EFFECT OF VARIOUS PARAMETERS ON NATURAL GAS MEASUREMENT AND ITS IMPACT ON UFG.

By
Gautam Chakraborty
Dy. General Manager (Pipeline)
GAIL (India) Limited

Background:

Unaccounted for Gas (UFG) is the difference between gas purchased/received and gas sold/send out .The term “unaccounted for gas", doesn't necessarily be merely a gas leak or gas theft, these are one of many other factors contributing to UFG.

The causes for unaccounted for gas can be broadly categorized into three, leak, theft and error in gas measurement. Normally gas leakages are fairly constant and increases gradually if the same is not attended and repaired. Gas lost due to measurement inaccuracies is very deceptive and sometime very difficult to detect. The cost and impact of the UFG sometimes passed directly to the consumers, but most of the companies strive to manage the impact of UFG for their valued consumers.

In this paper the UFG caused due to measurement inaccuracies will be discussed. There are many factors that can affect the overall uncertainty of the measurement; they can range from improper manufactured meter body to poorly designed installation. With the increasing price of natural gas, today the error that at one time seemed insignificant has now become unacceptable. UFG is now a common industry term and gas accounting is playing a bigger role in the decision making.

There are various challenges that natural gas Measurement system encounters day to day. The metering engineers all across the World are relentlessly working together to counter these challenges. Since inception, the natural gas metering is continuously evolving starting from flow nozzles to today’s highly accurate Ultrasonic meters.

It has been noticed that in addition to the inherent uncertainties of these different metering system, the major impact on natural gas measurement is because of the wrong/casual Operation & Maintenance practices of these systems. The effect of these impacts is more severe in case of custody transfer metering system, as it involves the stake of Company’s Profit. These impacts on natural gas metering can be due to error in various secondary measurement parameters like pressure, temperature, gas qualities etc or because of wrong installation, overlooking the periodic & preventive maintenance or even due to the wrong feeding of the fixed parameters in the system for measurement.

Let's consider a gas gate station. Very few use check meters to monitor the accuracy of these gate stations to ensure the accuracy of the measurement. Normally the gas volume at a gate station is corrected to a base temperature of 60°F/15.56 degC and base pressure of

1.01325bara/1.0332 Kg/cm2a, but if the gas being sold is not corrected to the same conditions, there will be unaccounted-for gas. If by mistake the base pressure has been entered in the flow computer say 1.3032 Kg/cm2a instead of 1.0332kg/cm2a, it can induce an error in the tune of 20% in the gas measurement. Similarly if instead of 15.56 deg.C base temperature if any one considers 15DegC, then it can cause an error of 0.19% error in gas measurement.

Now let's consider how gas temperature can affect accuracy. The ambient temperature affects the gas temperature. The amount of the effect is determined by how the temperature sensors are installed and how they are insulated to negate the environmental temperature effect. 1 Deg. C error of temperature measurement can cause a measurement error of 0.33%. The effect of inaccuracies in pressure measurement is also huge. An error of 1 bara in pressure measurement can induce an error of 5% in gas flow measurement.

Gas being the compressible fluid, the calculation of compressibility factor is also very critical for accurate gas measurement. Compressibility factor depends on pressure, temperature & gas composition. Suppose the Compressibility factor of a given terminal at a given pressure, temperature & gas composition was wrongly calculated by the flow computer as 0.93273 instead of 0.93072. A difference of 0.002 in compressibility factor can induce an error of 0.2% in gas flow measurement.

Similarly there is a direct effect of atmospheric pressure on gas flow measurement also.

These are the very few of the parameters which can directly affect the gas measurement hence the UFG. There are other factors like wrong designing of the installation, improper maintenance practices and above all the lack of awareness of the operating personnel which can lead to measurement error and in turn increase the “Unaccounted –for gas”.

This paper will cover many of the causes, effects and solutions for these measurement uncertainties including:

- Measurement uncertainties and how to reduce it.
- Meter inspection & Meter maintenance.
- Awareness

In this paper it has been shown through various measurement techniques, calculations & experiment data, how the various metering parameters affects the natural gas measurement system and its impact severity to the custody transfer application.

