

## Quality Assurance and Calibration of High Pressure Natural Gas Fiscal Meters

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### ABSTRACT

Fractional inaccuracy in metering causes huge revenue surplus / deficit in gas transactions. For example,  $\pm 0.5$  % error in 32.93 bcm of Natural Gas has a financial implications to the tune of INR 546 Crore annually in India. Even an improvement of  $\pm 0.1$  % will result huge changes in the revenue potentials. Of many factors, the calibration at near site operating condition is significant. Any pressure,  $> 4$  bar is termed as high pressure. Lack of sufficient facilities drives competition among calibration laboratories to maintain and up keep the standards to globally acceptable levels. This paper aims at surveying the technical concepts and requirements behind the quality assurance of gas flow meters at high pressure near operating conditions, recommendations of national / international standards and reports. Similarity analogies and their impacts, practices and tradeoffs followed around the world due to lack of appropriate calibration facilities at real operating conditions are also presented.

Four combinations of analogies that could be practiced in the case of deviations from site conditions are discussed. Reynolds Number and Flow rate Matching, Pressure and Flow rate Matching, Density and Reynolds Number Matching, Density and Flow rate Matching are evaluated and their limitations, practicality and the implications are deliberated in detail.

OIML, ISO, BIS, AGA, MID Recommendations for calibrations are presented. Evaluation of alternate fluids is presented with impacts.

### KEYWORDS

Flow Meters, meps, Pressure, Standards, Analogies

### 1. INTRODUCTION

Gas companies target reconciliations to the order of  $\pm 0.1$  % under “Third party audit for metering “for region wise pipeline networks both in volumetric and energy terms. This tolerance is possible if the flow metering systems is assured at high pressure to smallest possible uncertainty. For, example if two meters are involved in the reconciliation process and each having an overall uncertainty of  $\pm 0.3\%$  (which is common for custody transfer metering systems), the combined uncertainty in the flow rates will be  $\pm \sqrt{0.003^2 + 0.003^2} = 0.00424$  m<sup>3</sup>/h, if the meters handle 100 m<sup>3</sup>/h each. The reconciliation is reasonably to be expected within the above estimate. To achieve the targeted figures, calibration of all equipment must be performed to the order better than  $\pm 0.1\%$  including all accessories.

Even a small fraction ( $\pm 0.5$ ) of inaccuracy causes huge revenue fiscal surplus/deficit among the transaction companies participating and dealing with Natural Gas around the world. A  $\pm 0.5$  % error in metering 32.93 bcm gas has a financial implication of about INR 546 Crore annually in India. Many factors contribute to this metering inaccuracy

and the two prime factors are the calibration at off - operating conditions and uncertainty of the calibration laboratory. The calibration gas conditions practiced at laboratory and subsequently real site operating conditions drive the ultimate performance and accuracy that could be realized from these custody transfer gas flow meters. There are inadequate calibration facilities available for calibrating the meters at operating conditions or at high pressure (> 4 bar), and it drives competition among calibration laboratories to maintain and up keep the standards to globally acceptable levels.

This paper surveys the technical concepts and requirements behind the quality assurance / calibration of gas flow meters at high pressure near operating conditions, recommendations of national / international standards and reports. Practices and trade offs followed around the world due to lack of appropriate calibration facilities at real operating conditions are also presented.

AGA 7 [1] discusses four types of analogies that could be practiced in the case of deviations from site conditions viz. Reynolds Number and Flow rate Matching, Pressure and Flow rate Matching, Density and Reynolds Number Matching, Density and Flow rate Matching. For typical site conditions, the four analogies are evaluated and their limitations, practicality and the implications are deliberated in detail.

## **2. CUSTODY TRANSFER FLOW METERS**

Though orifice meters are extensively used for Natural gas metering, they are excluded from the discussions as they do not require wet calibrations. Coriolis meters are also excluded due to their lack of application in large scale custody transfer of Natural Gas

### **2.1 Turbine Meters**

Turbine Meters (Fig.1) are inferential velocity sensing flow meters measuring gas flow volume indirectly by counting the number of revolutions, when rotor is subjected to a gas flow. The flowing gas imparts force on rotor.

For idealized turbine meter, the angular velocity of the rotor is directly proportional to the volumetric flow rate and would have a single k-factor and a flat error performance curve as shown in Fig. 2. However the actual rotational speed depends on mechanical drag and fluid drag on rotor blades, blade tips, rotor hub and is function of Reynolds number. It also depends on velocity, passage way size, shape, rotor design, gas density etc. The non-fluid retarding forces are introduced by the friction of rotor bearings and the mechanical loading of the drive train in the flow indicating registers. Accuracy curve is practically independent of line pressure and temperature

As the kinetic Energy of gas,  $(0.5\rho V^2)$  (where  $\rho$  : density,  $V$  :velocity) determines the rotor speed, the output i.e. angular velocity of the rotor is dependent on the operating pressure and the velocity explicitly. The general accuracy curve (Fig.3) apply after adjustment of the change gears/setting of K-factors / application of the final meter factor/ any corrections performed within the meter itself ,but prior to the application of any linearization algorithms by equipment auxiliary to the meter. These tolerances are applicable at atmospheric pressure. As operating gas pressure increases, the performance of the turbine meter is expected to improve dramatically, with smaller values for repeatability and maximum peak-to-peak error, provided the meter is calibrated for the intended operating conditions. To minimize error, turbine meters should be calibrated for the applicable operating conditions.

### **2.2 Ultrasonic meters**

Ultrasonic meters as per AGA 9 [2] covers Multipath ultrasonic meters for custody transfer of natural gas. They are inferential meters that derive the gas flow rate by measuring the transit times of high-frequency sound pulses. Ultrasonic transducers are located on pipe wall and transducers are in direct contact with gas. Ultrasonic pulses are transmitted across flow by transreceivers .Without flow, they travel at same speed in both directions. With flow pulse along the flow moves faster (short

travel time) and pulse against flow moves slower (longer travel time). Transit times are measured for sound pulses traveling diagonally across the pipe, downstream with the gas flow and upstream against the gas flow. The difference in these transit times is related to the average gas flow velocity along the acoustic paths (Fig.4). Numerical calculation techniques are then used to compute the average axial gas flow velocity and the gas volume flow rate at line conditions through the meter.

