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CALIBRATION PARAMETERS IMPACT ON ACCURACY OF NATURAL GAS ULTRASONIC METER

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ABSTRACT

This paper discusses the impact on accuracy of Natural Gas USM that operate at different conditions than that of calibration. USM dry calibration is being done at vendor works during manufacturing and wet calibration at certified laboratories. There are various parameters measured along with volumetric calibration. These parameters cannot be left behind and there is a continuity required for carrying the accuracy levels from the test laboratories to the sites where it is installed. When Gas USM were calibrated at the laboratories, which is commonly known as Wet Calibration, only volumetric measurement and its comparison with the master meter was done for plotting the error curve against various flow rates, however the pressure and temperature during the entire flow rate calibration range were not being recorded. Either average pressure/temperature or instantaneous readings were indicated in the calibration report that is not utilized during meter operation for any corrections due to changes in pressure/temperature. These measurements such as calibration pressure and calibration temperature are primitive in nature forms the basis of meter performance at different conditions. Once the meter is subjected to different conditions relevant correction methods are required to be implemented for getting correct volume calculation. The correction of volume due to changes in the conditions, can impact the measurement accuracy at site. International standards for measurement of gas using USM generally specifies that the meters can be calibrated at conditions similar to that of meter operations at site. However it remains quite impossible for the laboratories worldwide to simulate exact conditions of site operating conditions. But that does not warranty that the meter can be calibrated at entirely different conditions than used at site. Different Manufacturers have come up with compensation methodologies that reduces the uncertainty in measurement. This paper describes the methodologies that can be followed for eliminating the error due to different operating conditions than that of calibration thereby reducing measurement uncertainty

KEYWORDS

Ultrasonic Flow Meter, Dry Calibration, Wet Calibration, Error/Calibration Curve, Pressure Compensation, Temperature Compensation, Expansion Correction

1.0 INTRODUCTION

Natural Gas measurement plays a vital role in the Oil & Gas Industry over 4 decades.

Flow meters used for custody transfer measurement of natural gas have undergone substantial improvement in the technologies. Every manufacturer brings advanced technologies for catering Industry customers of various sizes and capacities. Notwithstanding the competition faced by the manufacturers, customers' expectation rising over accuracy, reliability and site validation leads to improvement in metering methods. Initially individual meter accuracy was appreciated, later on its associated electronics, skid configurations, piping, diagnostics software, in-situ maintenance, external influences, calibration vs site installation uniformity played a much important role in achieving the performance. Only meter accuracy suffices the requirement of allocation metering or non-critical applications. For custody transfer applications, many parameters converge towards the metering acumen. One of the least known parameter is discussed in this paper which was grossly neglected by the user as well as the manufacturer. The impact of such negligence can cause revenue losses that may remain unnoticed by the metering experts. This paper discusses the identification, importance and impact of such parameter in custody transfer metering.

2.0 PARAMETERS INVOLVED IN NATURAL GAS ULTRASONIC METER

Basic principle involved in the measurement of flow through Ultrasonic flow meter mostly lies in the accurate measurement of the transit time between the transducers. Ultrasonic flow meter being a velocity meter, all other parameters involved in the flow rate measurement is calculated from the factory/no-flow & lab/natural gas flow calibration coefficients [1].

Factory/Dry/No-flow calibration coefficients can be as given below

1. Meter internal bore diameter
2. Meter body chord Face to Face distance
3. Individual transducer, holder & mount's length
4. Individual transducer's delay & delta times
5. Pressure & Temperature
6. Factory/Dry/No-flow calibration forward flow coefficients
7. Speed of sound measured by individual transducer

Lab/Wet/Natural Gas Flow calibration coefficients can be as given below

8. Pressure & Temperature during natural gas flow calibration
9. Natural gas flow calibration flow coefficients
10. Meter flow factors at different flow rates derived during flow calibration
11. Natural gas mixture dynamic viscosity
12. Young's modulus value
13. Poisson's ratio value
14. Transducer response parameters
15. Meter measurement tuning parameters

List of constant values derived during the above mentioned calibration process is generally inputted in the meter configuration; same configuration is required to be carried to the field for custody transfer measurement. Tuning parameters can be improved only based on the site operating conditions.

