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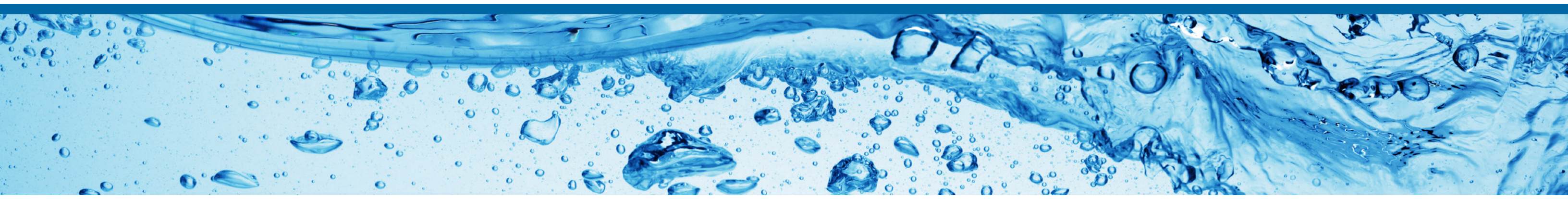

WHITE PAPER

Long Term Performance of V-Cone Flow Meters

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Abstract

In recent years, there has been an emphasis in technical papers on meter diagnostics, but little has been reported on the actual long term performance of flow meters. This presents a problem for industry, especially with newer technologies that do not have many years of service to set guidelines on maximum service life, recalibration and replacement intervals. Currently there is an information vacuum regarding the long term performance of many newer technologies that lead end users and standards writing organizations to write specifications that are conservative. While this helps to ensure safe and accurate measurement in the long term, it also increases the total cost of operation of these devices and forces shut downs leading to lost production and up-time.

This paper presents the results of 12 V-Cone DP Flow meters tested over a period of 17 years. Service applications for the V-Cones included natural gas as well as coke oven gas measurement, a dirty aggressive fluid that is problematic over long period of time for most flow meters. All testing was conducted in air by a 3rd party calibration laboratory, CEESI Colorado. Results will be presented for each of the meters over the 17 year span. Conclusions and recommendations will be made to the long term performance and re-calibration intervals for the V-Cone flow meter.

Introduction

After submission of the abstract additional data was received and added to this report. This paper presents the results of 15 V-Cone flow meters, an increase from the 12 as stated in the abstract. The data was collected from customers that were required to recalibrate by the US Environmental Protection Agency (EPA). Applications are Fuel Gas and Coke Oven Gas. All of the calibrations were performed by Colorado Engineering and Experiment Station Inc. (CEESI Co) an independent 3rd party. The data shows how the meters performed over time. The longest time period between the initial calibration and the most recent calibration is 17 years.

Cone Meter Description

Cone meters are a differential pressure (DP) meter that uses a cone to develop the DP. The flow rate is calculated using a modified Bernoulli's equation (equation 1). The basic Cone Meter design is shown in Figure 1. The DP is measured between a high pressure port at the pipe wall and low pressure port through the center of the cone.