The accuracy of an ultrasonic meter depends on several factors, such as, precise geometry of the meter body, ultrasonic transducer locations, integration technique inherent in the design of the meter, quality of the flow profile, levels of pulsation that exist in the flowing gas stream, gas uniformity and accuracy of the transit-time measurements. The accuracy of the transit time measurements depends on the electronic clock stability, consistent detection of sound pulse wave reference positions and proper compensation for signal delays of electronic components and transducers. Fig.5 presents the general accuracy curve before applying calibration corrections

### 3. FLOW COMPUTATIONS AND EQUATIONS

$q_f = \frac{V_f}{t}$  Volume Flow rate at Flowing Conditions.

$P_f V_f = Z_f N R T_f$  State Equation at Flowing Conditions.

$P_b V_b = Z_b N R T_b$  State Equation at Base Conditions.

For mass equivalence at the 2 conditions, the equations are combined to get

$V_b = V_f \frac{P_f}{P_b} \frac{T_b}{T_f} \frac{Z_b}{Z_f}$  Volume at base Conditions

$P$  : Pressure,  $V$  : Volume,  $Z$  : Compressibility,  $N$  : No. Moles,  $R$  : Universal Gas Constant,  $T$  : Temperature  
 $f$  : Flowing  $b$  : Base

## 4. PRESSURE EFFECTS

### 4.1 Turbine Meters

A sample of commercially available turbine meters of various designs was tested in natural gas at line pressures ranging from 30 to 700 psig [3, 4]. It was observed that the metering errors of all turbine meters were affected by line pressure changes. Although most of the sample meters reported less than  $\pm 1.0\%$  calibration shift over the entire pressure range, three of the nine meters tested exhibited calibration shifts more than  $\pm 1.0\%$ . This set of tests confirmed that the metering errors caused by calibration shift of some turbine meters under changing line pressures is significant. The maximum K-factor shifts of the sample meters at flow rates beyond 20% of the maximum rated flow rates ( $Q_{max}$ ) of these meters were within  $\pm 2.5\%$ . Furthermore, the maximum k-factor shift for one of the sample meters tested at flow rates lower than 20% of  $Q_{max}$  was found to exceed 7%.

From principle of dynamic similarity, the turbine meter must behave the same way at the same Reynolds number for different flowing fluids and the operating conditions. It is also apparent that the data points with similar Reynolds numbers exhibits similar error characteristics. Figs. 6-13 shows a series of turbine meter errors versus actual flow rates and Reynolds numbers plotted at different operating pressures

At low Reynolds number, the non-fluid force has a dominant influence on the error performance of the meter. At high Reynolds number, the non-fluid drag component of the retarding torque diminishes, and the meter responds strictly to the Reynolds number of the flow. Hence the error curve of the meter becomes much more linear and predictable.

Calibrating natural gas turbine meters with atmospheric pressure air is recognized by most regulatory agencies in the world. An atmospheric air calibration is easy and

inexpensive but the data is only applicable for very low Reynolds numbers.

K Factor arrived at Atmospheric air calibration is allowed for higher pressure applications. But the curve does not predict for other operating conditions. Use of Atmospheric Calibration Factors will under/over register. It is generally observed that the turbine meters under register the flow leading to revenue deficit in gas transactions, Errors of calibration matters most along with K Factors. Error patterns are distinct, different and unique. In addition to atmospheric calibration of meters, additional high pressure calibration is mandatory. Additional financial implications due to nonperformance of high pressure calibrations in addition to Atmospheric Pressure Calibration is to be assessed over the long run of operation of the meters. With Reynolds Numbers plot, data points tend to form a continuous smooth curve and Error Predictions possible for in-between Reynolds numbers Density effect is to be ignored at low Re (Figs.7,8,10,12). On the basis of Reynolds number, error curves at other pressures or with other gases can be estimated. It is generally impossible to extrapolate error curves beyond the range of measurements, Therefore calibration is recommended at least two conditions i.e. atmospheric air and with natural gas at 50 bar [5].

#### 4.2 Ultrasonic Meters

Ultrasonic Meters are influenced by the calibration pressures in three ways i.e. Reynolds Profile effect, Bourdon effect and SOS variations. Minimum operating pressures are recommended for most of the ultrasonic meters. Further a high pressure calibration is required above 4 bar operating pressure with appropriate corrections for the calibration factors. On - line correction for meter expansion/contractions must be applied in Flow Computers as recommended by the manufacturers. For high volume metering, this may have impacts on monetary transactions. Flow profile is function of Reynolds Number (Pressure / Density) (Fig.14) and is approximated

$$V(r) = V_{max} (1 - r/R)^{1/n}$$

V: Velocity, r, R : Radius and n s function of radius and pipe roughness. Ultrasonic path curved due to non-uniformity of the profile along the path.

Velocity perceived is average along the increased acoustic paths and hence profile correction coefficients are applied to the paths and remain constant over Re 10<sup>4</sup> to 10<sup>8</sup>. (Fig.15). Correction for deviation between calibration and actual field conditions is approximated for a typical ultrasonic gas meter.

$$q_f = q_i \left( 1 + \frac{4.12}{10^5} (T_f - T_c) + \frac{6}{10^6} (P_f - P_c) \right)$$

f: Corrected Flow rate for pressure and temperature

i: Indicated Flow rate ,c: Calibration Conditions

Fig.16 shows typical influence of pressure and temperature on the dimensions of meter body. Deviations are up to ±0.25%. Fig.17 illustrate the influence of calibration pressures on the meter. Errors up to ±0.35% can be expected depending on the flowrate. Fig.18 presents the effect of change of adjust factors. Ambient air calibration shows errors up to ±1% with 50 bar adjust factor. Fig 19 shows calibration results in terms of actual flow rates and Reynolds number for a ultrasonic meter .

#### 6. METROLOGICAL CHARACTERISTIC FOR GAS FLOW METERS

**OIML [6] defines the nominal operating conditions as normal, average or typical conditions of use** of a measuring system or a device provided by the manufacturer. Maximum permissible relative errors (mpes), positive or negative, for **measuring systems** are specified in Table 1-3 for Accuracy Class A. Maximum permissible errors on measuring volume at metering conditions apply to type approval or Initial verification where: **the meter is adjusted at nominal operating conditions;**

#### 7. QUALITY ASSURANCE AND CALIBRATION OF FLOW METERS

Under the following general circumstances, the meters must be assured for quality in a national international traceable flow calibration facility.