Commercial Angle of Analysis

- Say a fertilizer plant drawing at a rate of 3 MMSCMD. An error of 1% in volume measurement can results in 30,000SCMD, which is equivalent to approx. $ 4 million/annum. If we have even an error of 0.1%, the commercial impact per annum will be $0.4 million.

  This error in volume can be either or cumulative effect due to the error of measurement of the primary measuring equipments like flow meters or because of the secondary flow measurement devices say pressure transmitters, temperature transmitters, gas composition or because of wrong installation of the metering system.

- Let us take another example of the same plant, in this case suppose that instead of volume measurement error, there is an error in energy measurement by 1 kcal/scm, which appears very insignificant. But such an insignificant error can cost to the company in the tune of $ 50 K per annum.
- A thumb rule: With 1 SCM/hr loss can result to a financial loss of approx. $3.5 K per annum.

Some of the Major Challenges in Custody Transfer Gas Metering

Various Factors which will affect the Gas Metering

- Gas Quality (Composition, Impurities etc.)
- Installation Requirement – Upstream & Downstream
- Flow Profile
- Noise, especially in USM
- Rangeability
- Calibration
- Maintenance

Gas Equations

Boyle's Law

$$P_1V_1 = P_2V_2$$

Charle's Law

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

→ Ideal Gas Law

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

→

$$V_2 = V_1 \times \frac{P_2}{P_1} \times \frac{T_1}{T_2}$$

Considering the Compressibility factor, the equation can be re-written as

$$Q_b = Q_f \times \frac{P_f}{P_b} \times \frac{T_b}{T_f} \times \frac{Z_b}{Z_f}$$

or

$$Q_b = Q_f \times \frac{P_f}{P_b} \times \frac{T_b}{T_f} \times F_{PV}^2$$

$$\text{Where } F_{PV} = \sqrt{\frac{Z_b}{Z_f}}$$

The flow rate equation for orifice is :

$$Q_m = 359.072 C_d(FT) E_v Y_1 d^2 \sqrt{\rho_f h_w}$$

Where

$C_d(FT)$ = Coefficient of discharge for the orifice plate

$$E_v = \frac{1}{\sqrt{1 - \left(\frac{d}{D}\right)^4}}$$

Y_1 = expansion factor

d = orifice bore diameter

D = pipeline diameter

ρ_f = density at flowing conditions

h_w = differential presure

$$\text{Since Volume} = \frac{\text{Mass}}{\text{Density}}$$

$$Q_f = \frac{359.072 C_d(FT) E_v Y_1 d^2 \sqrt{\rho_f h_w}}{\rho_f}$$

Where

Q_f = Volume flow rate at flowing conditions (actual flow)

Comparison between flow equation of Orifice & Turbine Meter

$$Q_f = \frac{359.072 C_d (FT) E_v Y_1 d^2 \sqrt{\rho_f h_w}}{\rho_f}$$

$$Q_b = \frac{359.072 C_d (FT) E_v Y_1 d^2 \sqrt{\rho_f h_w}}{\rho_b}$$

$$\therefore Q_b = Q_f \times \frac{\rho_f}{\rho_b}$$

$$\rho_f = \frac{M_r P_f}{Z_f R T_f}, \quad \rho_b = \frac{M_r P_b}{Z_b R T_b}$$

Where

M_r = Molar mass of the gas mixture

R = Real gas constant

$$\therefore \frac{\rho_f}{\rho_b} = \frac{M_r P_f}{Z_f R T_f} \times \frac{Z_b R T_b}{M_r P_b}$$

$$\therefore \frac{\rho_f}{\rho_b} = \frac{P_f}{P_b} \times \frac{T_b}{T_f} \times \frac{Z_b}{Z_f}$$

$$Q_b = Q_f \times \frac{P_f}{P_b} \times \frac{T_b}{T_f} \times \frac{Z_b}{Z_f}$$

From above we can see that accurate measurement of temperature and pressure are just as critical to orifice plate metering as they are to turbine metering. Errors in pressure, temperature or compressibility will directly affect the error in the measured flow rate.However for Orifice, there are other factors also, like specific Gravity, Pipe ID, Orifice ID etc..

