during these tests but is scheduled for later in 1995.
The influence of the disturbances introduced by the bend was assessed by comparing the deviations obtained with the 2 meters located respectively at 100D (baseline reference) and 0D which corresponds to a location immediately at the exit of the bend.

The results as plotted in figures 8 and 9 show an insignificant difference between the deviation observed at 100D and 0D and confirm the insensitivity of the V-Cone meter to the specific K-Lab flow disturbances as it was also observed during the CPTC test.

CONCLUSIONS

1. The results obtained at CPTC and K-Lab are consistent with respect to the behaviour of the V-Cone in swirling flow.

2. The installation effects of three 6" V-Cone meters of 0.45, 0.55, and 0.65 beta ratios were tested in the CPTC low pressure air flow system with swirls of various intensities generated by a 10-blade swirler. In the limited flow rate range tested, the V-cone meters performed well in terms of reference accuracy, repeatability and immunity to swirls.

3. The V-Cone meter measurements were generally within ±1% of the sonic nozzle flow reference at CPTC. Due to mechanical problems with one of the blowers in the system, the flow rate range was severely limited in this test. At differential heads much lower than their recommended operating range, V-cone meters still showed an acceptable accuracy level.

4. The installation effect was assessed for 2 V-Cones ($\beta = 0.65$ and 0.45) in K-Lab's high pressure loop. The swirl effect which was observed confirmed the results obtained at CPTC. Additional test with other upstream pipe configurations are planned.

5. The difference between the V-Cone meters and reference flowmeter at baseline conditions at K-Lab varied approximately between 3% and 4%.

6. The differences observed between V-Cone and reference flowmeters (sonic nozzles) at CPTC and K-Lab will be further investigated.

7. Swirling flow seems to have little effect on V-Cone meter measurements. For swirler blade angles up to 40 degrees (at CPTC), the V-Cone meter measurements generally deviated within ±0.5% from the no-swirl baseline measurements. Above 40 degrees, V-Cone meters tend to overmeasure somewhat.

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In comparison, orifice meters are much more affected under similar swirling flow conditions with up to 10% undermeasurement at 40 degrees of swirls. At K-Lab the deviation between baseline (100D location) and the 0D location was similar to that observed at CPTC.

8. Since the accuracy of V-Cone meters are not significantly affected by swirling flow, they are better suited for applications in cramped quarters than orifice meters. The V-Cone meter should be able to measure the flow rate with reasonable accuracy with the upstream disturbances (out-of-plane elbows and/or header) located as close as 5D from the meter without any flow conditioning.

REFERENCES

1. Ifft, S. A. and E. D. Mikkelsen, "Pipe Elbow Effects on the V-Cone Flowmeter," presented at North Sea Flow Measurement Workshop, Peebles, Scotland, October 26-29, 1992.

2. Astleford, W. J., "Baseline and Installation Effects Tests of the V-Cone Meter," Final Report, Southwest Research Institute, San Antonio, Texas, July 1994.

3. Ifft, S. A., "Installation Effects on the V-Cone Flowmeter," presented at 3rd International Fluid Flow Symposium, San Antonio, Texas, March 20-22, 1995.

4. Dahlstøm, M. J, "V-Cone meter: Gas measurement for the real world", presented at the North Sea Flow Measurement Workshop, Peebles, Scotland, October 1994.

5. Shen, J. J. S., "Effects of a Swirler on Orifice Meter Flow Measurement," presented at AIChE Spring National Meeting, Houston, Texas, April 2-6, 1989.

6. Shen, J. J. S., "Characterization of Swirling Flow and Its Effects on Orifice Metering," SPE 22865, presented at SPE 66th Annual Technical Meeting and Exhibition, Dallas, Texas, October 6-9, 1991.

7. Mattingly, G. E. and T. T. Yeh, "Summary Report of NIST's Industry-Government Consortium Research Program on Flowmeter Installation Effects with Emphasis on the Research Period of February - December 1990," National Institute of Standards and Technology, Gaithersburg, Maryland, December 1990.

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Table 2. V-Cone No.950130 31
K-Lab. Beta:0.65 - Baseline 100D - Temp.: 37 Deg.C - Pressure:75 Bar

RUN NO.	V-CONE PRESSURE BAR	V-CONE DIF.PRESS 10-3BAR	V-CONE DENS. Kg/m3	V-Cone m3/hr Cd=0,843	S.Nozzle Ref Kg/s	S.Nozzle Ref m3/hr	Dev. %
24	78,532	1628	66,61	1638,142	29,449	1591,5127	2,930
25	78,536	1628	66,61	1638,143	29,441	1.591,269	2,946
26	78,536	1628	66,6	1638,266	29,443	1.591,602	2,932
27	77,36	1099	65,58	1362,850	24,082	1.321,891	3,099
28	77,38	1100	65,64	1362,837	24,102	1.321,913	3,096
29	77,387	1101	65,68	1363,030	24,106	1.321,291	3,159
30	76,371	625	64,5	1040,809	18,036	1.006,581	3,400
31	76,367	625	64,49	1040,889	18,035	1.006,782	3,388
32	76,353	625	64,48	1040,969	18,028	1.006,487	3,426
33	75,775	1	64,06		12,050	677,164	
34					12,044	677,131	
35					11,467	1.695,812	
36					11,461	1.697,570	
37	75,232	70	63,45	353,015	6,014	341,235	3,452
38	75,221	70	63,45	353,015	6,014	341,199	3,463
39	75,22	70	63,46	352,987	6,014	341,154	3,469
40	75,113	18	63,35	179,241	3,042	172,860	3,691
41	75,05	18	63,29	179,326	3,042	173,030	3,639
42	75,107	18	63,35	179,241	3,042	172,864	3,689