- a. Initial calibration by manufacturers as it is normally supplied
- b. For checking of accuracy by the end user and done in case confirmation required.
- c. After major repairs by the user or the supplier
- d. To improve accuracy in the order of  $\pm 0.25\%$  generally in high pressure calibration facility
- e. In case of dispute of measured quantities

Research has established that the performance of turbine meter varies with changes in flow rates and operating pressure. These variation are related to changes in Reynolds number and in some cases density and are particularly significant at low and intermediate operating pressure and flow rates, Attention to these issues during calibration is crucial for optimal measurement. Reynolds Number range and/or density for a meter need to be taken into account when designing a calibration program.

**At nominal operating conditions**, the errors shall be determined at a minimum of seven flow rates which are distributed over the measuring range at appropriate intervals e.g.  $q_{\min}$ ,  $0.05q_{\max}$ ,  $0.15q_{\max}$ ,  $0.25q_{\max}$ ,  $0.40q_{\max}$ ,  $0.70q_{\max}$  and  $q_{\max}$ . At each flow rate the errors shall be determined at least three times, independently and consecutively. Certain relaxations are permitted depending on the type of flow meters. For Ultrasonic Meters, 6-10 velocities with logarithmic spacing with three measurements of 100s duration required. At lower regions, 5-10 measurements for each velocity is required. It may be decided to concentrate the majority of the test points in the range of the meter's heaviest expected usage. OIML [7] stipulates that the error test shall be carried out at least at the **minimum and maximum operating pressure**. However, for specified

maximum pressure above 5 MPa( 50 bar) , a test at **5 MPa ( 50 bar)** is deemed acceptable

It is a requirement that all the flow calibration be completed in a certified flow calibration facility or by a calibration system that is traceable to a recognized national international standards. Any thermodynamic or physical properties ( density, compressibility, speed of sound, critical flow factor etc) used during flow calculation shall be computed using latest revision of the GERG equation of state or Detailed Characterisation method (DCM) from AGA Report No.8 [8],and 10 [9] .DCM calls for on line analysis of Gas composition at the metering conditions

Estimated expanded uncertainty of the method adopted at all flow rates must be assessed and reported. The calibration results must be presented as Calibration factor Vs line flow rate - for constant operating conditions and Calibration factor Vs Reynolds number - for varying operating conditions. Calibration factors must be applied to minimize bias errors by means of, flow weighted mean error or polynomial or piece wise interpolation

## 8. CALIBRATION CONFIGURATIONS

To minimize errors, **meters should be calibrated in the same configuration as intended to be installed in service**. Most test facilities routinely perform calibrations in the recommended configuration. The errors of meters calibrated in this manner will be acceptable when installed in any of the configurations described. For applications with more severe installation configurations, it is recommended to consult laboratory for experimental data to determine an adequate calibration configuration

## 9. NON DIMENSIONAL NUMBERS FOR FLUID FLOW CALIBRATIONS

### 9.1. Reynolds Number

Reynolds number is a dimensionless ratio of inertial to viscous forces that takes into account the flow rate, geometry and physical properties. Reynolds numbers are significant to all differential pressure flow meter calibrations and also in characterizing turbine, ultrasonic flow meters. Mathematically it is expressed

$$Re = VD\rho/\mu = 4q\rho/(\pi D\mu) = 4m/((\pi D\mu))$$

$$q = V\pi D^2/4$$

$q$ : Volume Flow Rate,  $V$ : Velocity

$m$ : Mass Flow Rate,  $\mu$ : Viscosity

When Reynolds Numbers are less than 2000, the flow is termed as laminar. For 2000 – 4000, the flow is in transition state between laminar and turbulent. If  $Re > 4000$ , the turbulent flow is characterized by mixing of the fluid and interactions (Fig.14). Solutions are possible by simplified theory and empirical correlations. Flow regimes encountered in the field of custody measurements are normally turbulent. Under turbulent flows, when an object is exposed to same Reynolds number but with different media, Pressure, temperature, viscosity etc., it would exhibit similar behavior. Characteristics calculated using differential pressures across the systems is expected to be similar and predictable (Common Examples are Orifice, Valves etc.). Forces acting at corresponding points and flow characteristics are predictable as in aero foils, scaled models of car, buildings etc. to predict the corresponding behavior of a full size object.

It is expected that the rotor of turbine would rotate at same speed for same  $Re$ . Reynolds number are used to correlate the calibration and operating conditions of a turbine meter under various flow rates, pressures and fluid types. A meter calibration carried out in a test facility over a particular range of Reynolds numbers characterizes the meter's performance when used to measure gas over the same range of Reynolds numbers when the meter is in service. Therefore, the K-factors established during such a calibration, in most instances, can be used to

compute flow measured by the meter in service.

## 9.2 Mach Numbers

Mach Number is a dimensionless ratio of inertial forces and elastic forces or simply the flow velocity/Sound Velocity

$$Ma = V/c \quad c = \sqrt{\gamma RT/M}$$

Ma: Mach number

c: Velocity of Sound

$\gamma$ : Real Gas Index

R: Universal Gas constant

T: Temperature

M : Molecular Weight

It is significant for all differential pressure flow meter operations, critical flow venturi nozzles and the ultrasonic meter.

## 10. Dynamic Analogies and Alternate fluids

AGA 7 [1] gives four combinations of analogies that can be useful while deciding the calibration programs. The expected operating Reynolds number range and or density for a meter needs to be taken into account when designing a calibration program. This requires establishing the expected range of flow rates and the properties of the gas to be measured at the intended meter location. The gas properties may be determined directly by measurement or by calculation from empirical equations. Table 4 presents the evaluation of 4 analogies for typical design of calibration facility.

