NEW IDEAS FOR ORIFICE METERING:
INCREASING TURNDOWN USING ORIFICE METER TECHNOLOGY & ESG MITIGTIGATION IN ORIFICE METERING SYSTEMS

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Introduction.

Well and pipeline flow rates are often variable. Shale wells experience a steep decline curve. Pad drilling can bring on new wells, increasing flow, followed by declining flow in the future. This paper describes a strategy that can be employed to increase the operational flow range over which an orifice meter may be operated, thus lowering costs. Orifice meter turndown can be greater than is often assumed.

Orifice plates used in natural gas custody transfer metering are subject to strict rules regarding flow rates and differential pressures that are allowed per each plate thickness versus diameter . Flow rates per area ratio (β)are defined to make sure that orifice plate elements are not overstressed or damaged, during normal operation .

Differential pressures (DP's) are fully described over specific ranges in all national and international measurement standards relating to orifice metering such as AGA, API, and ISO, to make sure that plate elements are kept from high DP distortion during flowing conditions.

Orifice plate and carrier removal/replacement in orifice fitting designs usually performed by using a mechanical crank handle and gear mechanism is left to each individual manufacturing company generally built to allow plate changes during flowing conditions.

Various orifice plate fitting manufacturers state in their technical bulletins and manuals that the flow rates (differential pressure) observed during custody measurement operations should be reduced for safety reasons during the plate extraction process, while others state that this is not required. Orifice plate fitting removal and replacement methods should be confirmed under flowing conditions, particularly when operated under high DP loading to improve turndowns and flowrates, as some midstream companies have implemented .

This technical paper describes information regarding natural gas measurement by using orifice plates at DP's up to 1000 inches water column in a natural gas flowing condition in the 2-8inch diameter range , and the benefits thereof regarding overall turndown. This concept has been enhanced due to the newer smart transmitters that have been introduced recently that claim "of-reading" performance, thus allowing greater turndown for orifice meters and fittings than had been previously implemented.

Orifice Plate Limits

With exception to 6-inch at a 0.125" plate thickness most of the smaller sizes can operate at 1000 inches water column without severe distortion while maintaining accurate measurement performance within national and international standards. The 6-inch meter size has a best DP limit of around 345" water column for a 0.125" plate thickness.

8-inch orifice meters are normally implemented with a 0.25" thick plate as updated in the year 2000 edition 4 of AGA part 2, The maximum calculated DP for a 6-inch orifice meter is only 317"water column and this value needs to be improved if larger turndowns are required. This will be discussed later in the paper.

Inputs			
Nominal Tube Size	6" S80	Inches	5.761 ID
Orifice Bore	3.000	Inches	0.521 Beta
Plate Thickness	0.125	inches	
Flowing Temp	90	deg F	
SS Yield Strength	30000	psi	0.2% offset method
SS Modulus of Elasticity	2.832E+07	psi	(ASME 31.3, TableC-6)
Intermediate Results			
Support Diameter	6.237		
R/r	2.079		
k (yield)	1.492		
β_s	0.481	Support Beta Ratio	
k_d	0.706		
y_L	0.014	Deflection limit per AGA	
Results			
Max operating DP allowed for plate per AGA3-Part 2	317.0	in WC	
	11.43	psid	
Estimated DP required to permanently bow plate	1050.0	in WC	
	37.9	psid	

Table 1. Maximum allowed DP for 6-inch Diameter Orifice Meter at 0.521 Beta

Operating a 6-inch orifice plate meter at higher DP's than stated at the 0.125" thickness is troubling and will cause some distortion and thus under-reading if bowed. The Table 2. example next, depicts the same meter as operated in Table 1. with effects of a bent plate at just 0.2" on the performance displayed. (4% under-read)

Inputs		
Tube Diameter	5.761	Inches
Orifice bore	3.000	Inches
Deflection	0.2000	Inches
Calculations		
Beta Ratio	0.5207	
Angle of Deflection	81.7566	
Contraction Coefficient Undeflected	0.64773302	
Discharge Coefficient Undeflected	0.63330884	
Contraction Coefficient Deflected	0.66202871	
Discharge Coefficient Deflected	0.64774648	
Phi	0.65796232	
Phi sub d	0.67296198	
Delta Phi Fraction	-0.02279715	
Fractional change in orifice bore	-0.01901782	
Multiply measured flow on bowed plate by	1.04364	to get actual volume.

Table 2. Measurement error sustained with a 0.2% deflection on the orifice plate

This is why it is critical to make sure that orifice plates are operated within geometric specification and applied correctly over the defined maximum and minimum differential pressures.