3.0 CALIBRATION CONDITIONS AND RESULT EVALUATION

In Natural Gas Ultrasonic meter calibration many parameters are measured for evaluating errors at various flow rates. These parameters are as follows

1. Master Meter Actual Flow rate
2. Test Meter Actual Flow rate
3. Gas Composition of flowing gas
4. Pressure measured at Master meter
5. Temperature measured at Master meter

6. Pressure measured at Test meter
7. Temperature measured at Test meter

Based on the above measurements mass balancing is done between the master & test meter so that the error at actual flow rates are evaluated. Standards being followed for standard volume comparison are AGA (American Gas Association) Report no.8 for standard compressibility (Z_{std}) & flowing compressibility (Z_f) and Gas equation as given below

$$Q_{std} = Q_f \ (P_f \, T_{std} \, Z_{std}) \, / \, (P_{std} \, T_f \, Z_f)$$

Whereas

Q_{std} – Standard flow rate
Q_f – Actual flow rate
P_{std} – Base or Standard conditions Pressure
P_f – Flowing Pressure
T_{std} – Base or Standard conditions Temperature
T_f – Flowing Temperature
Zstd – Standard conditions compressibility
Z_f – Flowing conditions Compressibility

The parameters measured during calibration are traceable to International standards and are calibrated on regular basis to achieve the stated uncertainty during calibration.

Once the calibration curve is evaluated based on the differences between master and test meter at different flow rates specified by the governing standard like AGA Report no.9, it is fed into the test meter configuration to be used at site and the meter is stamped for use with specified accuracy and calibration lab uncertainty.

In the calibration report, the test results are published stating the pressure and temperature at which the calibration is performed along with the flow rates and its corresponding diagnostic parameters. Calibration curve fed in the meter consists of flow rate & its corresponding error but the pressure & temperature at which the calibration performed are being left out without its importance.

The impact of calibration pressure and temperature and its usage in compensation of flow rates play a major role in USM uncertainty are discussed in the following sections.

4.0 CHALLENGE IN CALIBRATION AT SITE SIMILAR CONDITIONS

Operating conditions of custody transfer meters depends on the requirement of pressure, temperature and flow rate by customers or interconnecting pipelines. Simulating the operating conditions of meters in the flow laboratories is a daunting task. Industry experts suggest to perform the calibrations at pressures as close to the operating pressure as possible.

For a pipeline operating company calibration of meters are required at pressures that range from 40 barg to 100 barg or even higher. Moreover meters cannot be operated at a constant pressure and according to the requirement, pressure may vary from 40 barg to 100 barg. Under such conditions, calibration of meter at different pressures and their impact on accuracy is a wider subject for study. Such calibration may be done by research institutes or meter manufacturers for evaluating the meter performance under various pressure ranges.

Most of the calibration laboratories like CEESI, U.S.A are connected to cross country pipelines and the available operating pressure is utilized for calibration. Netherlands Metering Institute (NMi) is having a facility of calibrating the meter at any pressure upto 60 barg. Varying high pressure calibration facilities are very rare. GAIL India is having a facility certified by NMi, Netherlands to calibrate meters from 4” to 20” with pressure ranging from 45 to 60 barg which is again based on the upstream pressure from ONGC. Hence the economics of calibration at different pressures against the accuracy deviation due to pressure changes evaluation might give a better picture.

Due to constant evolution of metering technologies and growing awareness of accuracy, meter manufacturers devise their own method for compensation of such operating conditions with respect to calibration conditions. Pressure and Temperature are such parameters that impact the accuracy when the meters operate at different conditions than that of the calibration conditions.