Equation 1

$$Q = F_a \cdot C_D \cdot Y \cdot K_1 \cdot \sqrt{\frac{DP}{\rho}}$$

Where: F_a = Correction for Thermal Expansion

C_D = Meter Flow Coefficient

Y = Gas Expansion Factor

K_1 = Meter Geometric Constant

DP = Differential Pressure

ρ = Fluid Density

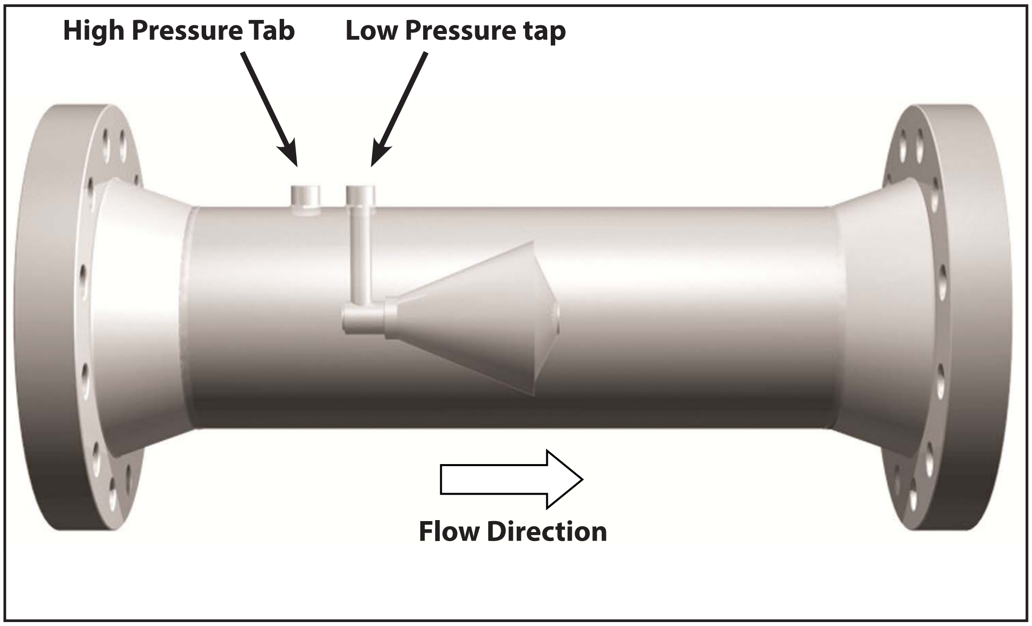

Figure 1. Standard V-Cone Meter

Test Meters

The meters in this report were in two types of service, Coke Oven Gas and Fuel Gas to burners. The meter sizes were 3", 8" and 12". The maximum design velocities ranged from 35 ft/s (11m/s) to 234 ft/s (71m/s). Table 1 shows a list of all the meters and their applications. There are 15 V-Cone flow meters with a total of 54 different calibrations over 17 years.

Table 1. Meter Applications

Meter	# of Cal	Service	Max Vel ft/s (m/s)		Line size
A	6	Fuel Gas	36	(10.97)	8"
B	3	Fuel Gas	182	(55.47)	3"
C	3	Fuel Gas	182	(55.47)	3"
D	5	Fuel Gas	36	(10.97)	8"
E	3	Fuel Gas	35	(10.67)	8"
F	2	Fuel Gas	170	(51.82)	12"
G	2	Fuel Gas	158	(48.16)	3"
H	2	Fuel Gas	184	(56.08)	3"
I	2	Fuel Gas	143	(43.59)	8"
J	3	Coke Oven	215	(65.53)	12"
K	5	Fuel Gas	129	(39.32)	8"
L	4	Fuel Gas	143	(43.59)	8"
M	5	Fuel Gas	144	(43.89)	8"
N	4	Coke Oven	234	(71.32)	12"
O	5	Coke Oven	234	(71.32)	12"

Test Facility

All of the calibrations were conducted at a 3rd party test lab, CEESI Co. Using a single test lab eliminated possible errors due to differences in labs and transfer standards. The meters were air calibrated in series with critical flow venturis (CFV) as the transfer standard with a mass flow rate uncertainty between 0.29% and 0.35%. Considering the error effects of DP, Pressure and temperature and using the root sum square method, this yields a meter uncertainty of approximately 0.4% to 0.5%. This varies depending on the DP transmitters used for the calibration. Due to the age and quantity of the data, the specific transmitter uncertainty data for each data set was not available.

Test Data

Over the time span that this data was collected there were changes made to the Y factor equation. For consistency purposes, the 2001 gas expansion factor was used on all calibrations, equation 2. For each V-Cone flow meter, the originally as-supplied ID and OD were used. The ID and OD for each meter was not re-measured and updated at each calibration to test the continuous effect of long term use of the V-Cone. All of the calibrations for a given meter were over the same Reynolds number (Re) range. With this method, all changes to the meter over time would be seen in the meter CD. The average CD for each calibration was then tabulated along with the calibration year. An example of meter A is shown in Table 2. The percent change in CD between each calibration was then calculated. So, for meter A there were 6 calibration tests which yielded 15 data sets. This method gives many data sets for each calibration test. However, one erroneous calibration will yield multiple erroneous data sets. The data for all meters is shown in the appendix.