One final point or reminder before moving on to a solution regarding high DP operations is that the plate direction is highly critical regarding custody or financial measurement. Orifice Plates installed in the reverse direction cause large errors. Table 3. below, indicates the error obtained with an orifice plate installed in the reverse direction.

Inputs		
Nominal Tube Size	5.761	Inches
Orifice Bore	3.000	Inches
Plate Thickness	0.125	inches
Bore Thickness	0.0625	inches
Intermediate Results		
Beta	0.520742927	
E/D	0.021697622	Plate thickness/Tude Dia.
e/E	0.500	Bore Thickness/Plate Thickness
Measurement Error	-14.0%	(Under measurement)
Multiply measured flow on backward-facing plate by 1.163 to get actual volume.		

Table 3. Magnitude of error obtained with a backwards installed plate

Considering a flow rate at 371 ”water column through the meter run at say 600 PSIG and 90 degrees F, the flow rate would be at around 28000 SMCFD at 1036 BTU /cuft this equates to a loss of $12,138.00 per day.

<u>Higher DP's</u>

When reviewing a meter station philosophy besides the normal review of gas composition, site area and installation etc. The flow profile over the life of the system is important also in the recent past DPs were limited due to the transmitter ranges. Modern transmitters do not have that limitation today a cost saving concept which would extend the meter run life is to size the system one size below a standard mid-range DP where possible, and then operate it within 1000 inches water column at the start. After some years when the flow rates from the wells have declined the system would be able to be configured to operate at lower DPs whilst maintaining good fidelity.

The question regarding the 6-inch diameter meter sizes is how to operate at 1000 inches water column , this is easily managed by using a 3/16th thick plate which is acceptable in the measurement standards. To use this in a dual chamber orifice fitting the plate carrier must be machined back the extra 1/16th to accommodate the new plate thickness. When the special plate carrier for the thicker plate is used, the maximum beta ratio orifice plate that may be used with it is .61.

Below is the latest chart showing rangeabilities available with orifice plates taking into consideration the changes in plate thickness. See table 4. below plate thickness versus DPs.

Nominal Pipe Size (NPS)	Published Inside Pipe Diameter	Orifice Plate Thickness E		Maximum Allowable ΔP (in. - H_20)	Maximum Allowable ΔP (in. - H_20)
		Recomended (inches)		Orifice Fitting	Orifice Fitting
(inches)	(inches)	Normal Range	Special 6 inch only	Normal Range	Special 6 inch only
2	1.687	0.125		1000	
	1.939	0.125		1000	
	2.067	0.125		1000	
3	2.300	0.125		1000	
	2.624	0.125	√	1000	√
	2.900	0.125		1000	
	3.068	0.125		1000	
4	3.152	0.125		1000	
	3.438	0.125		1000	
	3.826	0.125		1000	
	4.026	0.125		1000	
6	4.897	0.125	0.1875	345	1000
	5.187	0.125	0.1875	345	1000
	5.761	0.125	0.1875	345	1000
	6.065	0.125	0.1875	345	1000
8	7.625	0.250		1000	
	7.981	0.250		1000	
	8.071	0.250		1000	
10	9.562	0.250		570	
	10.020	0.250		570	
	10.136	0.250		570	
12	11.374	0.250		285	
	11.938	0.250		285	
	12.090	0.250		285	
16	14.688	0.375		465	
	15.000	0.375		465	
	15.025	0.375		465	
20	18.812	0.375		235	
	19.000	0.375		235	
	19.250	0.375		235	

1000” water column range (NPS 2 to 8)

Below 1000” water column range (NPS 10 to 20)

Table 4. Orifice Plate Thickness versus allowed DPs.

Rangeabilities using plate changes are very interesting to review and calculate. The concept that any increased pressure drop due to reduction in size will not affect the flow throughput (production) since usually production wells are at their highest pressure at the first gas stage and pressure fall off occurs near end of life of the well.

The following calculations are valid for typical production gas. Figures 1. (Gas Composition) through Figures 4 are flow calculations, based on standard AGA volumetric calculated values and also using AGA 8 detail method to determine the flowing densities. These particular values being derived from the listed gas composition.

Calculations will be tabulated at close to 1000” water column “first gas” then down to an “end of life” situation indicating the maximum and minimum flow rates achievable through the life of the 6-inch measurement system and then compared with the larger system running at lower DP’s.