The effect of the below mentioned parameters on gas measurement can verywell understood from the above mentioned gas equation

- **Effect of Base condition (Pressure & Temperatue) on Gas Measurement**

  The base pressure & Base temperature are that parameters which are agreed between the supplier & the customers and are written in the contract to correct the flow at these base condition. Let's consider a gas gate station. Very few use check meters to monitor the accuracy of these gate stations to ensure the accuracy of the measurement. Normally the gas volume at a gate station is corrected to a base temperature of 60°F/15.56 degC and base pressure of 1.01325bara/1.0332Kg/cm2a, but if the gas being sold is not corrected to the same conditions, there will be unaccounted-for gas. If by mistake the base pressure has been entered in the flow computer say 1.3032 Kg/cm2a instead of 1.0332kg/cm2a, it can induce an error in the tune of 20% in the gas measurement. Similarly if instead of 15.56 deg.C base temperature if any one considers 15DegC, then it can cause an error of 0.19% error in gas measurement.

- **Effect of Pressure & Temperatue of the gas flowing through the gas meter on Gas Measurement**

  Now let's consider how gas temperature can affect accuracy. The ambient temperature affects the gas temperature. The amount of the effect is determined by how the temperature sensors are installed and how they are insulated to negate the environmental temperature effect. 1 Deg. C error of temperature measurement can cause a measurement error of 0.33%.The effect of inaccuracies in pressure measurement is also huge. An error of 1 bara in pressure measurement can induce an error of 5% in gas flow measurement.

- ***Effect of Compressibility Factor***

  The compressibility factor depends on pressure, temperature & gas composition. Error in measurement in any one these can cause error in compressibility factor calculation. A small change in Z can have huge impact on gas flow measurement; an error in third decimal point in calculation of Z can induce an error of more than 0.25%.

Failing to account for the compressibility factor in the AGA7 calculation can result in errors as high as 20% of the metered flow rate. Even for a fixed gas composition, the compressibility factor changes with temperature and pressure.

- ***Effect of Atmospheric Pressure***

  The pressure used in gas equation shall be in absolute. In most of the metering station gauge type pressure transmitters are being used, so to get the absolute pressure we have to taken in account of the local atmospheric pressure. Most of the people use a fixed atmospheric pressure that too atmospheric pressure at sea level. If the actual measurement is being done at a higher altitude, then this cause more than 0.1% measurement inaccuracies in the gas measurement.

Apart from above there some other factors which needs to be kept in mind by the metering engineers. Some of these aspects are as mentioned below:

Application of Proper standard for measurement of volume & Energy

Adopting standards for calculation of volume & energy is very significant. The metering engineer must be conversant with various standards, contract provisions before working in the metering system. One such common mistake sometimes happened like suppose the base condition as per the contact agreement between the consumer & the supplier is 15 deg.C as base temperature & 14.696 Psia as base pressure, but for energy measurement it adopts GPA 2172. GPA 2172 table takes temperature of 60 Deg.F (15.56 DegC) and pressure 14.696 Psia. This different base temperature can resulted in energy measurement error up to 0.19%.

Effect of higher hydrocarbons C6+ on gas measurement

The most of the Gas chromatographs used by the supplier can analyze the natural gas components are up to normal Hexane. But in most of the natural gas we can find higher hydrocarbons C7, C8,C9 etc. may be of very little quantity. But these heavier hydrocarbons can affect your gas measurement considerably.

