Managing Lost And Unaccounted For Gas Volumes

Part 1- Metering and Measurement Calculations

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Introduction

This series of papers will focus on possible causes of what is often known as Lost And Unaccounted For (LAUF) gas. The LAUF is a calculated value which compares the amount of gas coming into a system (purchased) to the amount of gas leaving the system (sold and/or otherwise accounted for). LAUF most often results from measurement issues, improper adjustment and handling of measured values, lack of accounting of controlled gas venting, and gas lost to damage and leakage. The series will discuss and address each of these areas, starting with measurement calculations, and ending with reporting requirements.

In general the natural gas system in the US is reasonably tight and leak-free, especially in the transmission and distribution portions of the system. Unaccounted for gas is not necessarily an issue of leaking pipes, but something else. In many cases poor accounting (as in math) is the primary cause of unaccounted for gas volumes, specifically in regards to appropriate metering and measurement calculations. Let's start our journey by looking at these potential issues.

Note: This series uses nomenclature, terms, and values associated with the Natural Gas Industry in the United States. However, the concepts and issues presented are applicable regardless of the location of the operation or system.

The Cubic Foot

In the United States (US), the basis for a quantity of gas is usually the cubic foot, or some multiple thereof. What this means is that we quantify an amount of gas by how many molecules fit into a physical space of one cubic foot, a 1 foot x 1 foot x 1 foot "Cube". Larger quantities of gas may be expressed in terms of thousands or millions of cubic feet (Mcf or MMcf).

Natural gas is a compressible fluid. Gas expands and contracts depending on pressure and temperature. To determine how much gas is in a given Cube, we need to know the pressure and temperature of the gas contained in the Cube. This is where the concept of a "standard" cubic foot becomes important. A standard cubic foot of gas is the amount of gas contained in the Cube at a standard pressure and temperature, also referred to as the Base Pressure and Base Temperature, "standard conditions", or "base conditions".

The standard conditions can vary based on jurisdiction and contract. In 1963, the American Gas Association (AGA) endorsed the values of 14.73 Psia for Base Pressure and 60 Fahrenheit for Base Temperature. Although common, these values are not consistently used throughout the United States, nor are they valid for every location. It is not completely clear as to the origin of these values.

For metering at custody transfer locations, or town gate or border stations, Base Pressure and Base Temperature values can be found in the "tariff" or contract governing the associated transaction. The Base Pressure and Base Temperature for local distribution sales is generally established by the local jurisdiction such as town council, utility board, or public utility commission.

Using the wrong or inappropriate Base Pressure and Base Temperature is a common error in gas accounting.

Base Pressure

In the distant past, local distribution systems in the United States commonly established a Base Pressure for measurement based on the average local atmospheric pressure plus the delivery pressure at the meter. This combination closely equates to the absolute pressure in the meter. Base Pressures were often established for each town or district. Although some operators still use this approach, presently it is more common to find a Base Pressure of 14.73 Psia being used regardless of location. This practice is not necessarily a problem, however it can introduce error in the gas measurement if adjustments for local conditions are not appropriately applied.

A common form of gas measurement is by diaphragm meter. With this type of meter, a chamber of fixed size is continually filled and emptied to measure the gas flow. The quantity of gas contained in the chamber is directly related to the absolute pressure present in the chamber. The absolute pressure is the sum of the measured (gauge) pressure and the local barometric pressure. The barometric pressure varies constantly due to localized atmospheric conditions (temperature, humidity, etc). In the gas industry the local barometric pressure is often referred to and represented by a static pressure value known as the atmospheric pressure.

Compensating a non-local Base Pressure for local conditions requires applying an adjustment factor to the quantity measured by the uncorrected meter index. This factor is expressed as:

$$V_{PB} = V_{Index} \times \frac{(P_{Meter} + P_{Atm})}{P_B}$$

Equation 1

Using a meter pressure of 0.25 Psig (7 inches water column), the commonly used Base Pressure value of 14.73 Psia is only valid at locations where the local barometric pressure is 14.48 Psia. Using the recommended AGA calculation method for atmospheric pressure, this value would only be valid for locations where the elevation above mean sea level is about 475 Feet.