Table 3. V-Cone No. 950130 31
K-Lab. Beta:0.65 - Exit bend:0D - Temp.:37 Deg.C - Pressure: 75 Bar

RUN NO.	V-CONE PRESSURE BAR	V-CONE DIFF.PRESS 10-3BAR	V-CONE DENS. Kg/m3	V-Cone m3/hr Cd=0,843	S.Nozzle Ref Kg/s	S.Nozzle Ref m3/hr	Dev. %
85	79,163	1610	67,11	1623,441	29,4636	1580,413	2,723
86	79,143	1611	67,1	1624,045	29,458	1580,434	2,759
87	79,161	1611	67,1	1624,051	29,4659	1580,79	2,737
88	77,916	1094	65,79	1357,736	24,107	1319,085	2,930
89	77,899	1093	65,77	1357,331	24,1059	1319,527	2,865
90	77,872	1093	65,77	1357,326	24,0891	1318,627	2,935
91	76,631	622	64,86	1035,472	18,0812	1003,593	3,176
92	76,576	621	64,84	1034,804	18,0867	1004,266	3,041
93	76,611	622	64,85	1035,550	18,0932	1004,397	3,102
94	75,735	277	63,92	698,292	12,0394	678,118	2,975
95	75,725	277	63,91	698,346	12,039	678,187	2,973
96	75,724	277	63,9	698,401	12,0353	678,0348	3,004
97	75,315	70	63,49	352,904	6,0285	341,8211	3,242
98	75,325	69	63,48	350,405	6,0262	341,7391	2,536
99	75,294	69	63,43	350,543	6,022	341,7722	2,566
100	75,339	69	63,5	350,350	6,0265	341,6559	2,545
101	75,167	18	63,46	179,085	3,0513	173,107	3,454
102	75,136	18	63,44	179,114	3,0505	173,1059	3,47[illegible]
103	75,107	18	63,4	179,170	3,0495	173,1511	3,476

Table 4. V-Cone No. 950130 33
K-Lab. Beta:0.45 - Baseline 100D - Temp.:37 Deg. C - Pressure: 75 Bar

RUN NO.	V-CONE PRESSURE BAR	V-CONE DIFF.PRESS 10-3BAR	V-CONE DENS. Kg/m3	V-Cone m3/hr Cd=0,879	S.Nozzle Ref Kg/s	S.Nozzle Ref m3/hr	Dev. %
21	82,154	6765	70,4	1450,764	27,1692	1389,3271	4,422
22	82,156	6765	70,39	1450,868	27,2655	1389,3353	4,429
23	82,16	6766	70,39	1450,968	27,1653	1389,3992	4,431
24	80,627	5321	68,98	1313,205	24,1147	1258,6029	4,338
25	80,64	5321	69,02	1312,833	24,1254	1258,3644	4,329
26	80,638	5322	69,04	1312,755	24,1255	1258,0256	4,350
27	78,15	2977	66,63	1016,642	18,071	976,4239	4,119
28	78,174	2979	66,68	1016,593	18,0864	976,536	4,102
29	78,163	2978	66,68	1016,427	18,0882	976,5993	4,078
30	76,466	1317	64,73	694,644	12,0313	669,1257	3,814
31	76,47	1317	64,74	694,591	12,0343	669,1884	3,796
32	76,472	1317	64,74	694,591	12,0358	669,2361	3,789
33	75,423	328	63,67	352,186	6,0139	340,0228	3,577
34	75,436	328	63,64	352,269	6,0139	340,2056	3,546
35	75,44	328	63,64	352,270	6,0128	340,117	3,573
36	75,168	83	63,34	177,960	3,0367	172,5937	3,109
37	75,164	84	63,35	179,014	3,0354	172,4832	3,786
38	75,124	83	63,33	177,974	3,034	172,4657	3,194

Table 5. V-Cone No. 950130 33
K-Lab. Beta:0.45 - Exit bend:0D - Temp.: 37 Deg. C - Pressure: 75 Bar