The gas composition plays a dual role in gas measurement, one it affects the gas compressibility fact & another is in energy calculation. Both are very significant from the point of view of gas measurement. An availability of C7, C8 of 0.1 mole% each & C9, C10 of 0.05 mole% can

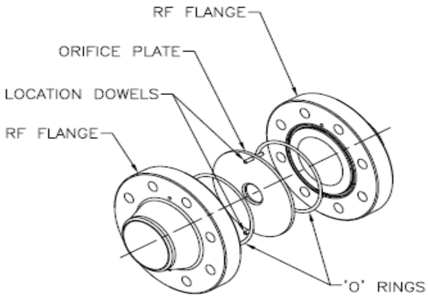
- Change in compressibility factor, which can results into 0.056 % reduction in NG volume between with and with-out taken into account of these heavier hydrocarbons separately.
- As the heavier hydrocarbon has higher calorific value, so there can be 0.466% increase in energy with and with-out taken into account of these heavier hydrocarbons separately.

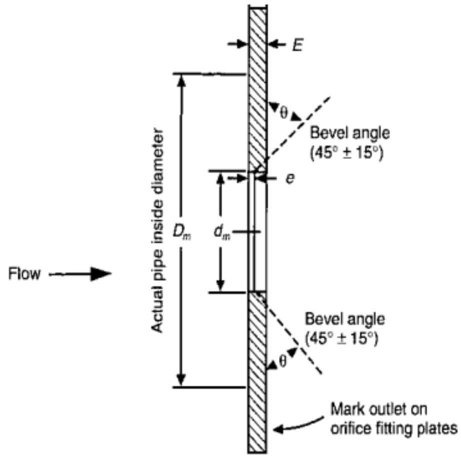
However in case non-availability of Gas Chromatograph having capability of analyzing heavier hydrocarbon, a fixed split ratio (based on the gas analysis done in a lab) can be introduced to reduce these errors.

MEASUREMENT ERROR DUE TO WRONG/FAULTY INSTALLATION

❖ FLOW METERS

- **Orifice Metering**: Concentricity of Orifice plate is most essential for accurate gas flow measurement.Large errors associated with Orifice Plates not Centralised. Based





  on the experiment it has been seen that if a Orifice plate carrier raised approximately 3/8" from bottom (Plate not centered) , it can cause an error of upto (-) 8.2%.

  Based on the experiment results, it has also been seen that leakage around orifice plate (sealing not proper) can result an error in the range of 3 to 6% in the gas flow measurement. Effect of Bend /Warp in orifice plate can induce an measurement error even beyond 5%. Even a difference of 0.01in. Bevel width can results an error up-to 2.2%, the difference can be as high as 13% with difference in bevel width of 0.05in. In addition to above the flow profile also acts an important role in accuracy of measurement in case of orifice measurement. The required straignt length, the flow profiler, the innerwall rough ness, the ovality of the ID of meter tube should be as per the recommendations mentioned in AGA-3 or equivalent.

- **Turbine Meters** : Turbine meters have normally a fast response to flow variation. They follow increasing flow variations faster than decreasing flow variations. At high flow rates, the meter response is very fast. When the flow reduces to very low values, the meter becomes very slow to follow.Turbine meters should therefore not be used on installations that are controlled in on-off mode with short "on" periods, as they may seriously over-register under those conditions.

  The flow profile also plays an important role in flow metering accuracy. With 10D upstream (without conditioner) and having 90 Deg. Elbow (in), an measurement inaccuracies of more than 0,2% can be resulted.

- **Ultra Sonic Meter**: For Ultrasonic flow meter, noice is a major factor for inaccuracies of measurement. These noices can be induced due to poor/improper installation. The low noice Pressure control Valves installed at the up-stream of these meters can generate noice which can effect the performance of these meters.

  The speed of sound is more sensitive to temperature and gas composition than pressure. For example, a 0.5 degree C error in temperature at 750 psig, with typical pipeline gas, can create an error of 0.13%. An error of 5 psig at 750 psig and 60 degrees F only contributes 0.01% error. Thus, it is extremely important to obtain accurate temperature information. Lets consider a gas with approx. 95% methane. Suppose the methane reading is low by 0.5%, and the propane reading was high by that amount, the error in computed speed of sound would be 0.67% .

- For custody transfer application always install "A" class temperature element.Large temperature errors can be generated when using lower accuracy devices . A class B type PT100, RTD can have +/- 0.5 DegC deviation error comapre to a class A type PT-100 RTD.