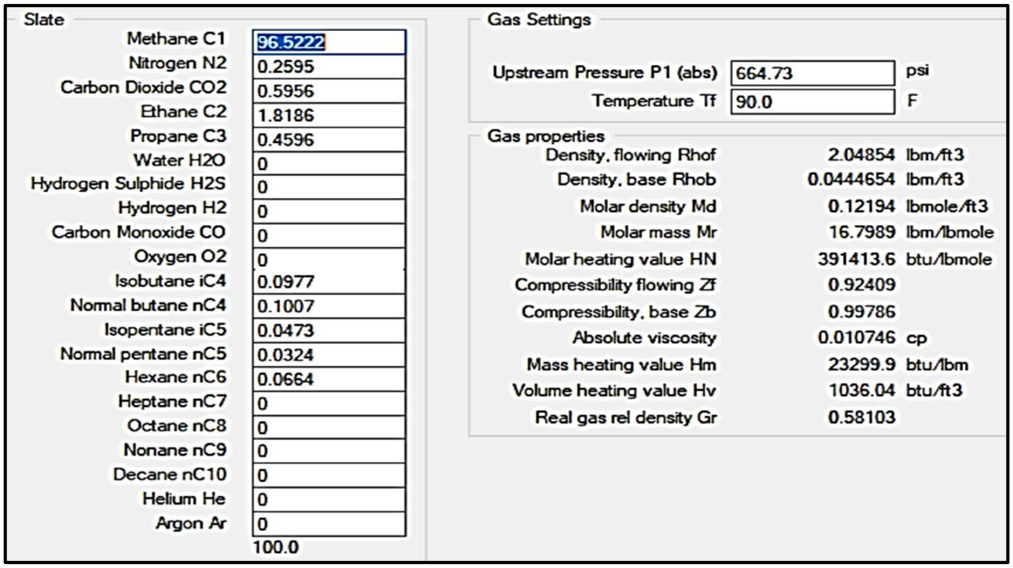

Figure 1. Example Base Gas Composition - Sea Level & 14.73PSI (contract base pressure)

The following calculations are based on a typical gas composition above with a 1036 BTU/cuft heating value (Hv) and DP at 1000"water column through 20 inches water column with beta ranges from 0.2 - 0.65.

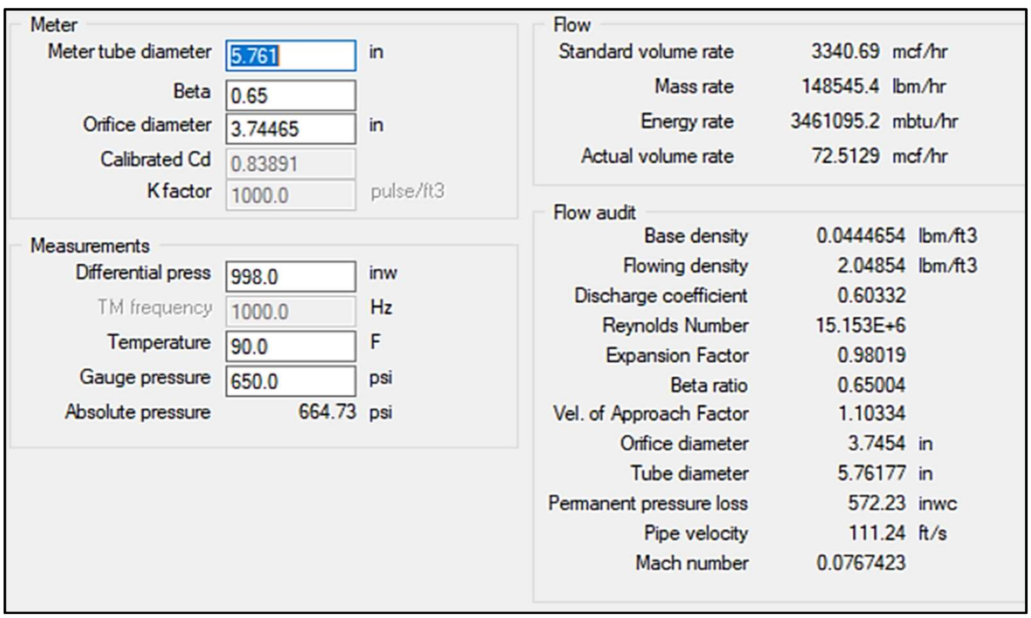

Figure 2. High Gas Flow rate at 0.65 Beta 650PSIG /90DegF & 998"w.c. (First Gas) (80.172 MMSCFD)

Figure 3. Shows the minimum flow rate available at around 20 inches water column (End of Life) it is possible to operate at lower DP.s however common industry practice is to shelf the DP at around 20 inches unless there are exceptional circumstances !