Based on the economies of scale, compensating a meter due to pressure and temperature changes during operations seems more viable than calibrating a meter under different pressures and feeding the calibration curve at different operating conditions

5.0 EVALUATING UNCERTAINTY DUE TO DIFFERENCE IN OPERATING VS CALIBRATION CONDITIONS

In the previous section, it has been reviewed that difference between operating conditions and calibration conditions rise to compensation requirement. How such difference in pressure and temperature impacts the meter performance is required to be evaluated.

Meters when subjected to different pressure and temperature induce strain and stress due to which the internal diameter (ID) can change. Ultrasonic meter being a velocity meter depends on the accuracy of the ID measurement for calculating the volumetric flow i.e.,

Volumetric flow, Q = A X V

Whereas

A – Area of cross section

V – Velocity of gas measured by USM

Meter ID is measured during meter manufacturing stage at a constant pressure and temperature by highly precise micrometers traceable to international standards. Due to operating pressure and temperature, impact on the meter material and the ID will change. The effective change is described in the formula given below.

$ExpCorr_{Pres} = 1 + [3X\ \beta\ X(P_{abs.f}-P_{ref})]$

Where

$ExpCorr_{Pres}$ = expansion correction factor due to pressure (dimensionless)

β = pipe strain per unit stress ($MPaa^{-1}$) calculated as shown in the below equation

$P_{abs,f}$ = flow-condition absolute pressure (MPaa)

P_{ref} = reference absolute pressure (MPaa)

Pressure-Effect Strain Per Unit

$$\beta = \frac{[D_{out}^2(1+\upsilon)] + [D_{in}^2(1-2\upsilon)]}{E \cdot (D_{out}^2 - D_{in}^2)}$$

Where

β = pipe strain per unit stress ($MPaa^{-1}$)

D_{out} = outside diameter of the meter or pipe (m)

D_{in} = inside diameter of the meter or pipe (m)

υ = Poisson's ratio (dimensionless)

E = Young's Modulus of elasticity (MPaa)

Similarly equation for temperature correction is as given below

$ExpCorr_{Temp} = 1+3 * \alpha * (T_{abs.f} - T_{ref})$

Where

$ExpCorr_{Temp}$ - expansion correction factor due to temperature (dimensionless)

α - Temperature expansion coefficient in per degC

$T_{abs.f}$ - flow-condition temperature, deg C

T_{ref} - reference condition temperature

Both pressure and temperature corrections are required to be applied to the actual flow measured by the meter as given below.

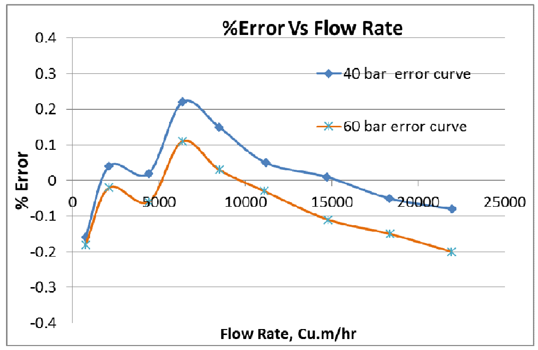
Corrected Flow = actual flow * $ExpCorr_{Pres}$ * $ExpCorr_{Temp}$

These corrections are required to be reviewed before applying it for calculation based on the following situations

1. Operating pressure is required to be within a certain range of calibration pressure
2. Whether reference pressure/ temperature recorded during measurement of ID / OD in manufacturer's lab for no-flow dry condition or during wet flow calibration condition to be considered

In a study by one of the meter manufacturer, it is evaluated that if the pressure is beyond 500psi for a thick walled cast meter, it requires calibration close to the new operating pressure. Within the range of 500 psi these corrections can be effectively applied.