RUN NO.	V-CONE PRESSURE BAR	V-CONE DIF.PRESS 10-3BAR	V-CONE DENS. Kg/m3	V-Cone m3/hr Cd=0,879	S.Nozzle Ref Kg/s	S.Nozzle Ref m3/hr	Dev. %
39	82,688	6693	70,75	1440,724	27,1841	1383,1688	4,161
40	82,67	6691	70,73	1440,719	27,1755	1383,2223	4,157
41	82,666	6695	70,72	1441,204	27,1824	1383,6428	4,160
42	82,206	5359	70,07	1308,249	24,4639	1256,8236	4,092
43	81,058	5278	68,95	1308,889	24,0862	1257,6631	4,073
44	81,016	5275	68,92	1308,804	24,1008	1258,8271	3,970
45	81,051	5275	69,15	1306,648	24,1199	1255,6577	4,061
46	81,058	5280	69,19	1306,844	24,133	1255,6953	4,073
47	78,494	2964	66,65	1014,471	18,0896	977,077	3,827
48	78,471	2963	66,67	1014,148	18,1006	977,3586	3,764
49	78,472	2964	66,68	1014,236	18,1024	977,356	3,773
50	76,631	1325	64,78	696,454	12,0607	670,2808	3,905
51	76,624	1314	64,68	694,151	12,0535	670,8699	3,470
52	76,62	1324	64,68	696,734	12,0565	671,0342	3,830
53	75,401	326	63,71	351,006	6,03	340,7375	3,014
54	75,421	327	63,72	351,514	6,033	340,8244	3,136
55	75,414	327	63,73	351,486	6,0325	340,7623	3,147
56	75,155	83	63,46	177,792	3,0491	172,964	2,791
57	75,135	83	63,45	177,806	3,0484	172,9533	2,806
58	75,154	83	63,45	177,806	3,0484	172,9474	2,809

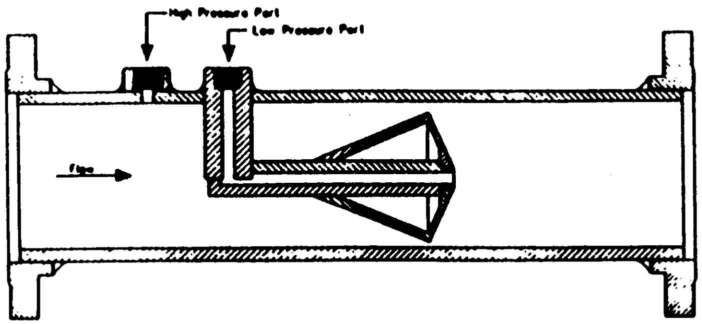

Figure 1
Cutaway Drawing of V-Cone Differential Pressure Flowmeter

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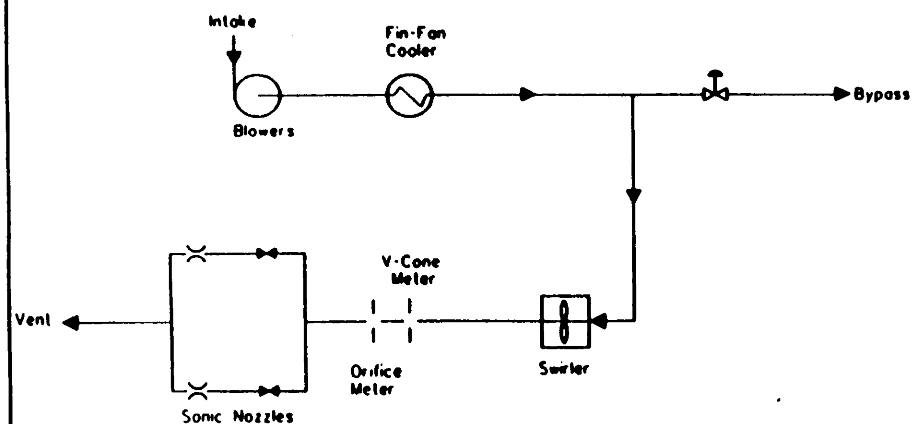

Figure 2
Schematic of Air Flow System in La Habra, CA

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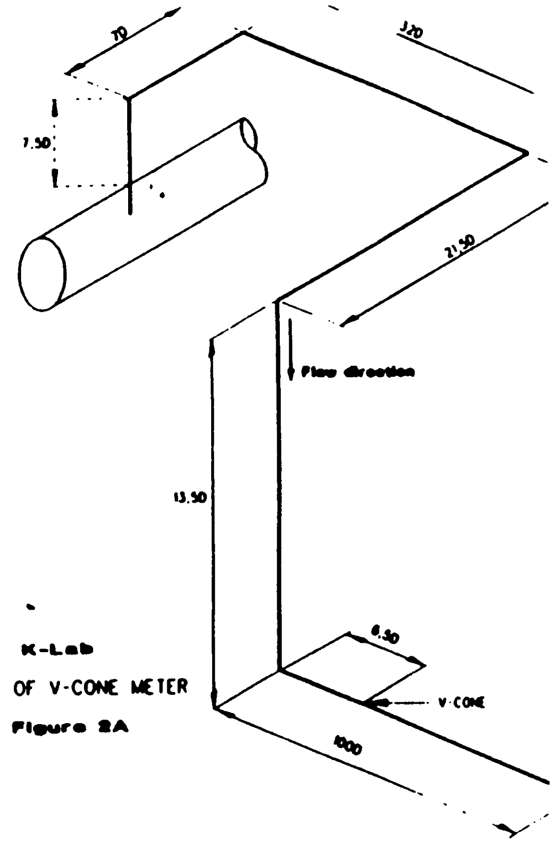