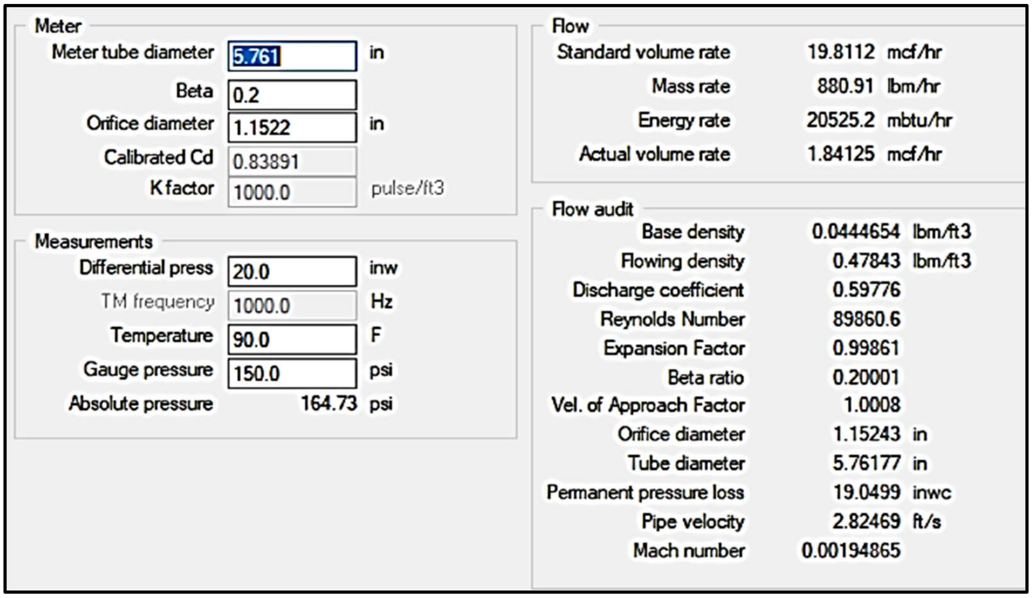

Figure 3. Minimum flow rates (End Life) available at around 20 inches water 0.2 beta ratio at 150 PSIG

The overall rangeability is seen to be from 3340 SMCFH. to 19.8112 SMCFH. which is an amazing turndown of 168 - 1 , if the pressure is kept at 650 PSIG which is highly unlikely as wells decline (the writer has seen these low pressures in midstream applications in the past) the pressures also reduce. However, is the pressure is kept a 650PSIG the low rate is 41 SMSCF , which is a turndown of App. 82-1. If the meter station is kept well maintained the measurement system should give many years of economical and accurate service.

The comparison with larger meter runs will be discussed next and it is evident that the low-end operation at the end of life of the system is a key factor in this type of high DP application. The cost of valves and piping also is an economical approach in today's environment where steel prices are moving higher day by day.

The following calculation indicates the flow range of an 8-inch meter diameter meter operating at 446 inches water column based on the same gas composition. Normally the range of the 6-inch diameter fitting with 1/8 plate in its carrier is around 345" w.c. at the top range. The enhanced range allows a rangeability improvement over the full life of the meter. The 8-inch diameter meter with a 0.6 beta plate at 446" w.c. matches the 6-inch plate with a 0.65 beta at 998 "w.c.