### 10.1 Reynolds Number and Flow rate Matching

Reynolds numbers calculated for field conditions will be matched in the test facility during calibrations. With Atmospheric Pressure calibration, Reynolds Number simulation for higher operating pressure is

impossible. The performance of some meters may also be sensitive to variations in gas density. Variations in calibration tend to be larger at lower gas densities as in turbine meters. **It is recommended that the users with low-pressure, low-flow applications should obtain the meter performance characteristics and calibration data at the operating density** to ensure that no significant measurement errors exist. Under this analogy

$$Re_f = Re_c \quad q_c = q_f$$

$$\rho_f/\mu_f = \rho_c/\mu_c \quad \rho_c = \rho_f/\mu_f \times \mu_c$$

f: Field c: Calibration

The density of the calibration gas can be calculated. From the calibration density, the necessary pressure/Z of the test gas is determined. The K-factors measured at each test flow rate can then be programmed directly into a flow computer for linearization purposes or used to calculate the meter's final meter factor .K-factors determined in this manner can be used directly for measurement of natural gas regardless of the calibration gas. In the event that natural gas is used as the test medium, the densities and viscosities between field conditions and laboratory conditions need be adjusted for temperature and composition differences only. In the event, an alternative test gas is used, the properties of the test gas will determine its density and viscosity characteristics. In either case, the pressure of the test gas is adjusted to create equivalent conditions of Reynolds numbers and flow rate. Table 4 lists the calculated pressures for different media. As it exceed 50 bar, this analogy cannot be practiced. Further CO<sub>2</sub> is unsuitable for ultrasonic meter

## 10.2 Pressure and Flow rate Matching

Traditionally, the practice has been to match both in-service pressure and flow rates during calibration tests. With same media, the forces could be within limits.

$$P_f = P_c \quad q_c = q_f$$

When the medium is a gas of high relative density ( N<sub>2</sub>, CO<sub>2</sub> etc) , this results in density and, in some cases, Reynolds conditions in the meter that are significantly higher than those in service. Calibration/Testing with heavy gases at matched pressure and flow rates results in high momentum at the rotor. This means that the rotor thrust bearing could be overloaded, with detrimental effects on accuracy and meter life. As Table 4 indicates this results in either low or high Reynolds numbers.

## 10.3 Density and Reynolds Number Matching

Turbine meters can exhibit density-related performance effects. This effect is observed only at low pressures and low flow rates. Density and Reynolds number would be matched instead of flow rate and Reynolds number. Using the same notation as above, equating the field and test Reynolds number and density, leads to the relationship:

$$q_f/\mu_f = q_c/\mu_c \quad q_c = q_f/\mu_f \times \mu_c$$

Calibration flow rates are calculated using the above equation. The calibration flow rate range will differ from that in the field by the ratio of the viscosities involved. When using density and Reynolds number matching in alternative calibration gases, it may not be possible to calibrate the meter over its designed flow rate range.

## 10.4 Density and Flow rate Matching

Alternative approach to assessing density-related performance effects is to match density and flow rate during calibration.

$$\rho_f = \rho_c \quad q_c = q_f$$

Pressures and Reynolds Numbers will differ. With typical alternative calibration gases, this approach leads to Reynolds numbers, which are significantly lower than those in the field. It may be desirable to calibrate some meters under more than one set of conditions in

order to fully assess their expected performance in the field.

## 11. CALIBRATION GASES

Analogy / Similarity data show that meters used in natural gas can be effectively calibrated with different gases ( Air/Nitrogen,CO<sub>2</sub>,Methane/Helium etc.), and that satisfactory measurement will result provided calibration is conducted over the range of Reynolds numbers and/or density expected at operating conditions. K Factors, Meter Factors, Change Gears can be confidently used. Operating media also shows noticeable shift in calibration factors though they are within acceptable limits (Fig.20-21). Calibrating meters in other gas presents several advantages: (1), being noncombustible, is safer to handle than natural gas; (2) comparing to both natural gas, the lower operating pressures needed to reach the target meter test Reynolds number require less compression; (3) the fact that the carbon dioxide meter proving loop can operate at a lower pressure means that time saving devices such as automated test meter clamps can be easily and inexpensively deployed; (4) because of the higher density no density related correction would be necessary to improve the accuracy of calibration. For the case presented in Table 4, Nitrogen/air is recommended as the medium along with pressure & flow rate and density & flow rate matching

## 12. RECOMMENDATIONS

Since calibration is so important to flow measurement accuracy, many regulatory agencies and professional organizations have recommendations for good calibration practices. OIML [6, 7] recommends that **turbine meters be calibrated at or close to their operating conditions.**

**AGA [1] suggests that “a meter calibration carried out in a test facility over a particular range of Reynolds numbers characterizes the meter’s performance when used to measure gas over the same range of Reynolds**

**numbers when the meter is in service”.** It further recommends that **“the expected operating Reynolds number range and/or density for a meter needs to be taken into account when designing a calibration program”.** For best performance, calibration conditions should match the anticipated service conditions including considerations such as fluid characteristics, operating pressure and expected flow rates.

**ISO 9951 [10] states that an individual calibration of each meter shall be made. The calibration is preferably carried out at conditions as close as possible to operating conditions.** The facility at which the calibrations is carried out shall be traceable to the primary standards of a mass, length, time and temperature

**Measuring Instrument Directive (MID), and EN 12261, [11] states that each meter used at an operating pressure exceeding 4 bar must be calibrated close to the operating pressure, meaning all turbine meters require a high pressure calibration.** Meters with  $P_c < 100$  mbar calibrated with air and can be used up to 40 mbar. For  $P_c < 4$  bar, meters can be calibrated with air. For  $P_c > 4$  bar an **additional high pressure calibration** is mandatory. Test at  $P_c$  allows the meter to be used in the range  $0.5P_c$  and  $2P_c$ . For example, if  $P_c = 10$  bar and usable range will be 5 – 20 bar. Calibration tests in several pressures allows the meter to be used in wider range. For example if  $P_t = 10$  & 30 (usable range will be 5 – 60 bar). Extrapolation is allowed if calibration test done at least  $0.7 q_{max}$  for pressures  $P_c > 8$  bar, provided  $q_{max}$  is realized at low pressure. Valid errors must be found at low pressure ( $< 4$  bar). Extrapolation error must not exceed half the specified error. With polynomial correction, check to be done at 2 flow rates

**AGA 9 [2] dictates that any flow conditioning must ensure that there is no significant difference between the velocity profile experienced by the meter in the laboratory and the velocity profile**

**experienced in the final installation.** Since the velocity profile is a strong function of Reynolds number (Flow rates, geometry and fluid properties), this similarity can only be achieved with high pressure calibrations.