K-Lab
TEST OF V-CONE METER
Figure 2A

SCHEMATIC LAYOUT OF THE K-LAB TEST LOOP

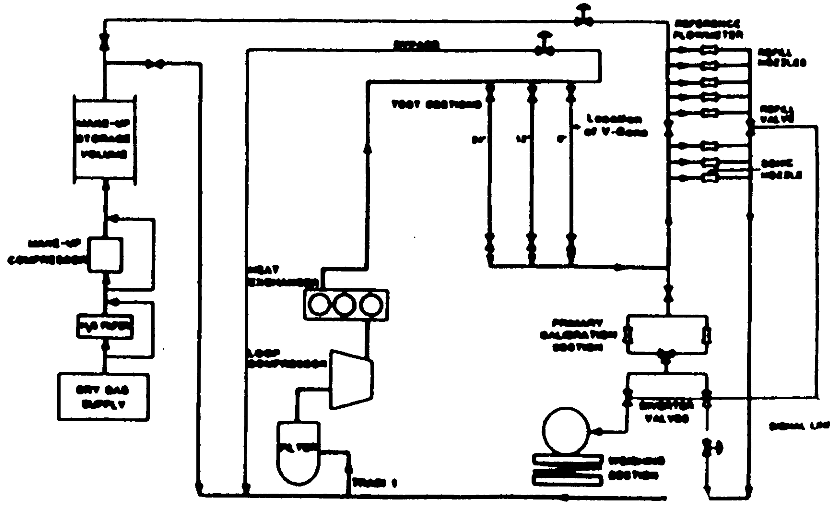


Figure 2B

EFFECT OF SWIRL ANGLE ON V-CONE METER (β=0.45) FLOW MEASUREMENT

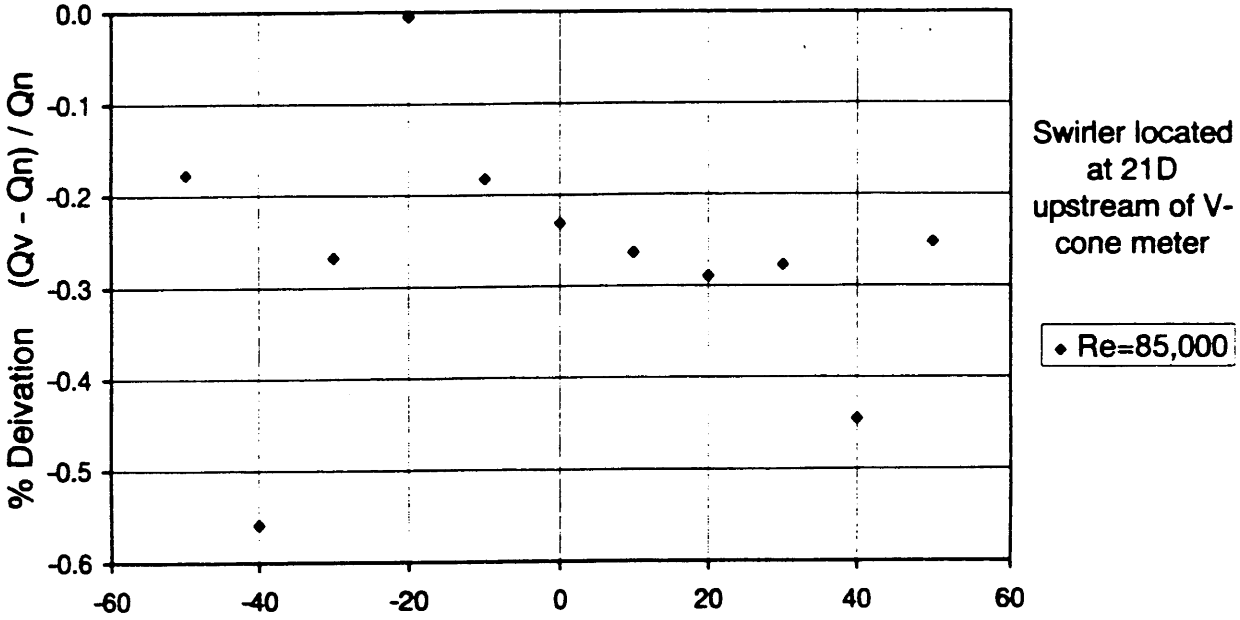


Figure 3 Swirler Blade Angle (degree)