Typically when a meter is calibrated at two different pressures, the resultant error curve is not large enough to infer due to limitations on uncertainty of measurement in wet calibration laboratories which is illustrated in the picture below. The error as seen is between 0.1 to 0.2% but the uncertainty of measurement is around 0.3 to 0.6%, hence it cannot be concluded that the pressure difference during two different calibration is contributing the error, however applying the corrections as described above can nullify the errors.



%Error Vs Flow rate cu.m/hr

In the above chart it seems that the error of 0.1% is apparent between the meter calibrated at 40barg & 60barg. If the correction is not applied, the error will remain as a lost to accuracy.

It was discussed in many conferences whether the wet-flow calibration conditions or no-flow calibration conditions are required to be taken as reference pressure and finally all vendors have come to a conclusion that flow calibration conditions are applied for correction, since the meter is calibrated with calibration pressure and temperature as the operating conditions.

Following table will show how the %error when correction is applied w.r.t the no-flow condition parameters applied. The following example has been worked out for a 12" meter.

Table1 Comparison of Expansion Corrections Result with No-Flow/Wet Calibration

Comparision of Expansion corrections for Different Pressure & Temperature conditions with respect to no-flow conditions or no correction					
Parameter	Unit	No Correction applied	Using no-flow calibration conditions	Using wet flow calibration conditions	Using wet flow calibration conditions
Line Pres	barg	0	82	95	82
Line Temp	deg	0	25	25	25
Calibration pressure	barg	0	0	78	78
Calibration temperature	deg	0	20	22	22
Ext. dia, D_{out}	m	0.3048	0.3048	0.3048	0.3048
Int. dia, D_{in}	m	0.2889	0.2889	0.2889	0.2889
D^2_{out}	cu.m	0.0929	0.0929	0.0929	0.0929
D^2_{in}	cu.m	0.0835	0.0835	0.0835	0.0835
Young.mod, *E*		2068426	2068426	2068426	2068426
strain, β		0.000008	0.000008	0.000008	0.000008
ExpCorr-Pressure		1.000000	1.001942	1.000403	1.000095
Temp co-ef, α		0.000015	0.000015	0.000015	0.000015
ExpCorr-Temperature		1.000000	1.000227	1.000136	1.000136
Total Correction		1	1.0021689	1.000539	1.000231
Change between no-correction & correction applied			-0.0021689	-0.000539	-0.000231
			-0.22%	-0.05%	-0.02%

In the above example, the %error perceived of no correction to with respect to that of no-flow conditions is -0.22% that implies that no-flow conditions, if applied, will incur wrong correction of 0.22% over measurement. In case of applying calibration conditions of 78 barg & 22degC, correction with respect to operating conditions of 82barg & 25 deg C will correct the respective expansion of the spool. Even the operating condition pressure of more than 15 barg will correct upto 0.05% of spool expansion.

In another example as shown below, the operating conditions differ much larger than the calibration conditions, that result in much significant contribution to the corrections. In such a case the correction becomes appreciable to the operating company with such meters

Table2 Comparison of Higher Operating Conditions Expansion Corrections Result with Wet Flow Calibration

Comparision of Expansion corrections for Different Pressure & Temperature conditions with respect to no correction				
Parameter	Unit	No Correction applied	Using wet flow calibration conditions; Case 1	Using wet flow calibration conditions ;Case 2
Line Pres	barg	0	95	82
Line Temp	deg	0	25	25
Calibration pressure	barg	0	50	50
Calibration temperature	deg	0	22	22
Ext. dia, D_{out}	m	0.3048	0.3048	0.3048
Int. dia, D_{in}	m	0.2889	0.2889	0.2889
D^2_{out}	cu.m	0.0929	0.0929	0.0929
D^2_{in}	cu.m	0.0835	0.0835	0.0835
Young.mod, *E*		2068426	2068426	2068426
strain, β		0.000008	0.000008	0.000008
ExpCorr-Pressure		1.000000	1.001066	1.000758
Temp co-ef, α		0.000015	0.000015	0.000015
ExpCorr-Temperature		1.000000	1.000136	1.000136
Total Correction		1	1.001202	1.000894
Change between no-correction & correction applied			-0.001202	-0.00089
			-0.12%	-0.09%

In the following table, a case of the operating conditions that goes below the calibration conditions have been evaluated.