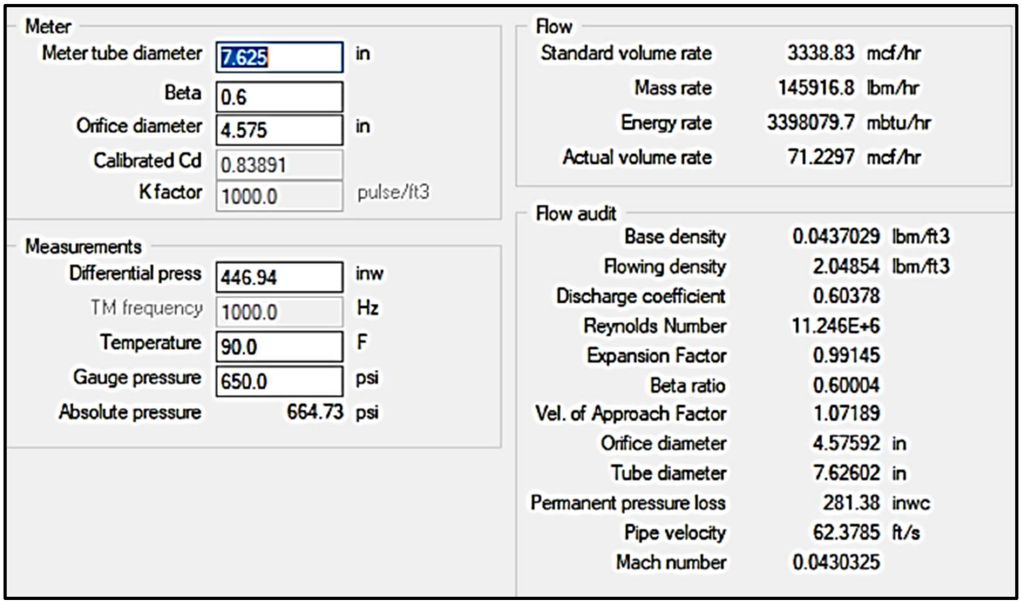

Figure 4. 8-inch diameter orifice meter schedule 80 with 0.6 Beta ratio at 446.94" w.c. (80.132MMSCFD)

The calculation for the maximum allowed DP at 0.65 beta ratio n 90 degrees F before deformation is shown below and is approximately 3000 inches water column.

Inputs			
Nominal Tube Size	**6" S80**	Inches	5.761 ID
Orifice Bore	**3.750**	Inches	0.651 Beta
Plate Thickness	**0.1875**	inches	
Flowing Temp	**90**	deg F	
SS Yield Strength	30000	psi	0.2% offset method
SS Modulus of Elasticity	2.832E+07	psi	(ASME 31.3, TableC-6)
Intermediate Results			
Support Diameter	6.237		
R/r	1.663		
k (yield)	1.160		
β_s	0.601	Support Beta Ratio	
k_d	0.528		
y_L	0.010	Deflection limit per AGA	
Results			
Max operating DP allowed for plate per AGA3-Part 2	**1000.0**	in WC	
	36.06	psid	
Estimated DP required to permanently bow plate	**3039.8**	in WC	
	109.6	psid	

Table 5. Stress calculation for a 6-inch diameter Orifice Meter

The next review is to look at the 10-inch meter which has a range of 570" w.c. maximum at 0.25" thickness by using the 8-inch diameter meter in place of the 10 inch it should be possible to improve the rangeabilities similar to the 6-inch diameter meter.

The 8-inch diameter meter is normally standardized with a ¼" (0.25") plate thickness within a plate carrier and fitting.

The calculation using an 8-inch diameter meter at approximately 1000"w.c. is shown below in Figure 5.

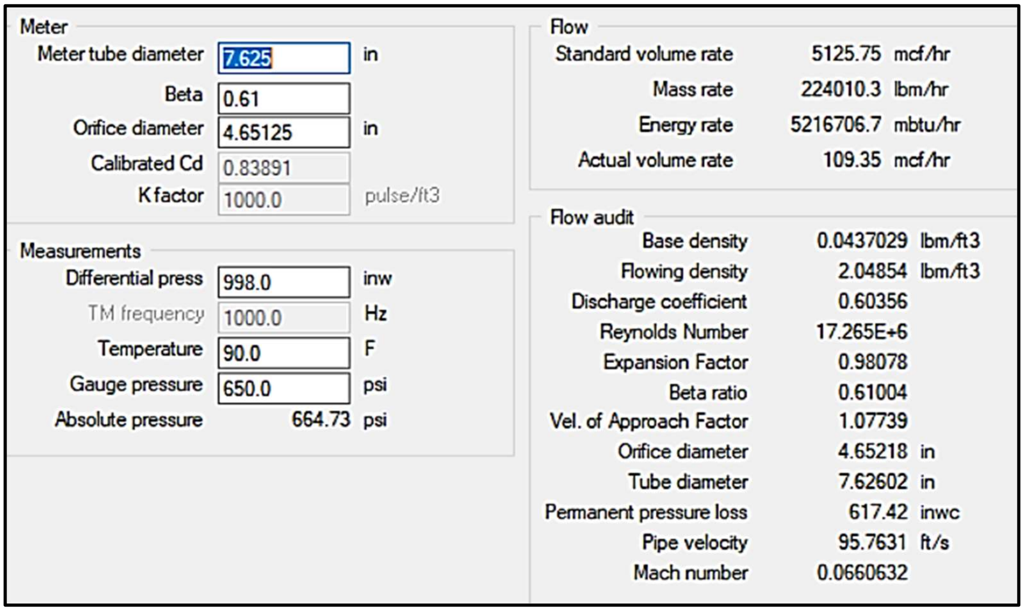

Figure 5. 8-inch diameter Orifice meter operating at 998"w.c. (123 MMSCFD)

The 10-inch meter diameter meter calculation in Figure 6. below is below to the 8-inch meter flow rates however the meter specifications at ¼" thickness (0.25") allows a lower DP range and limited to 0.5 beta ratio maximum to maintain performance.