V_SW45A.XLS

9/14/95

EFFECT OF SWIRL ANGLE ON V-CONE METER (β=0.45) FLOW MEASUREMENT

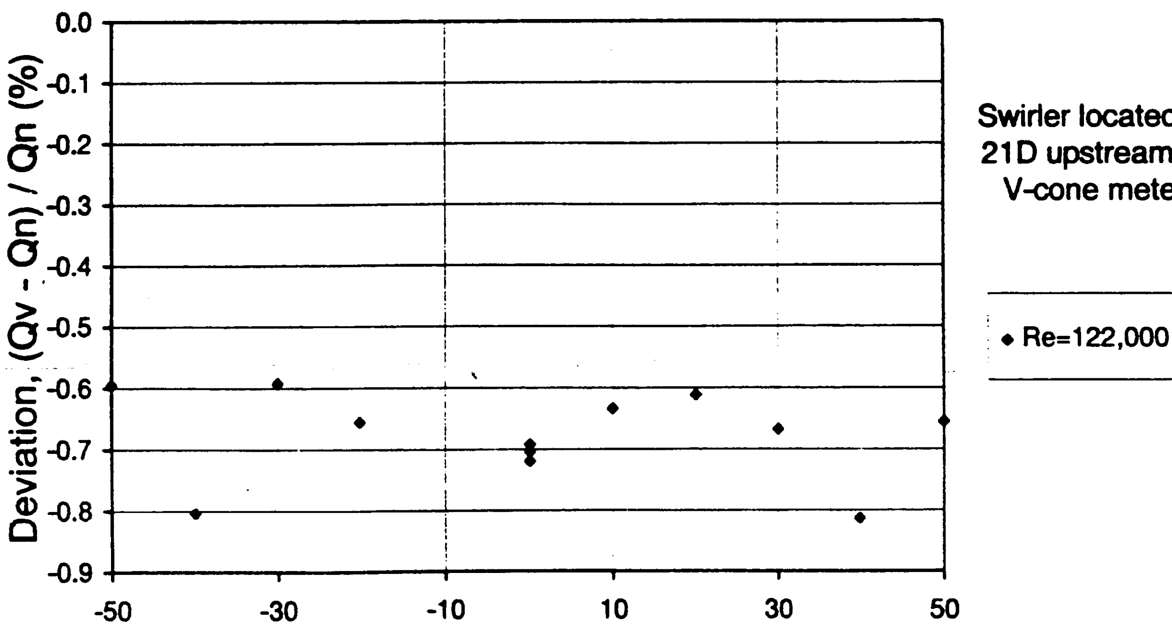


Figure 4 Swirler Blade Angle (degree)