**IS 15674 [12], Recommends that the flow calibration tests shall be performed at a gas pressure, temperature and density near the expected average operating conditions** specified by the designer. Tests at any other specific pressure temperature and gas density range may be performed if necessary.

### 13. CONCLUSIONS

Regulators in many countries either mandate or recommend the calibration of gas meters close to their **intended operating conditions of pressures** in order to minimize measurement errors caused by pressure variation. OIML / ISO /BIS/ AGA recommend meters to be calibrated over a range of **operating pressures** which characterizes these meters' performance when they are placed in service.

As the calibration media is not significant, the meters can be calibrated with any gas such as Natural Gas, Air, Nitrogen, CO<sub>2</sub> etc. Any one of the 4 combinations viz Reynolds Number and Flow rate Matching, Pressure and Flow rate Matching, Density and Reynolds Number Matching Density and Flow rate Matching could be followed while calibration. However due care must be exercised to restrict the over speeding of turbine or over pressures above design pressures during calibrations.

Analysis of analogies reveals that Nitrogen/Air could be an alternative media in lieu of flammable natural gas for a specific application. However, Pressure and Flow rate Matching, Density and Flow rate Matching must be adopted. This will address the issue of pressure effect on calibrations of the fiscal meters.

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**Table 1. mpes for measuring systems**

<b>Maximum permissible errors on determining:</b>	<b>Accuracy class A</b>
Converted volume, converted mass or direct mass	± 0.9 % (<0.3 %)
Energy	± 1.0 % (<0.5 %)

**Table 2 - mpes for modules**

<b>Maximum permissible errors on:</b>	<b>Accuracy class A</b>
Measuring volume at metering conditions	± 0.70 % (<0.3%)
Converting into volume at base conditions or into mass	± 0.50 % (<0.01 %)
Calorific value measurement (only CVDD)	± 0.50 % (<0.2 %)

**Table 3 mpes for measuring instruments**

<b>Maximum permissible errors on:</b>	<b>Accuracy class A</b>
Temperature	± 0.5 °C (<0.27 °C )
Pressure	± 0.2 % (<0.1%)
Density	± 0.35 % (<0.2%)
Compressibility	± 0.3 % (<0.1%)

Values within ( ) are current practice

**Table 4: Analogies for calibration**

<b>Reynolds &amp; Flow rate matching</b>							
Sl.no	Parameters	Units	Natural gas	Air	Nitrogen	CO <sub>2</sub>	Helium + Nitrogen
1	Pressure	bar(a)	47	53.9693124	54.4539	26.87	86.5724
2	Temperature	deg C	30	30	30	30	30
3	Universal gas constant	J/kmol K	8314	8314	8314	8314	8314
4	Molecular weight	kg/kmol	17.9515	28.959	28	44	18.04
5	Flow rate	m <sup>3</sup> /h	5000	5000	5000	5000	5000
6	Compressibility		0.90800655	0.990981	0.997574	0.859327	1.01058
7	Density	kg/m <sup>3</sup>	36.8673588	62.57451971	60.63922529	54.58820472	61.31657833
8	Flow velocity	m/s	19.6487584	19.64875841	19.64875841	19.64875841	19.64875841
9	Reynolds number		1.9013E+07	1.9013E+07	1.9013E+07	1.9013E+07	1.9013E+07
10	Implications	Pressures high for other media . CO <sub>2</sub> unsuitable for Natural Gas					
<b>Pressure &amp; Flow rate matching</b>							
11	Pressure	bar(a)	47	47	47	47	47
12	Flow rate	m <sup>3</sup> /h	5000	5000	5000	5000	5000
13	Compressibility		0.90800655	0.991682	0.997285	0.726239	1.0081
14	Density	kg/m <sup>3</sup>	36.8673588	54.45545557	52.35630748	112.9804693	33.3705361
15	Flow velocity	m/s	19.6487584	19.64875841	19.64875841	19.64875841	19.64875841
16	Reynolds number		1.9013E+07	1.6546E+07	1.6416E+07	3.9351E+07	1.0348E+07
17	Implications	Reynolds equivalence is not satisfied by other media. CO <sub>2</sub> unsuitable for USM					
<b>Density &amp; Reynolds no matching</b>							
18	Pressure	bar(a)	47	31.8746079	33.1074385	19.0511582	52.18137355
19	Flow rate	m <sup>3</sup> /h	5000	8339.82727	8153.5292	6798.58789	8420.111642
20	Compressibility		0.90800655	0.99338764	0.997640339	0.90228216	1.013073076
21	Density	kg/m <sup>3</sup>	36.8673588	36.86735878	36.86735878	36.86735878	36.86735878
22	Flow velocity	m/s	19.6487584	32.7734503	32.0413451	26.7167622	33.08894788
23	Reynolds number		1.9013E+07	1.9013E+07	1.9013E+07	1.9013E+07	1.9013E+07
24	Implications	Pressures are low & Flow Rates are high for other media.CO <sub>2</sub> unsuitable for USM					
<b>Density &amp; Flow rate matching</b>							
25	Pressure	bar(a)	47	31.8746079	33.1074385	19.0511582	52.18137355
26	Flow rate	m <sup>3</sup> /h	5000	5000	5000	5000	5000
27	Compressibility		0.90800655	0.99338764	0.997640339	0.90228216	1.013073076
28	Density	kg/m <sup>3</sup>	36.8673588	36.86735878	36.86735878	36.86735878	36.86735878
29	Flow velocity	m/s	19.6487584	19.64875841	19.64875841	19.64875841	19.64875841
30	Reynolds number		1.9013E+07	1.1381E+07	1.1560E+07	1.4042E+07	1.1290E+07
31	Implications	Pressures & Reynolds Numbers are low for other media.CO <sub>2</sub> unsuitable for USM					
	<b>Options</b>		<b>I</b>	<b>III</b>	<b>II</b>	<b>V</b>	<b>IV</b>
	<b>Calculated Values</b>						