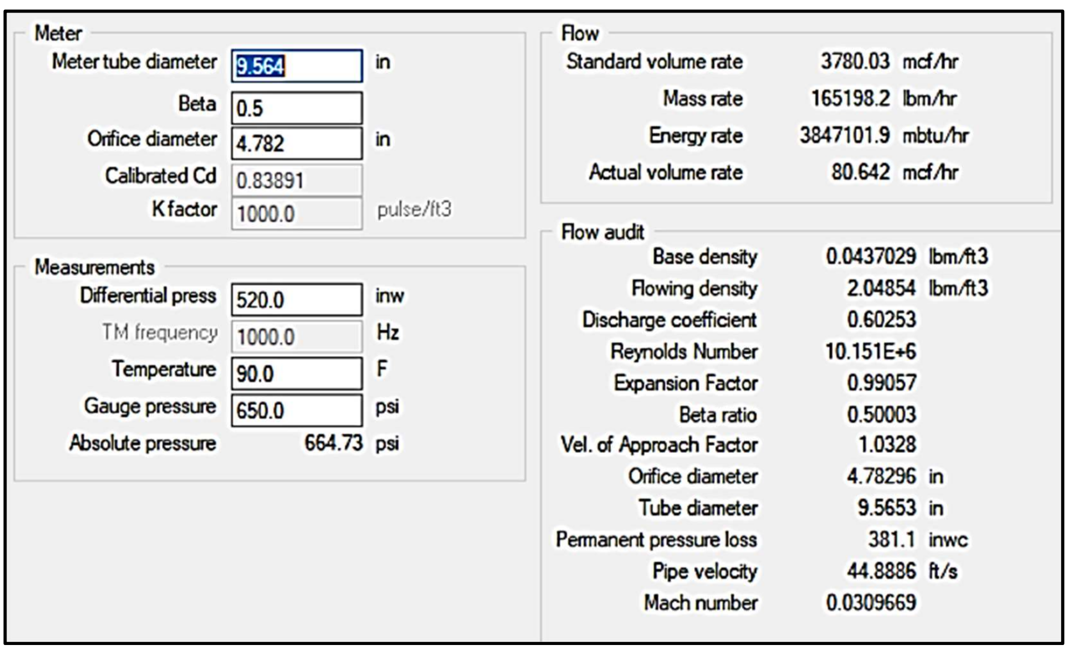

Figure 6. 10 -inch diameter Orifice meter at sched 80 flow rate is reduced due to limited rangeability (w.c.)

The stress calculations in Table 7. for the 10-inch diameter 0.25" thickness plate is shown below one interesting point is the flow-rate for the larger meter is half the 8-inch diameter meter flow range operating at 998"w.c. Only circa 61 MMSCFD ! This is because higher DP ranges are close to the stress tolerance on this size of meter to bow the plate at 1000"w.c. If a 0.375" plate is used this can reach 1000"w.c. however very special machining of the orifice carrier is needed to sustain this DP.

The pipe velocity is reduced to 45 ft/s. while the 8-inch orifice meter velocity is under 100 ft/s at the high DP which is often seen on USM meters with isolating plate flow conditioners installed.

Inputs			
Nominal Tube Size	10" S80	Inches	9.564 ID
Orifice Bore	5.000	Inches	0.523 Beta
Plate Thickness	0.25	ches	
Flowing Temp	90	deg F	
SS Yield Strength	30000	psi	0.2% offset method
SS Modulus of Elasticity	2.832E+07	psi	(ASME 31.3, TableC-6)
Intermediate Results			
Support Diameter	10.487		
R/r	2.097		
k (yield)	1.503		
β_s	0.477	Support Beta Ratio	
k_d	0.711		
y_L	0.023	Deflection limit per AGA	
Results			
Max operating DP allowed for plate per AGA3-Part 2	**520.7**	in WC	
	18.78	psid	
Estimated DP required to permanently bow plate	**1512.4**	in WC	
	54.5	psid	

Table 6. 10-inch Orifice plate meter stress calculations – 0.5 beta ratio max

Conclusions

Orifice plate technology is robust and has a long reputation despite newer electronic metering devices appearing. The device has a simple understanding and can be used without a flow calibration at a laboratory providing that the rules of similarity are maintained according to national standards.