Table3 Comparison of Lower Operating Conditions Expansion Corrections Result Wet Flow Calibration

Comparision of Expansion corrections for Different Pressure & Temperature conditions with respect to no correction				
Parameter	Unit	No Correction applied	Using wet flow calibration conditions ;Case 1	Using wet flow calibration conditions ;Case 2
Line Pres	barg	0	48	38
Line Temp	deg	0	25	25
Calibration pressure	barg	0	78	78
Calibration temperature	deg	0	22	22
Ext. dia, D_{out}	m	0.3048	0.3048	0.3048
Int. dia, D_{in}	m	0.2889	0.2889	0.2889
D^2_{out}	cu.m	0.0929	0.0929	0.0929
D^2_{in}	cu.m	0.0835	0.0835	0.0835
Young.mod, *E*		2068426	2068426	2068426
strain, β		0.000008	0.000008	0.000008
ExpCorr-Pressure		1.000000	0.999290	0.999053
Temp co-ef, α		0.000015	0.000015	0.000015
ExpCorr-Temperature		1.000000	1.000136	1.000136
Total Correction		1	0.999426	0.999189
Change between no-correction & correction applied			0.000574	0.002013
			0.06%	0.20%

In the above table it seems that a correction of 0.2% is being applied. In most of the USM manufacturer, the accuracy specified after wet flow calibration is 0.1% and a correction of 0.2% only due to operating conditions against calibration conditions is a eye-opener. In such a case the meter is required to be calibrated within the appreciable range of operating pressure implies.

6.0 CORRECTIONS METHODOLOGY APPLIED BY DIFFERENT VENDORS

Initially when USM is used as a custody transfer meter to replace much accurate turbine meter in order to overcome the difficulties of moving parts, frequency maintenance, frequent calibration and less diagnostic features, the spool expansion correction of USM was not envisaged. Later on every manufacturer identified the hollow spool with no moving parts can have impact in measurement to a considerable quantity when the meter is operated at different conditions than calibration conditions.

Much earlier, when the concern for spool material expansion correction was envisaged, ID and OD measured during no-flow conditions and their respective pressure/temperature were taken for correction. However it was identified that the spool changes have been corrected during wet flow calibration and accordingly corrections applied with respect to calibration conditions for operating conditions. An error of more than 0.2% is evaluated in Table 1 applying no-flow conditions for expansion compensation.

Most of the vendors incorporate such compensation in the meter configuration with their DSP electronics capable of such calculations in-situ. However these corrections require online values of pressure and temperature that allows manufacturers/users with following 2 different methods.

1. M/s Daniel and M/s Elster use flow computer to do the correction by collecting the actual flow from the meter and calculating online with pressure and temperature inputs so as to evaluate corrected flow rate.
2. M/s SICK meter is having a facility to input pressure/temperature readings of calibration in the meter during calibration which is required to be enabled otherwise fixed pressure / temperature values will be taken for corrections during calibration. This meter corrects the USM spool expansion during calibration also. At site, line operating conditions are required to be inputted to the meter for required USM spool expansion correction.

7.0 CONCLUSION

- Ultrasonic Meters are required to be calibrated similar to operating conditions
- Compensation for USM spool expansion corrections can only be applied if the operating conditions are close enough to calibration conditions
- Expansion corrections, if applied, requires wet-flow calibration pressure and temperature and operating pressure and temperature for desired results
- Corrections, go or no-go, depends on the economies of operation taking care of above points

Understanding the meter operations with its impact of external influences and conditions will enable us towards better accuracy of metering and its significances.

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