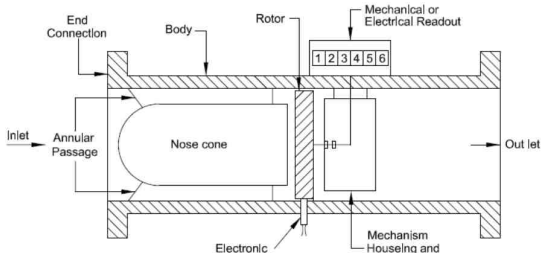


Fig.1 Turbine Meter

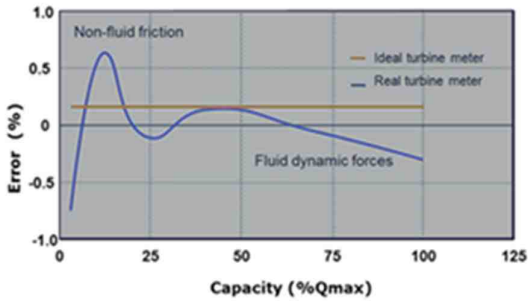


Fig 2 Effect of fluid and non-fluid retarding torques

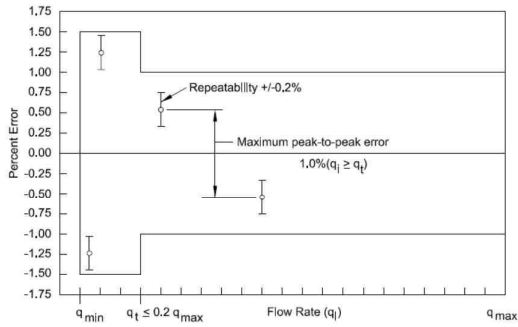


Fig.3. Accuracy Envelope of Turbine Meters

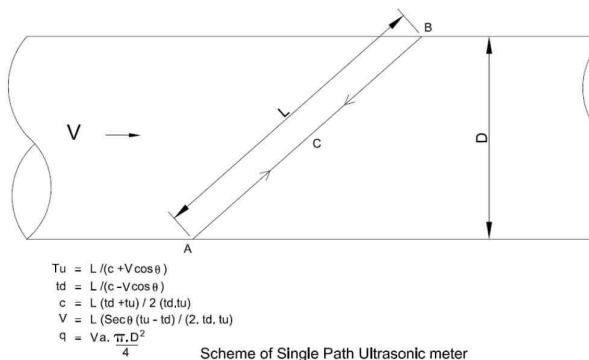


Fig.4. Scheme of Ultrasonic Meter

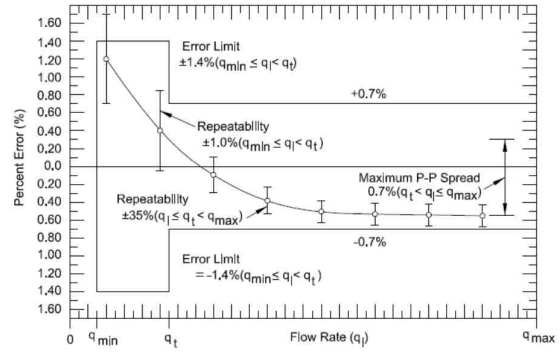


Fig.5. Accuracy of Ultrasonic Meters

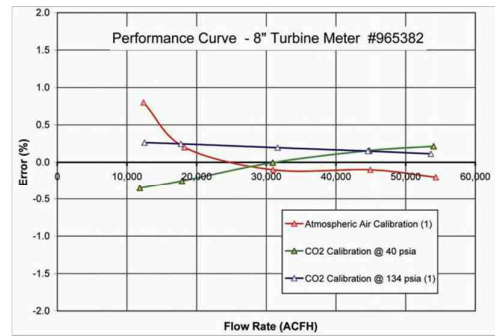


Fig 6 Turbine meter performance in different fluids plotted against flow rate

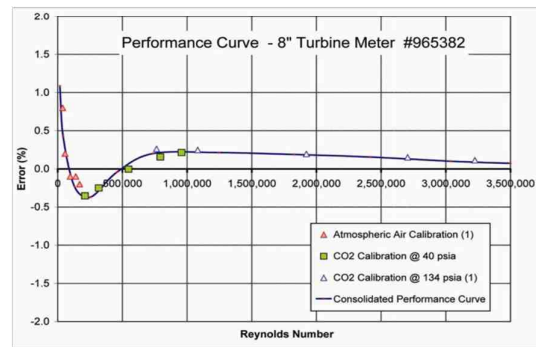


Fig. 7 Turbine meter performance plotted against Reynolds number

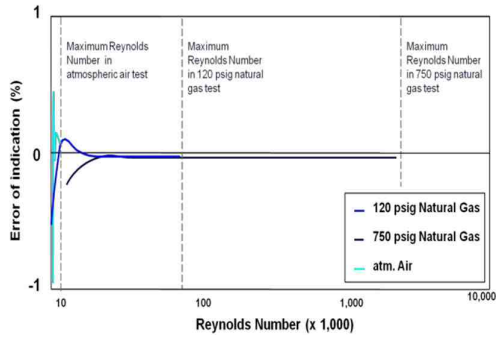


Fig. 8 Turbine meter error vs Reynolds number

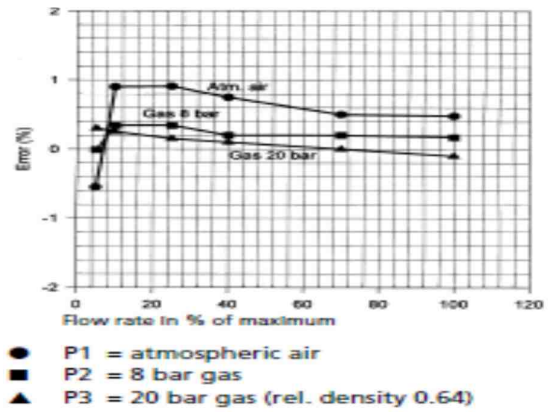


Fig. 11 Error Curves of 150 mm Turbine Meters (NMI)