The use of higher DP's due to improved electronic smart transmitters means a broader range of flow can be measured by a single size of orifice meter. This in turn can mean that smaller pipe runs, valves, flow conditioning etc. can be used to save cost and cost of ownership. The orifice meter can operate to low static pressures circa 20PSIG without the issues that other electronic meters have in performance at these pressures.

The orifice and other DP meters will be around for some time , the technology is improving with new ideas regarding condition-based maintenance / monitoring being some of the latest innovations to arrive in the marketplace.

Introduction

Reduction of Methane emissions is increasingly a priority for all companies in the oil and gas industry. Methane is a potent greenhouse gas according to many government bodies. Regulations by government entities at all levels to reduce methane leaks have increased. Methane is a large revenue producing product, so reducing leaks increases revenue for an operator and also improves the environment. Most public companies today are being pressured to report on Environmental, Social, and Governance (ESG) risks, including ESG strategies to reduce methane emissions.

Properly designed, manufactured and maintained gas flow measurement systems typically emit minimal amounts of methane. This paper provides the computations to quantify the difference in gas emitted in blow down operations between (1) flange union and single chamber (simplex) meter runs and (2) dual chamber (senior) meter runs. This provides some basic data to assist users in their ESG reporting effort and developing methane emission reduction strategies.

Orifice Plate Measurement Operations

Orifice plate meters have been used for over 50 years to measure natural gas an integral part of the world energy system, financial gas (energy) transactions amounting to millions of dollars are managed every day. To operate an orifice plate custody system effectively with low uncertainty requires periodically checking the orifice plate for nicks, damage, wear or accumulated deposits. With an orifice union or single chamber meter run, the line must be shut down or diverted and the gas between the bypass or shutoff valves must be blown down or vented.

With a dual chamber meter run, the plate may be inspected without shutting down the line and only a very small amount of gas in the upper chamber is then vented to atmosphere. A blow down of the entire meter run is not required for routine inspection, cleaning, or changing the orifice plate if a beta ratio change is required, (due to process flow changes) or if an orifice plate becomes subsequently damaged due to erosion or edge deterioration. Therefore, the best strategy to reduce methane emissions and improve ESG strategies is to use an orifice fitting with a dual chamber to allow change outs of an orifice plate quickly and with only a small volume of gas bleed- off, noting that the volume of a gas is inversely proportional to its's pressure and directly proportional to its temperature and the amount of gas in the trapped vent volume.

A typical single chamber 6-inch meter run is shown in Figure 7. below with the conditioning plate and associated flanges, the vent volume and associated cost to change the plate is based both on blowing down the meter run and also the cost to close the system down, remove bolting and gaskets inspect the plate or change out then assemble and bleed-off the air in the system after re-assembly to maintain natural gas composition integrity.

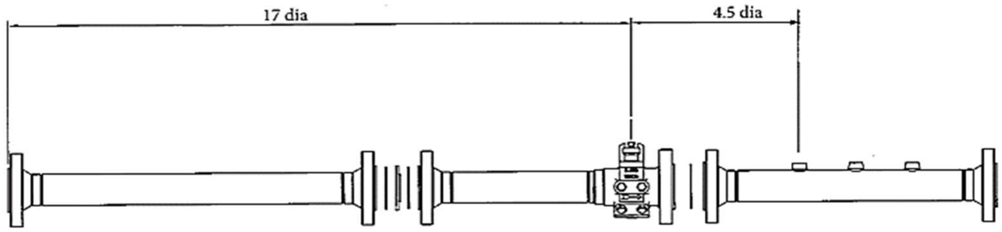

Figure 7. Typical Single Chamber Custody Transfer Meter Run

A typical containment volume for this meter arrangement is the internal volume of the meter run and single chamber unit plus the impact of the pressure and temperature on the contained volume. Considering this 82" long meter run used in a typical midstream operation at 650 PSIG and say 80 degrees F and 1020 BTU, the blow down time is calculatable based on using a 1-inch Tap usually installed for this purpose, also the vented volume can be determined by using Equation 3-15 from the GPSA ENGINEERING DATA BOOK; Vol. 1 Sec. 3, Eleventh Edition.)

Typical vent data is shown next based on the 6-inch diameter meter run in Figure 1 above.

Typical example for the Single chamber volume at 82 inches o/all length at atmospheric pressure blocked each end is 1.372 cu feet. At 750 PSIG and 80 Degrees F, the trapped natural gas volume available to be released to the environment would be appx. 70.25 cu ft. for each blow down attempted without any valve leaks.