Using a Base Pressure of 14.73 Psia, at elevations below 475 Feet, the uncorrected volume would under-report the actual quantity of gas passing through the meter. For example, at a delivery pressure of 0.25 Psig and an elevation of 100 Feet, the volume would be under-reported by about 1.4%. Conversely, at elevations above 475 Feet, the uncorrected volume would over-report the actual quantity of gas passing through the meter. At the same delivery pressure and an elevation of 1000 Feet, the volume would be over-reported by about 1.8%.

Using the correct and appropriate Base Pressure value, or correction factor, will ensure accurate reporting of the measured quantities either in-to or out-of a system.

Atmospheric Pressure

When we refer to pressure, we need to realize that there are several different values of pressure. Gauge pressure is the value commonly referred to when discussing operating pressure. It is the value measured by a pressure gauge or recorder, and is most often presented in dimensional units that end with a "g", such as Psig. Barometric or Atmospheric Pressure refers to the hydrostatic pressure of a column of air above the measurement point. Absolute Pressure is the sum of the Gauge and Atmospheric Pressures. Absolute Pressure dimensional units often end with an “a”, for example Psia. To calculate a gas volume, all three pressure values must be known or calculated.

When determining the quantity of gas actually measured by most meters, the Absolute Pressure within the meter must be known. The most accurate measurement would result from using the local Barometric Pressure to calculate the Absolute Pressure in the meter. This is not necessarily practical, especially for the millions of small capacity meters used by local distribution companies.

In the natural gas industry, in lieu of using the local Barometric Pressure, it is common practice to calculate an average Atmospheric Pressure for a town, a district, or a service area using a formula based on geographic elevation. As elevation increases, the amount of air above a given point decreases, thus decreasing the Atmospheric Pressure at that point. Atmospheric Pressure decreases with increasing elevation. As used in most gas volume calculations, Atmospheric Pressure represents a theoretic Barometric Pressure at a specific elevation. It differs from the actual local Barometric Pressure, which is affected by many other factors including temperature and humidity.

Depending on the calculation method used, the Atmospheric Pressure ranges from approximately 14.7 Psia at an elevation of zero (mean sea level) to 12.2 Psia at an elevation of 5280 Feet (one mile above mean sea level). At a 0.25 Psig delivery pressure, using an Atmospheric Pressure value that is 1.0 Psia in error, would result in about a 5% misreporting of the measured volume.

There is no industry standard for calculating Atmospheric Pressure. The AGA recommends a calculation method for Atmospheric Pressure in their GEOP Transmission and Distribution Measurement text book. Using this method yields an Atmospheric Pressure value at an elevation of mean sea level of 14.73 Psia, a familiar number. This value should not be confused with the AGA recommended Base Pressure value. Even though the two numbers are the same value, they represent completely different parameters.

Each operator will need to determine which calculation method is best for their particular use. The value itself is important, however more important is to be consistent with the method that you use to calculate the Atmospheric Pressure value, so that valid and consistent comparisons can be made between measured values.

Base Temperature

In the US a Base Temperature value of 60 Fahrenheit is commonly used through out the industry. Is this value valid or reasonable? That's debatable, but not here at this time.

As with pressure, the actual quantity of gas passing through a meter is related to the flowing temperature of the gas. The cooler the gas in the meter, the greater the quantity passing through. The warmer the gas in the meter, the lesser the quantity of gas passing through the meter.

Generally the temperature of gas flowing in a pipeline, distribution main, or a service line is equivalent to the ground temperature at the line's burial depth. Depending on the depth and geographic location, this temperature may remain fairly constant over the annual seasons or may vary significantly.

The Flowing Temperature of the gas upstream of any sudden pressure reduction will be warmer than the pressure downstream. The cooling is caused by the Joule-Thomson effect. For example the Flowing Temperature of gas downstream of a pressure reducing regulator is cooler than the upstream temperature. Most meters are installed downstream of a pressure reducing regulator. Therefore, the actual temperature of the gas flowing through the meter will be cooler than the upstream pipeline gas. What is this value? It could be estimated through calculation. Fortunately many modern meters provide intrinsic temperature compensation, or are equipped with an electronic corrector that compensates for the actual flowing gas temperature.