EFFECT OF SWIRL ANGLE ON V-CONE METER (β=0.55) FLOW MEASUREMENT

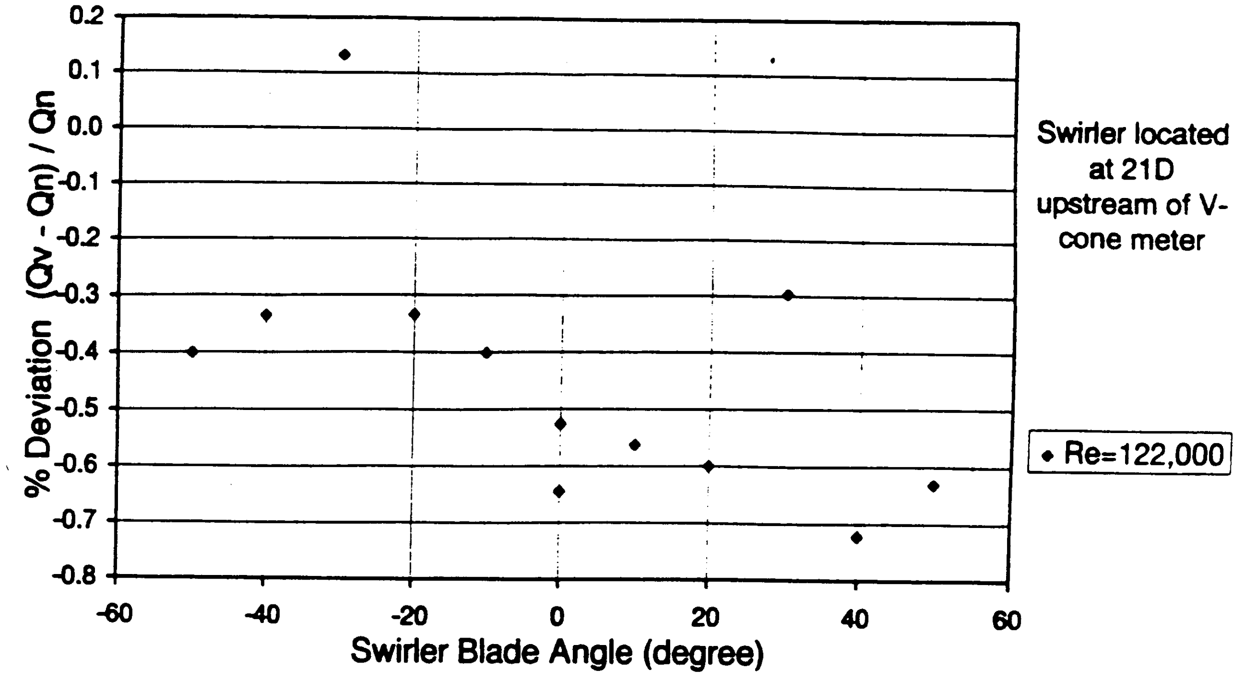


Figure 5

V_SW55.XLS

JJSS 9/14/95

EFFECT OF SWIRLING FLOW ON V-CONE METER (β=0.65) FLOW MEASUREMENT

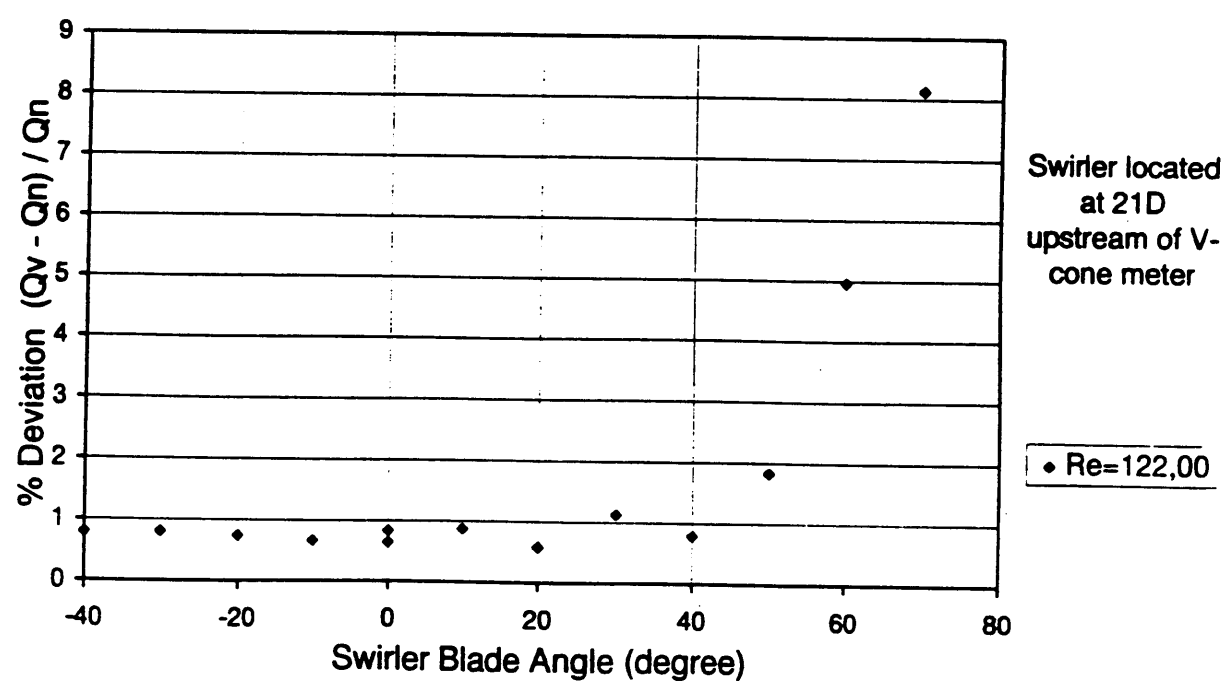
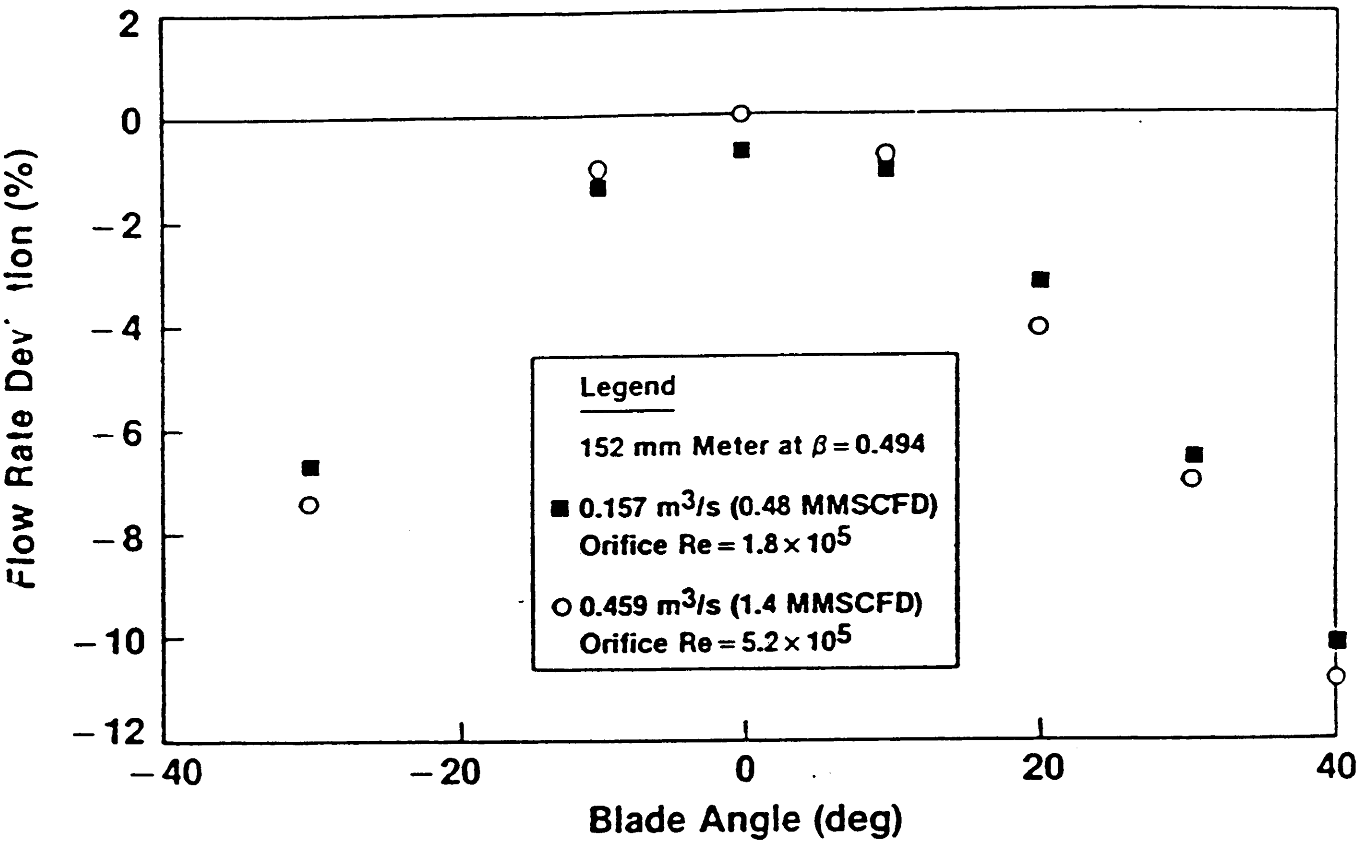