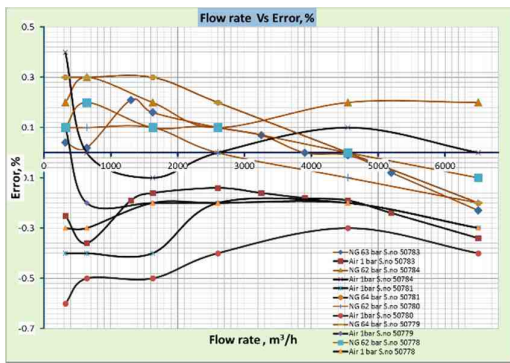


Fig.9 Error Curves of 300 mm Turbine Meters (NMI)

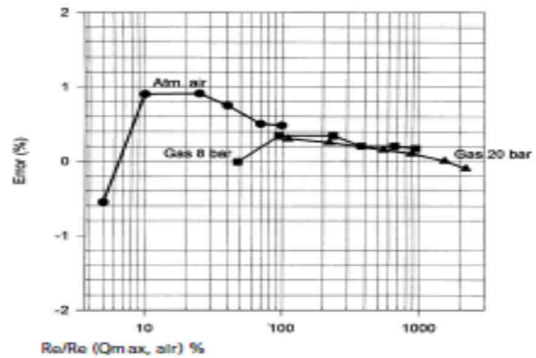


Fig. 12. Error Curves of 150 mm Turbine Meters (NMI)

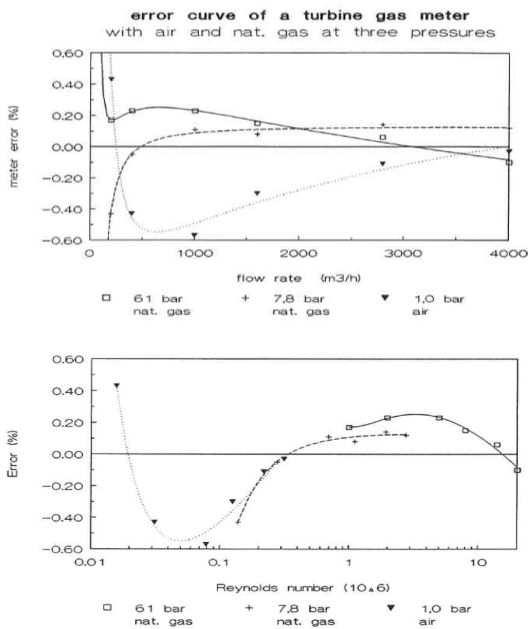


Fig.10 Error Curves of 300 mm Turbine Meters (NMI)

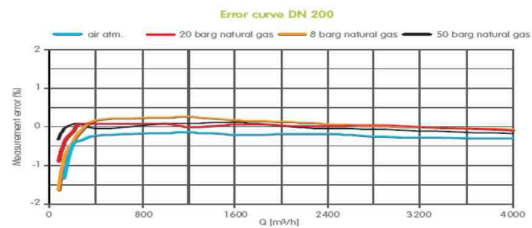


Fig. 13 Error Curves of 200 mm Turbine Meters (NMI)

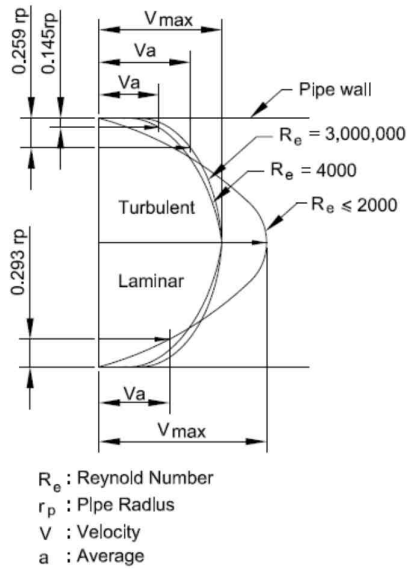


Fig.14 Velocity Distribution in Pipes

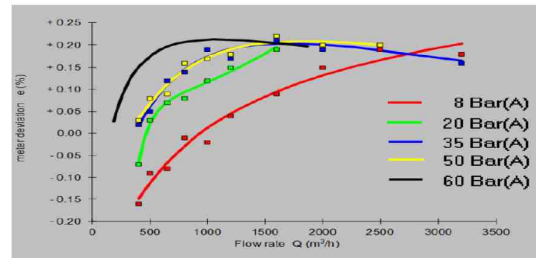
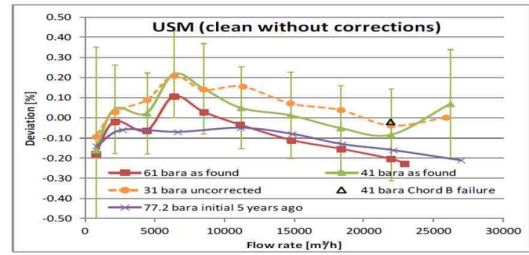


Fig. 17 Influence of Calibration Pressure (Source NMI)