❖ Insulation of Metering Run

To minimize the effect of environment the flow meters,It is essential that each metering stream is completely insulated [including the orifice fitting body, flanges, impulse lines & temperature elements) to ensure an even heat transfer throughout the meter run when installed within an exposed environment.

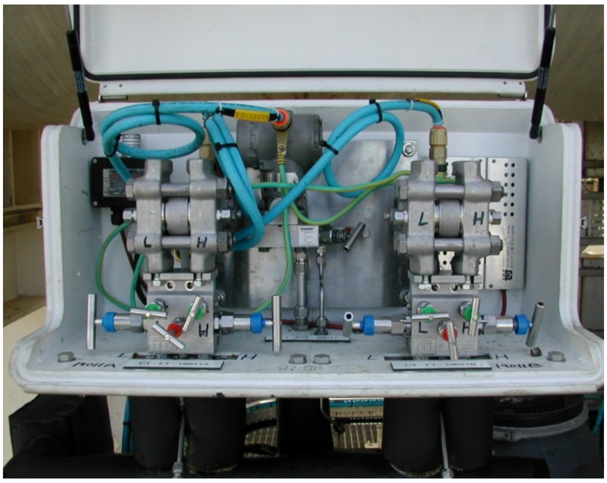


Large flow measurement errors can be generated from inherent temperature gradients within the metering system due to ambient temperature effects.

If temperature gradients existed between the measured temperature & that actually flowing through the meter say ±0.2ºC (due to the distance between the two points, which is very much likely); then the error can be in the range of ±0.06% of flow.This is severe in case of Orifice meter & meters operating at a less velocity of flowing gas.

❖ Field Instruments to be installed within Controlled environment

The custody transfer field instruments like PTs, DPTs & TTs should not be exposed to ambient condition (with temperature variation of 10°C) . The changes in ambient temperature will affect the instrumentation measurement accuracy.



Typical ambient temperature effect per 50ºF for a transmitter is ± 0.125% of the calibrated span. Therefore, if a transmitter is calibrated 0-100"WG on a suitably selected URL range, the shift in calibration could be potentially more than 0.1% for every 50ºF (10 Deg.C) change.

- ***Ensuring Optimised Calibration Ranges***

Calibration of the instrument range to ensure typical operating conditions is approximately 70% of the span. High measurement uncertainty issues are inherent within inappropriately "ranged" instruments.

If a pressure transmitter is calibrated 0 – 100 BarG, operating at 15 BarG and calibrated to a tolerance of ±0.25% of span, the calibration uncertainty weighting is; (100/15) x 0.25 = 1.67%

However if the calibrated range is reduced to 25 BarG, then; (25/15) x 0.25 = 0.417% (4 times lower).

OPERATION & MAINTENANCE PRCTICE & ITS EFFECT ON GAS FLOW MEASUREMENT

- ***Routine Primary Device Inspection***

The primary metering devises shall be inspected regularly as per schedule & as and when required. Any damage in the primary devises can cause huge error in gas flow measurement. Deposition of dust & debris can be a major source of error in gas measurement.

Such a small Cut on the edge of ID can have an error of -3.3% measurement

Deposition of Dust/Debris (in this case bottom part) can result into an error of around -1%

❖ ***Over-speeding in Turbine Meter***

The turbine meters are generally designed to be subjected to a 20% higher flow rate than the maximum rating for short periods. They should not be run at higher speeds, as bearing damage and ultimately turbine wheel damage will occur. Over-speeding is generally caused by filling up or pressurizing a section of pipe through the meter in an uncontrolled way. The pressurizing can be done through a small diameter tube or through the equalizing valve in a controlled way.