Figure 6

V_SW65 XLS



Effect of Flow Rate on Orifice Metering ($\beta = 0.494$) in Swirling Flows

Figure 7

LE 89—0102

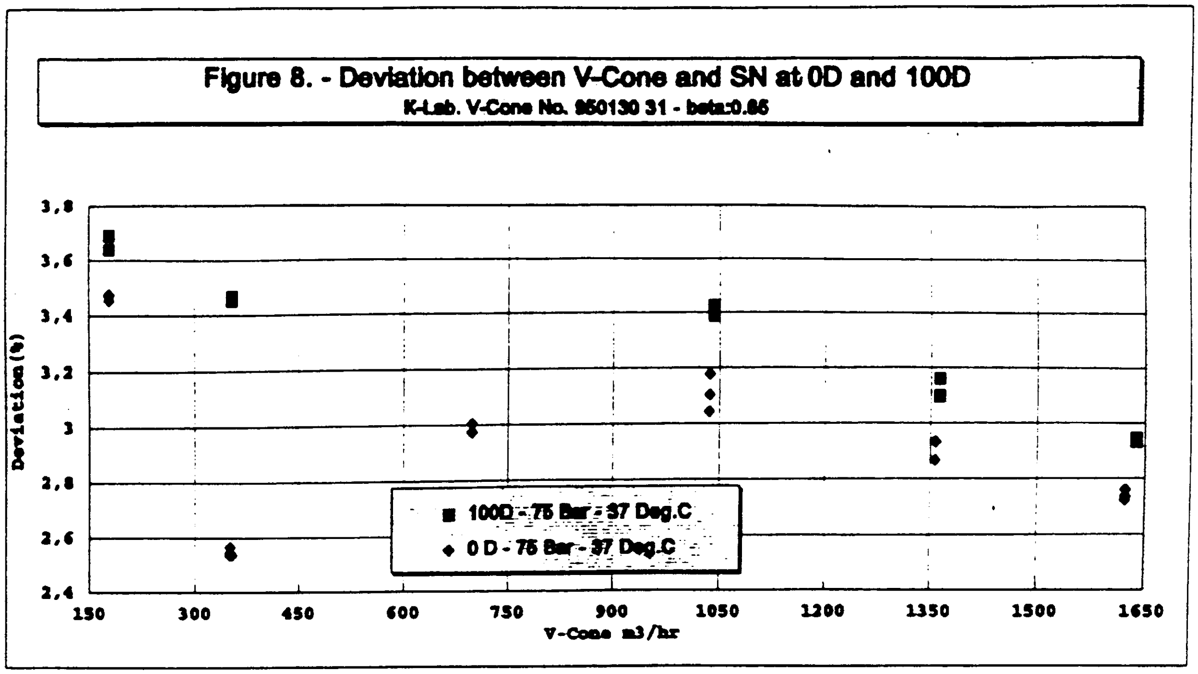


Figure 8. - Deviation between V-Cone and SN at 0D and 100D
K-Lab. V-Cone No. 950130 31 - beta:0.86
Deviation (%)
3,8
3,6
3,4
3,2
3
2,8
2,6
2,4
150 300 450 600 750 900 1050 1200 1350 1500 1650
V-Cone m3/hr
100D - 75 Bar - 37 Deg.C
0 D - 75 Bar - 37 Deg.C