Equation 2

$$Y = 1 - (0.649 + 0.696 \cdot \beta^4)\left(\frac{U_1 \cdot DP}{K \cdot P}\right)$$

Where: β = Meter Beta Ratio

U_1 = Unit Conversion Constant

DP = Differential Pressure

K = Isentropic Exponent

P = Absolute Line Pressure

Table 2. YBC = Years Between Calibrations

Meter A												
Mon.	Cal Year	Ave Cd	YBC	Cd shift	YBC	Cd Shift	YBC	Cd Shift	YBC	Cd Shift	YBC	Cd Shift
Sep	1995	0.844681	0									
Dec	2001	0.849769	6	0.60%	6							
Mar.	2006	0.850767	11	0.72%	5	0.12%						
Sep.	2008	0.84994	13	0.62%	7	0.02%	2	-0.10%				
Sep.	2010	0.852034	15	0.87%	9	0.27%	4	0.15%	2	0.25%		
Jan	2012	0.853277	17	1.02%	11	0.41%	6	0.29%	4	0.39%	2	0.15%

After review of the data, two calibrations were identified as possible "outliers". They were then tested using the Grubbs test method. The selected level of confidence was 99.9% (That is a "risk of false rejection of .1%) which gives a critical value of 3.709 with n=45. In one instance the test value was 4.105, in the other it was 5.518. Both cases are well beyond the level of confidence in identifying those tests as "outliers". All data is included in the appendix. The rejected data is in Table 15 and Table 16 with a strike through the rejected data.

The data for all meters is shown in Figure 2. The X axis shows the years between calibrations and the Y axis is the change in the CD for the corresponding time period. There are 5 data points outside ±1% change with the greatest value of 1.22%. The 1% value is significant because it represents experimental error. Recall in section 3, the CD uncertainty is 0.5%, and we are comparing two CD's each with a 0.5% uncertainty. The data is also well distributed above and below the 0% change for time periods less than 12 years. This distribution is an indication that the uncertainty test values are correct. The data points with time periods greater than 12 years came from two meters and are within the test uncertainty.

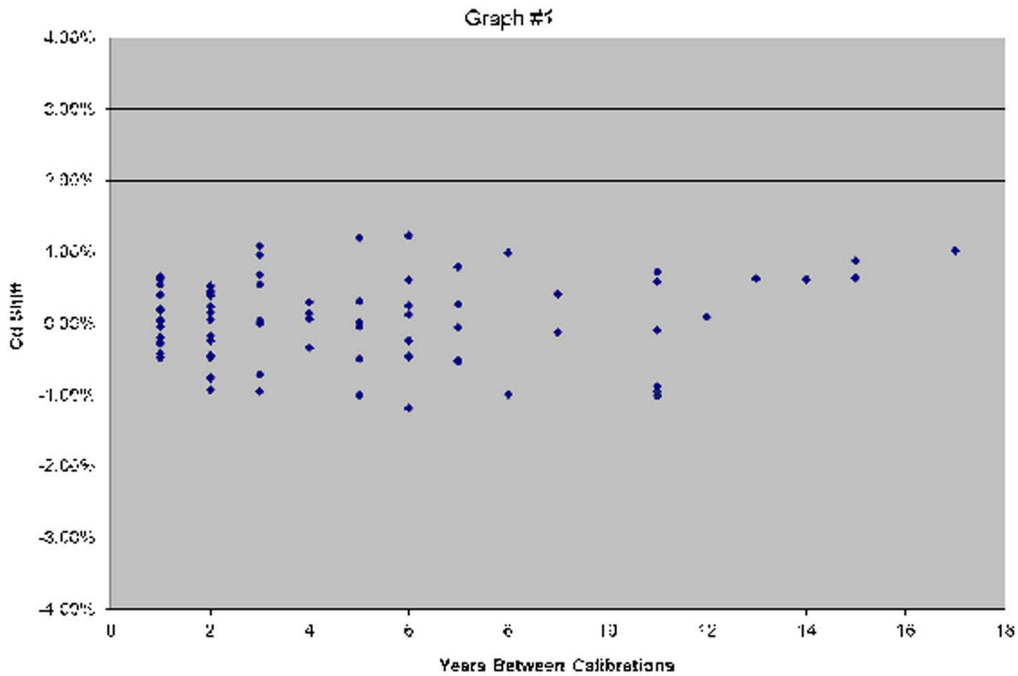

Figure 2.