Companies that use single chamber fittings, which is extensive in certain areas of the world are emitting this typical gas loss value for each station maintained or inspected. For say 100 stations at 6-inch diameter this would be 7025 cu feet of Methane / Natural Gas released to the atmosphere per each maintenance visit / blow down, for all units.

Further Facts and Figures

The following data shows a comparison for various meter tube diameters with standard custody transfer length requirements, the data shown below indicates the volume losses per a single chamber blow down per diameter assuming a 600 PSIG line pressure. The associated volumes per diameter are also compared to the blow down (bleed off) for a dual chamber orifice fitting and meter run, both vented emission volumes are shown in Table 7 for meter runs from 2 -16 inches bore with schedule 40 pipe at 68^{o} F, both these meter run types are used in various custody / non custody meter stations world-wide.

Diameter Schd 40 inches	Upstream Length in Diameters	Downstream Length in Diameters	Upstream Length Inches	Downstream Length Inches	Total Length	Volume in cu inches	Single Chamber Vented Volume ft^3 Atmos (14.73) 68 deg F	Dual Chamber Vented Volume ft^3 Atmos (14.73) 68 deg F
2.07	17.00	4.50	35.14	9.30	44.44	149.12	3.52	1.520
3.07	17.00	4.50	52.16	13.81	65.96	487.63	11.49	2.280
4.03	17.00	4.50	68.44	18.12	86.56	1101.92	25.97	3.180
6.07	17.00	4.50	103.11	27.29	130.40	3767.22	88.80	4.830
7.98	17.00	4.50	135.68	35.91	171.59	8584.21	202.35	9.050
10.02	17.00	4.50	170.34	45.09	215.43	16987.58	400.44	13.220
11.98	17.00	4.50	203.71	53.92	257.63	29055.28	684.90	16.490
15.00	17.00	4.50	255.00	67.50	322.50	56990.45	1343.40	28.020

Table 7. 3 x Section Meter Run (up/down + conditioner) Showing Volumes at Pressure and Blow Down at 14.73 psi

The 12-inch diameter OFU would emit appx. 700 Std Cu Ft of gas each time the pipe was opened to affect a plate change or maintenance, by comparison the dual chamber orifice fitting which will bleed of a very small amount for the same orifice plate change out due to the small chamber volume in the fitting itself Circa: 16.5 cu ft for these same pressures and temperatures this means that the single chamber unit emits 45 X more natural gas during a blow down at these conditions .

Note: Blow down requirements are not unique to orifice meters. Ultrasonic meter runs must be blown down completely any time that transducers are changed, inspected or cleaned also with the same emission effect as a single chamber meter.

Conclusion

The amount of gas emitted by a normally functioning orifice meter run in reality is relatively small in either the dual or single chamber mode. However, the dual chamber meter run emits significantly less natural gas than the single chamber meter run for the same conditions as seen from the above data and over a large installed base can have an effect on L&U (loss and unaccounted for) product.

The benefits of the dual chamber orifice meter are key where maintenance, plate changes and custody pipeline operations are required such as in the midstream operations space.

The simplicity of orifice plate removal for a dual chamber unit is immensely more cost effective by reducing maintenance times from many hours, to minutes together with reduction in exposure to hydrocarbons during the process. Over the long term the savings in ESG impacts plus manpower are large.

References

GPSA ENGINEERING DATA BOOK; Vol. 1 Sec. 3, Eleventh Edition.

AGA / API - Meter Run Lengths for Custody Transfer

ESG : Environmental, Social, and Governance (ESG) Risks 2021 (US Government).

Engineering Drawings and Blow Down Volumes (courtesy of TMCO the Meter Company)

Table 1. DP limits in AGA 3, Part 2 for flowing Temperatures to 150 °F

Table 2. Calculations based on: ASME Publication 75-WA/FM-6 and Mason Wilson and Birkhead Publication - Measurement Error Due to the Bending of Orifice Plates.

Table 3. based on the equation by Morrow, T. B., D. L. George and M. G. Nored in "The Metering Research Facility Program. Orifice Meter Operational Effects: Operational Factors that Affect Orifice Meter Accuracy," Topical Report to Gas Research Institute (GRI) , Report No. GRI-00/0141, GRI Contract No. 5097-170-3937, April 2002.

Table 4.5,& 6. AGA 3, Part 2-F. (DP limits in AGA 3, Part 2 are for flowing temp=150Deg F)

Calculation Figures 1-6 based on AGA 3 1992 and ISO 5167 Gas composition AGA 8.0 detail method