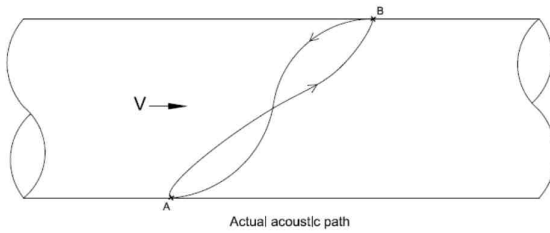


Fig.15 Reynolds Effects on the acoustic Path

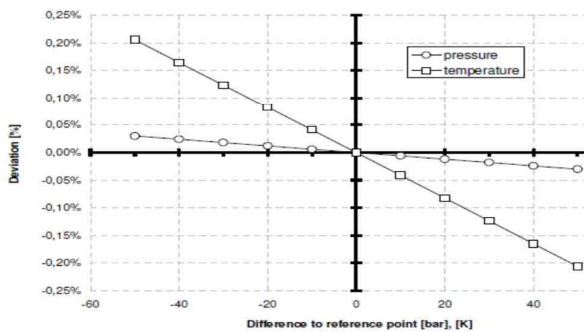


Fig. 10 – Influence of the meter body dimension changes

Fig.16 Influence of Pressure and Temperature on USM Dimensions

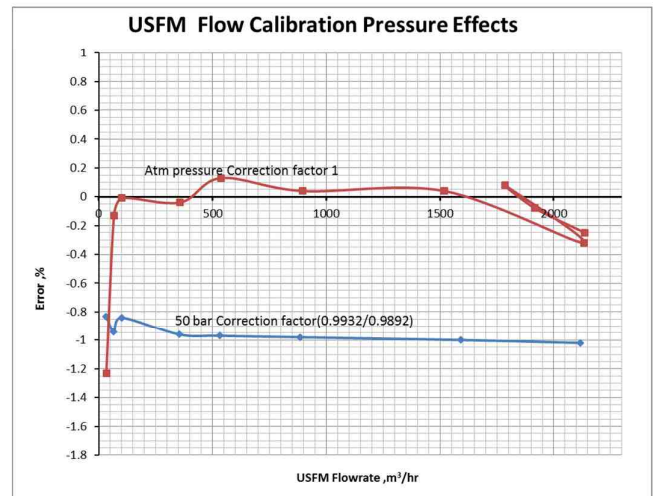
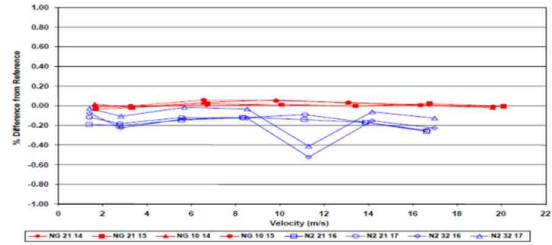
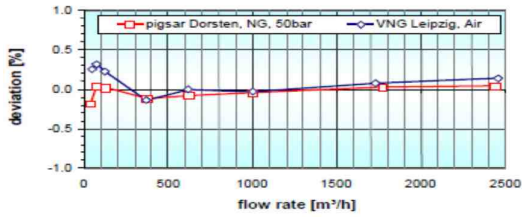
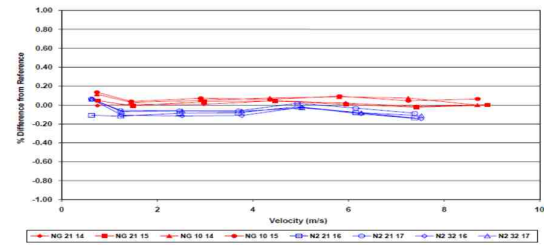
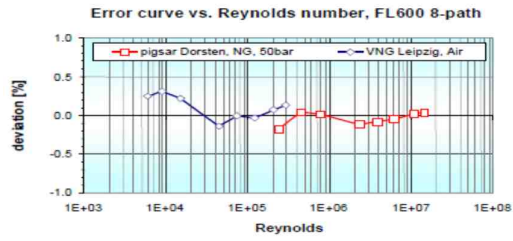


Fig.18 Influence of Calibration Factors on USM

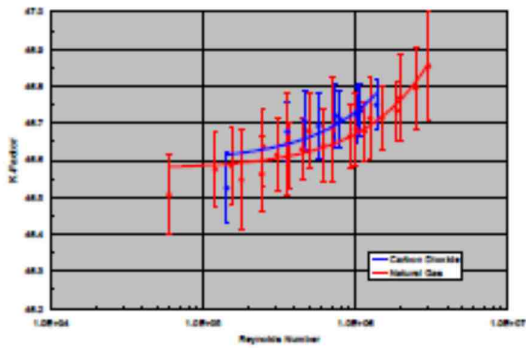


200 mm

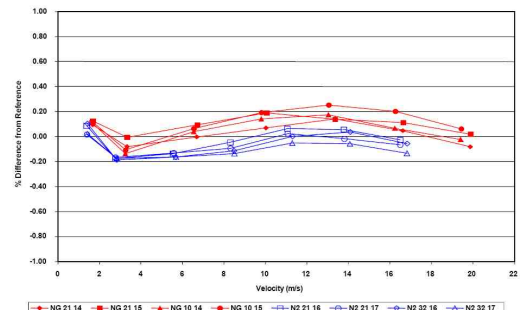


300 mm

Fig. 19 Error Curves (Actual and Reynolds Numbers)

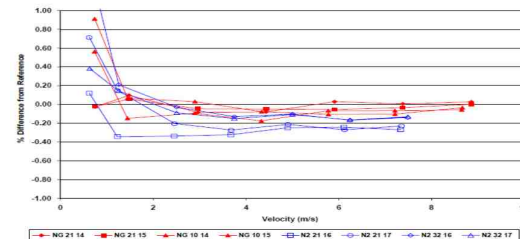


100,200,300 mm



200 mm

Fig. 20 Effect of Media on Turbine Meters (Terasen Gas)

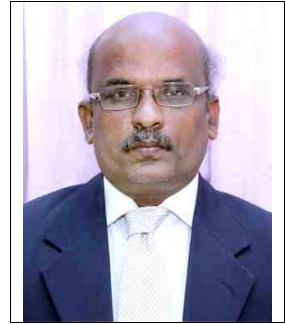


300 mm

Fig.21 Effect of Media on 200 mm Ultrasonic Meter

## Presenting Author Bio data

**Name** : R.Mascomani  
**Designation** : Deputy Director  
**Company** : Fluid Control Research Institute, Palakkad  
**Qualification** : M.Tech  
**Area of Expertise** :



- Have roughly 30 years of professional experience under various capacities in FCRI.
- Have worked as a technical /administrative head of various laboratories guiding the laboratory staff in R&D Activities and projects.
- Regularly deliver lectures on flow measurement for annual courses and customized training programs ( National and International)
- Design and development of new flow meters for special applications
- Design and development of new calibration facilities.
- Flow product research

### **Significant Achievements:**

**More than 35 Major projects completed.**

- **Establishment of Flow Facilities include**  
Air Flow Laboratory ,Wind tunnels, Breather valve test facility, PVTt calibration facility, 20 bar Closed Loop Test facility, 250 bar CNG Laboratory ,50 bar Natural Gas Laboratory
- **Development of Flow products include**  
Cone meter, Averaging Pitot Tubes and Mass flow meters
- **Major Projects include**  
Model testing of mixing device and top tube sheet of IHX, PFBR and Estimation of flow and Pressure distribution in PSP SH of PFBR ,Design, fabrication and experimental studies on sparger ,Air Damper test Facility
- **Conduct of Global Conference and Exhibition, flotek**

**Number of Papers Published in Journals: 2**

**Number of Papers Published in Conferences: 35 (app)**