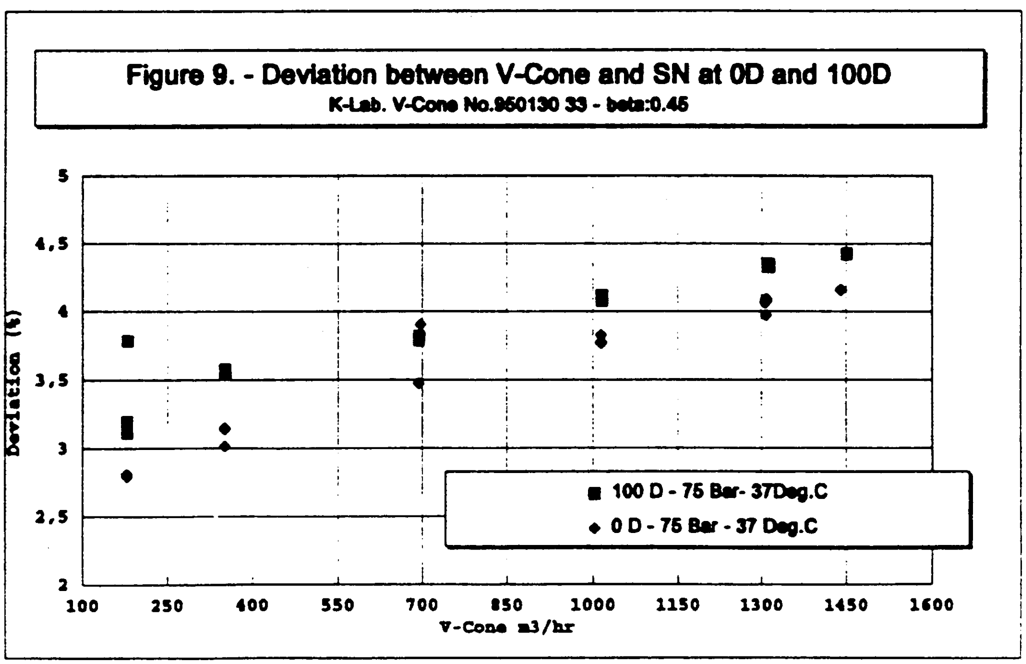


Figure 9. - Deviation between V-Cone and SN at 0D and 100D
K-Lab. V-Cone No.950130 33 - beta:0.45
Deviation (%)
5
4,5
4
3,5
3
2,5
2
100 250 400 550 700 850 1000 1150 1300 1450 1600
V-Cone m3/hr
100 D - 75 Bar- 37Deg.C
0 D - 75 Bar - 37 Deg.C

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APPENDIX A

V-Cone Equation of Flow

Flow equation:

$$Q = \frac{\pi}{4} \sqrt{\frac{2g_c}{\rho}} \frac{D^2\beta^2}{\sqrt{1-\beta^4}} \sqrt{\Delta P}\ C_f Y$$

Beta equation:

$$\beta = \sqrt{1 - \frac{d^2}{D^2}}$$

Gas expansion factor:

$$R = 1 - \left(\frac{\Delta P}{P_L}\right)$$

$$Y = \sqrt{\frac{\left(\left(1-\beta^4\right)\left(1-R^{\frac{k-1}{k}}\right) \times \frac{k}{k-1} \times R^{\frac{2}{k}}\right)}{\left(1-\left[\beta^4 \times R^{\frac{2}{k}}\right] \times (1-R)\right)}}$$

Nomenclature

β	meter beta ratio, dimensionless
C_f	flow coefficient of the meter, dimensionless
d	cone outside diameter, in meter
D	meter inside diameter, in meter
ΔP	differential pressure, in Pa or kg/ms^2
g_c	conversion constant (g_c = (1 lb_m) (32.174 ft^2/s^2) / (1 lb_f) kgm/Ns^2) = 0.45359 (kg). 32.174 *0.3048(m/s^2)/4.4482 kgm/s^2). For all practical purpose g_c = 1 when SI units are applied.
k	fluid isentropic exponent at flowing conditions,dimensionless
P_L	absolute static line pressure, in Pa or kg/ms^2 at the meter
Q	gas flowrate,in actual m^3/sec
Y	gas expansion factor for contoured elements, dimensionless
ρ	flowing fluid density in kg/m^3

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