If the meter is not temperature compensated the measured (indexed) value can be corrected for Flowing Temperature using the following equation:

$$V_{TB} = V_{Index} \times \frac{T_B}{T_{Meter}}$$

Equation 2

As with the other parameters discussed so far, it is important to correct for the actual Flowing Temperature in the meter when it is not the same as the Base Temperature.

Compressibility

Most calculations for gas volume are derived from the Ideal Gas Law. Natural gas and other pipeline gases are "real" gases that do not exactly follow "ideal" gas behavior. The deviation from ideal behavior is known as compressibility. It varies with changes in pressure and temperature.

At low pressure, natural gas more closely follows ideal gas behavior. As pressure increases, deviation from the ideal gas law is more exaggerated.

Often compressibility is ignored in low volume, low pressure measurement from distribution systems. To most accurately account for the gas being measured, it would be prudent to calculate and apply a factor to account for compressibility. At high pressures, compressibility can have a larger influence on the results. For large volume applications, compressibility should be included at any pressure.

The factor used to compensate for compressibility is known as the Compressibility Factor. The following equation can be used to compensate for compressibility deviation:

$$V_{ZB} = V_{Index} \times \frac{Z_B}{Z_{Meter}}$$

Equation 3

A Compressibility Factor of 1.0 represents ideal gas behavior. The Compressibility Factor is very near 1.0 at very low pressures. The value becomes smaller as pressure increases, and becomes larger as temperature increases.

The Compressibility Factor is a function of pressure, temperature, and gas composition. It is not easily measured, and is a bit complicated to calculate. There are many methods for calculating this value. The most accurate methods available at the time of this writing are those described in the 2017 edition of the AGA Report Number 8.

Many electronic correction instruments have simplified versions of these methods programmed in their firmware and can estimate the compressibility during measurement correction. For non-corrected metering applications, if the meter pressure is relatively constant, for example downstream of a fairly good quality regulator, the Compressibility Factor can be periodically calculated for the anticipated conditions and applied using Equation 3.

Heating Value

It is common practice to buy and sell gas based on energy content. Unfortunately, it is not currently possible to actually measure the energy flow of the gas stream. There is no energy meter for gas flow. Instead the gas flow is continuously measured on a volumetric basis, and energy content is periodically determined through a separate process. The accumulated energy bought or sold is then calculated from the determined energy value and measured gas volume using the following formula:

$$Energy_B = V_B \times HV_B$$

Equation 3.1

With respect to LAUF, an error often occurs when an energy based value is being used to try to compare bought and sold volume values. For this comparison, the energy value needs to be converted back to a volume value. Often the energy content varies over time. It is not uncommon for the gas being supplied into the system (bought) to be corrected for energy at an hourly or daily interval. The gas being supplied to the customers (sold) is only corrected for energy at the end of the billing cycle, which is most often monthly. These mismatched correction intervals make it difficult to accurately calculate the original volume values from accumulated energy values. If the same energy content is not used as was used in the original calculation, then the original volume value is incorrectly calculated and the comparison is not correct. It is best to use the actual measured volume values, than to try to convert energy values back to volume values.

Delivery Pressure

As a reminder, the quantity of gas measured by a meter is directly affected by the Absolute Pressure within the meter, the Meter Pressure. The Meter Pressure is approximately equal to the Delivery Pressure (in gauge units) plus the local Atmospheric Pressure. If the Meter Pressure is greater than the established Base Pressure, and not corrected for, the reported volume will be under-reported. Conversely if the Meter Pressure is less than the established Base Pressure, the reported volume will be over-reported.

Elevated Delivery Pressures (Meter Pressures) can be accounted for by application of an appropriate Pressure Factor, often known as the Fixed Pressure Meter Factor (FPMF). The FPMF can be calculated using the following equation:

$$FPMF = \frac{(P_{Meter} + P_{Atm})}{P_B}$$

Equation 4

This factor should be applied to all uncorrected measured (indexed) volumes where the Meter Pressure is higher than the Base Pressure.