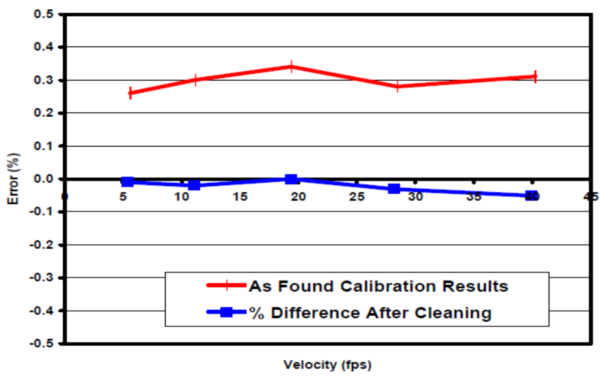
❖ ***Dirty Vs Clean USM Performance***

Dirty bottom of USM

Debris on Profiler

Dirty Transducer Port

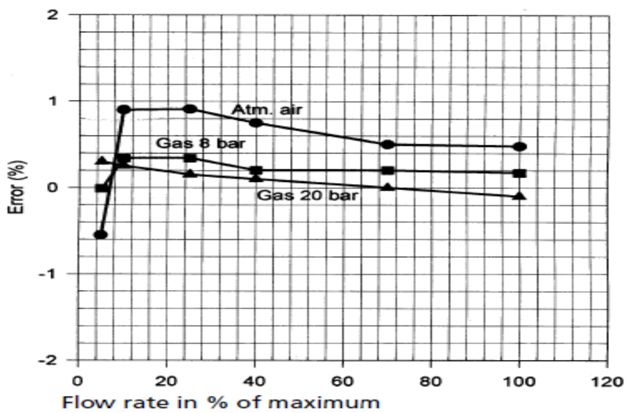
Let us assume a build-up is 0.025 of an inch on each face, and the path length is 16 inches. Also assume the speed of sound through the contamination is twice that of the typical gas application (2,600 fps vs. 1,300 fps). With no buildup on the transducer, and at zero flow, the average transit time would be 1.025641 milliseconds. With buildup the average transit time would be 1.024038 milliseconds, or a difference of 0.16%.



Gas velocity is proportional to a constant (*L2/2X)* multiplied by the difference in transit times. The volumetric error will be is the same as the percentage of transit time (0.16%).

❖ **Turbine meter shall be proved at SITU condition**

The lower end of the flow range of a Turbine meter is determined by mechanical friction and is extended by increasing density and therefore by increasing pressure. At the higher flow rates, where friction forces are small compared with available hydrodynamic forces, the error is determined by the Reynolds number.

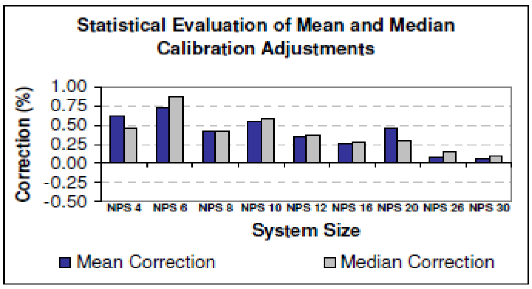


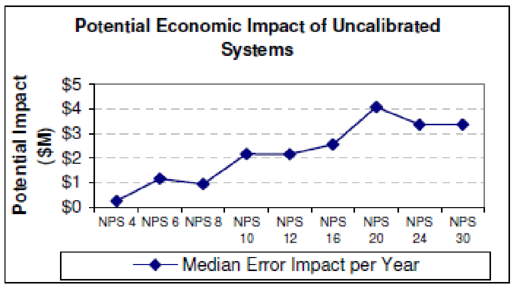
The Reynolds number is dependent on the flow rate, the density, and the dynamic viscosity of the gas:

$$Re = K \cdot Q \cdot \frac{\rho}{\eta}$$

Where K is a constant depending on the geometry of the meter, Q is the flow rate, ρ the density and η the dynamic viscosity of the gas under operating conditions.

- **Flow calibration is required in USM for better accuracy**





From the graph it is seen that mean correction applied between (NPS 4 to NPS 8) ranges between 0.42% and 0.73%. For (NPS 10 to 16), the range is from 0.25% to 0.56% & for (NPS 20 and larger) the range is from 0.02% to 0.45%.

The loss for not doing wet calibration is considered, the values are un-imaginable .The cost of wet calibration for a 12" USM is approx. $ 0.05 M. So we shall agree that the custody transfer USM shall be wet Calibrated.