As a cone meter wears or erodes it generates less DP. Based on equation 1.1, the CD values must increase as DP decreases. It is then important to look at trends. Figure 3 shows all V-Cone flow meters that had 4 or more calibrations. There are 6 meters on this graph. Three of these meters, meters A, D & O trend up with time. Meters K & M trend down and meter L has no trend. The error bars on the Meter A plot were added for reference representing the 0.5% CD uncertainty.

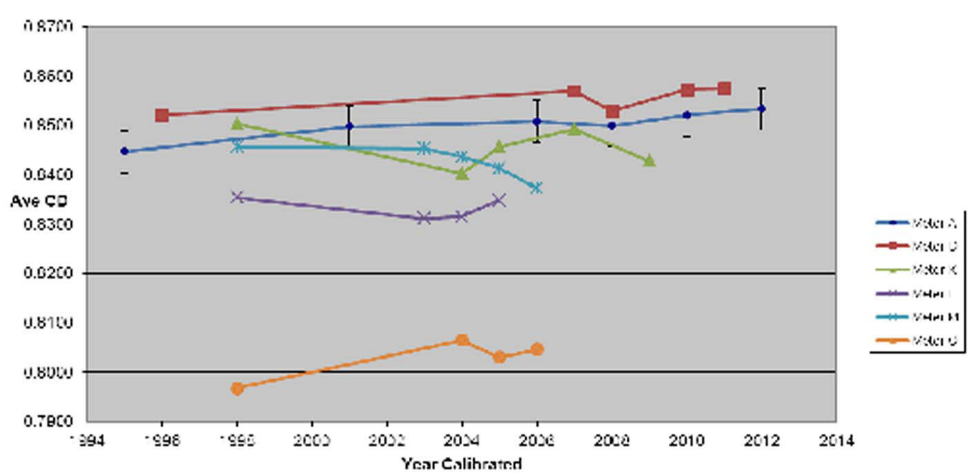

Figure 3.

Conclusions

The data clearly shows that the V-Cone flow meter has extremely good long term performance. Over a 17 year period the CD values stayed within experimental error. This data strongly supports that the practice of recalibrating cone type meters is not necessary for a minimum of 17 years after the original calibration. Longer intervals between the original and re-calibration tests are likely. However, recalibration intervals could be much less for applications with abrasive fluids, e.g. sand. In place of costly and time consuming recalibration, it is suggested that V-Cone flow meters be inspected for foreign objects or damage.

Diagnostic systems and programs can be used to supplement visual inspection and reduce the frequency of shutdown/shut-in. Both visual inspection and diagnostics can be used to verify the V-Cone is still in its original as-calibrated state. See McCrometer document, "Methodology for Field-Measuring the McCrometer V-Cone" for more information on the recommended verification system.

The advantages of inspection instead of re-calibration are many and include the reduction of time a line must be shut down or shut-in to prove a meter is still within the as-calibrated condition. The impact of this advantage is compounded in difficult metering environments such as on offshore oil rigs or in cryogenic service.

Appendix

Table 3.

Meter B						
Mon.	Cal Year	Ave Cd	YBC	Cd shift	YBC	Cd shift
Nov	2007	0.7907	0			
July	2010	0.7982	3	0.96%		
Jan	2012	0.8001	5	1.19%	2	0.23%

Table 4.

Meter C						
Mon.	Cal Year	Ave Cd	YBC	Cd shift	YBC	Cd Shift
Nov	2007	0.7934	0			
July	2010	0.7988	3	0.67%		
July	2011	0.7984	1	0.63%	1	-0.04%

Table 5.

Meter D										
Mon.	Cal Year	Ave Cd	YBC	Cd shift	YBC	Cd Shift	YBC	Cd Shift	YBC	Cd Shift
Sep	1996	0.8520	0							
Sep	2007	0.8570	11	0.58%	0					
Sep	2008	0.8528	12	0.09%	1	-0.48%				
Mar	2010	0.8572	14	0.61%	3	0.03%	2	0.52%		
July	2011	0.8574	15	0.64%	4	0.06%	3	0.54%	1	0.02%

Table 6.