Meter Pressures or Delivery Pressures less than the Base Pressure can also be accounted for by use of the same equation. However, in contrast to elevated Delivery Pressures, low Delivery Pressures are often not intended. Unintended low Delivery Pressures are often caused by a poorly adjusted or operating regulator upstream of the meter. This condition should be corrected in the field, not by a correction factor.

It is prudent to periodically review and audit the elevated Delivery Pressure meters in your system to ensure that the Delivery Pressure is as intended, that the FPMF is correct, and that the FPMF is appropriately entered and applied into the accounting/billing system.

Gas Laws

All of the previously mentioned corrections or adjustments were derived from the basic gas laws which include Boyle's Law, Charles' Law, and their combination known as the Ideal Gas Law. With the addition of compressibility, the general volume correction equation is as follows:

$$V_B = V_{Index} \times \frac{(P_{Meter} + P_{Atm})}{P_B} \times \frac{T_B}{T_{Meter}} \times \frac{Z_B}{Z_{Meter}}$$

Equation 5

Applying the above equation, with the appropriate Compressibility Factor, to an uncorrected measured volume will provide the most accurate accounting of the gas passing through the meter.

Volume Comparisons

When comparing measured/metered volumes, for example when comparing purchased volumes to sales volumes, ensure that both volumes are with respect to the same Base Pressure and Base Temperature. If the values are expressed at different base conditions, one value can be expressed in terms of the other using the following equation:

$$V_{PB2,TB2} = V_{PB1,TB1} \times \frac{P_{B1}}{P_{B2}} \times \frac{T_{B2}}{T_{B1}}$$

Equation 6

A comparison of two volumes at different base conditions is not a valid comparison, and will introduce an error into the results. This is particularly important to consider when completing required regulatory reports where the required reporting base conditions may be different than your base conditions.

What It All Means

If you are not applying the appropriate adjustments and corrections to your uncorrected volume measurements, you are not providing the most accurate accounting of your sales or receipt volumes. Furthermore, if your correctors and instruments are not setup appropriately, you are reporting not just inaccurate but incorrect values from these devices.

With the exception of the calculation of the Compressibility Factor, the implementation of the adjustments and corrections mentioned in this Part is quite simple. Most gas accounting/billing software can accommodate entry of a meter correction factor , FPMF, and/or Compressibility factor.

The cost to implement the above is just the time and labor involved in reviewing and auditing your current practices, determining the appropriate adjustments or corrections, and implementing them in your existing devices and software systems, with no additional capital cost involved at all.

What's Next

The next part of this series will focus on measurement hardware and potential impacts on LAUF.

Variable Definitions

$Energy_B$ = Energy content of accumulated volume at specified Base Pressure, Base Temperature, and corrected for Compressibility.

FPMF = Fixed pressure meter factor.

HV_B = Heating Value (energy content) per unit volume at specified Base Pressure, Base Temperature, and corrected for Compressibility.

P_B = Base Pressure.
P_{Meter} = Gas pressure in the meter (gauge).

T_B = Base Temperature.
T_{Meter} = Gas temperature in the meter (absolute).

$V_{PB1,TB1}$ = Measured (first) volume at the specified first base conditions.
$V_{PB2,TB2}$ = Equivalent first volume at the specified second base conditions.
V_B = Corrected volume at specified Base Pressure, Base Temperature, and corrected for Compressibility.
V_{Index} = Measured volume as indicted by the meter index.
V_{PB} = Corrected volume at specified Base Pressure.
V_{TB} = Corrected volume at specified Base Temperature.

Z_B = Compressibility Factor calculated at the associated Base Pressure and Base Temperature.
Z_{Meter} = Compressibility Factor calculated at the flowing pressure and temperature in the meter.

Note: When used in the listed equations and formulas, each parameter must be in compatible dimensional units.

About The Author

Bradley Bean is the managing member and senior partner of B3PE. Through its predecessor company (Bradley B Bean PE) the firm has been providing engineering software and services to the Natural Gas Industry since 1992. Mr Bean has been involved in the industry since 1982.

B3PE provides software tools to calculate all of the adjustments and corrections, including the calculation of Compressibility Factors mentioned in this Part. The firm provides services to assist in the review, audit, and implementation of these values.