- **Traceable Certification & Detailed Documentation**

Traceable certification & detail documentation is very important to ensure proper metering.

0.1" difference in orifice plate diameter entered within the flow computer to that actually "certified" for the orifice plate in use;

I.e. 5.1239" versus 5.2139" equates to typically a -4% error.

❖ Precaution to be taken for doing calibration using Dead-weight tester

Dead weight tester operates on the principle of balancing a known mass against the force exerted by an unknown pressure on a piston of a known area.

When an exact balance is achieved, the unknown pressure *P is equal to mass M of the* weights divided by the area *A of the piston, according to the formula P = M/A*

The output pressure from the deadweight tester is affected by a difference in local gravity, buoyancy, ambient temperature, elevation of the transducer relative to the piston, and the pressure effect on the piston effective area must be considered.

$$P_{corr} = \frac{1}{1000}\left(\frac{M_{app}}{A_{cyl}} F_{gravity} F_{buoyancy} F_{temp} F_{press}\right) \pm P_{head}$$

$$F_{buoyancy} = 1 - \frac{D_{air}}{D_{mass}} \qquad F_{press} = \frac{1}{1+bP} \qquad F_{temp} = \frac{1}{1+(a_{cyl}+a_{piston})(T-T_{ref})} \qquad F_{gravity} = \frac{G}{G_s} \qquad P_{head} = D_{oil}(H - H_{ref})$$

H = transducer elevation above or below the base plate, cm
A_{cyl} = piston area at reference temperature and pressure, cm2
a_{cyl} = thermal expansion coefficient of the cylinder, 1/°C
a_{piston} = thermal expansion coefficient of the piston, 1/°C
b = pressure coefficient of the effective area, cm2/kg
P = nominal pressure, kg/cm2,
M_{app} = total of the masses from the test certificate, grams
Href = distance from the top of the base plate to the bottom of the piston, cm

CONCLUSION

Unaccounted for Gas (UFG), the term used in our industry is to describe the material imbalance in a pipeline and its associated metering system. A perfect balance is when gas received into a pipeline exactly matches the gas going out of a system. Since it is impossible to achieve a perfect balance on a pipeline system, so most of the distribution companies calculate the overall imbalance of the system and do various checks & balances to reduce these imbalances and try to keep within a stated percentage. This percentage varies from company to company, and is often included while calculating the tariffs.

In this paper the UFG caused due to measurement inaccuracies has only been discussed. There are many factors that can affect the overall uncertainty of the measurement; they can range from improper manufactured meter body to poorly designed installation. With the increasing price of natural gas, today the error that at one time seemed insignificant has now become unacceptable. UFG is now a common industry term and gas accounting is playing a bigger role in the decision making.

As long as these imbalances are within the specified limit, the company as well as its metering engineers are happy. However, good metering engineers will always tries to keep this UFG well below the benchmark limit specified by his company, they try to find out the reasons behind it. If root cause analysis is being done properly, then this UFG problem can be solved or proper reasoning can be given for the UFG.

In order to accurately determine the UFG in a system, a methodology must be developed. The methodology shall include proper metering of all the receipt & delivery stations, accounting for system use gas i.e. used as internal consumption, accounting for line pack and its variation & also for account for recovered liquids.

Every organization shall develop a systematic, logical approach to UFG mitigation, which shall consists of

1. Team work between the field personnel & the metering engineer.
2. Verify data entry and report configuration
3. Inspection of the entire pipeline & metering system for theft or leakages.
4. Regular auditing of meter stations

--X--

References:

1. American Gas Association Reports
2. Flow Measurement System Audit Findings & Recommendations- Kelton
3. Determination of Leakage & unaccounted for gas- Transmission : Lonnie Grady
4. Profiting from accurate gas measurement- Craig Abbott
5. Ultrasonic Flow Meter Calibration, Considerations and Benefits-Wayne Haner
6. Dirty vs. Clean Ultrasonic Gas Flow Meter Performance- JOHN LANSING
7. Gas Turbine meter Handbook- Instromet