Meter E						
Mon.	Cal Year	Ave Cd	YBC	Cd shift	YBC	Cd shift
May	2009	0.8553	0			
Feb	2011	0.8537	2	-0.18%		
July	2012	0.8552	3	0.00%	1	0.18%

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Table 7.

Meter F				
Mon.	Cal Year	Ave Cd	YBC	Cd shift
1-Nov-99	1999	0.8399	0	
1-Nov-10	2010	0.8313	11	-1.02%

Table 8.

Meter G				
Mon.	Cal Year	Ave Cd	YBC	Cd shift
Nov	1999	0.8202	0	
Nov	2010	0.8124	11	-0.96%

Table 9.

Meter H				
Mon.	Cal Year	Ave Cd	YBC	Cd shift
Oct	2010	0.7913	0	
July	2012	0.7916	2	0.05%

Table 10.

Meter I				
Mon.	Year	Ave Cd	YBC	Cd shift
Dec	2007	0.8358	0	0
Dec	2009	0.8281	2	-0.93%

Table 11.

Meter J						
Mon.	Year	Ave Cd	YBC	Cd shift	YBC	Cd Shift
April	2004	0.818494	0	0		
May	2005	0.816319	1	-0.27%	0	
Jun	2007	0.812657	3	-0.71%	2	-0.45%

Table 12.

Meter K										
Mon	Year	Ave Cd	YBC	Cd shift	YBC	Cd Shift	YBC	Cd Shift	YBC	Cd Shift
Apr	1998	0.8503	0	0.00%						
Apr	2004	0.8402	6	-1.19%	0					
May	2005	0.8457	7	-0.54%	1	0.65%				
Jun	2007	0.8493	9	-0.12%	3	1.08%	2	0.42%		
Dec	2009	0.8428	11	-0.89%	5	0.30%	4	-0.34%	2	-0.76%

Table 13.

Meter L								
Mon.	Year	Ave Cd	YBC	Cd shift	YBC	Cd Shift	YBC	Cd Shift
Aug	1998	0.835344	0	0.00%				
Aug	2003	0.831135	5	-0.50%	0			
Jul	2004	0.831517	6	-0.46%	1	0.05%		
Oct	2005	0.834853	7	-0.06%	2	0.45%	1	0.40%

Table 14.

Meter M										
Mon.	Year	Ave Cd	YBC	Cd shift	YBC	Cd Shift	YBC	Cd Shift	YBC	Cd Shift
Jul	1998	0.8457	0	0.00%						
Jul	2003	0.8453	5	-0.04%	0					
Aug	2004	0.8436	6	-0.24%	1	-0.20%				
Nov	2005	0.8413	7	-0.52%	2	-0.48%	1	-0.28%		
Nov	2006	0.8373	8	-0.99%	3	-0.95%	2	-0.76%	1	-0.48%

Table 15. Table 6.15 (strike through data identified as outliers)

Meter N								
Date of Ca	Year	Ave Cd	YBC	Cd shift	YBC	Cd Shift	YBC	Cd Shift
Aug	1998	0.805933	0	0.00%				
Aug	2003	0.79781	5	-1.01%	0			
Jul	2004	0.802147	6	-0.47%	1	0.54%		
Jul	~~2005~~	~~0.819658~~	~~7~~	~~1.70%~~	~~2~~	~~2.74%~~	~~1~~	~~2.18%~~

Table 16. Table 6.16 (strike through data identified as outliers)

Meter O										
Mon	Year	Ave Cd	YBC	Cd shift	YBC	Cd Shift	YBC	Cd Shift	YBC	Cd Shift
	1998	0.796725	0	0.00%						
Jul	~~2003~~	~~0.815987~~	~~5~~	~~2.42%~~	0					
Aug	2004	0.806479	6	1.22%	~~1~~	~~-1.17%~~				
Nov	2005	0.802998	7	0.79%	~~2~~	~~-1.59%~~	1	-0.43%		
Nov	2006	0.804563	8	0.98%	~~3~~	~~-1.40%~~	2	-0.24%	1	0.19%

References

Title 40, Code of Federal Regulations, Appendix D to Part 75

Taylor, J.K. Statistical Techniques for Data Analysis (Lewis Publishers Inc, 1990)

Richard W. miller, Flow Measurement Engineering Handbook (McGraw Hill, 1983)