

OVERALL MEASUREMENT ACCURACY

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Abstract

This paper presents methods for determining the uncertainty of both differential and positive metering stations. It takes into account the type of meter, number of meters in parallel, type of secondary instruments, and the determination of physical properties. The paper then relates this information to potential influence on system balance

Introduction

Gas measurement uncertainty is a function of the following items:

- Selection of the appropriate metering device.
- Correct Installation of the metering device.
- Proper meter operation and processing of the metering information.
- Proper maintenance of the metering device.

Understanding how measurement uncertainty applies to metering requires a basic knowledge of the terminology and assumptions used in the calculation of measurement uncertainty.

Measurement uncertainties can be categorized as the following:

Pseudo Pseudo uncertainties are potential human errors or those associated with the malfunction of an instrument. Once identified, these errors can usually be corrected and are not included in the calculation of measurement uncertainty.

Random Random uncertainties are potential measurement errors that have an equal chance of being higher or lower than the true value of the measured variable. If a large number of measurements are made, the random error in the individual measurements cancel and the mean of the measurements will be approximate to the correct value.

Systematic Systematic uncertainties are measurement errors that are directional or contain a bias. Because these errors are directional, they do not cancel as additional measurements are made.

Random uncertainty reduces as the number of measurements increases. However, additional measurements will not reduce the systematic uncertainty.

Because the random and systematic uncertainties are characteristically different, the calculation of each must be performed independently. The combination of the two independently performed calculations then forms the total measurement uncertainty.

The elements of the random and systematic uncertainties are classified as either independent or dependent and must be determined before the total measurement uncertainty can be obtained. The determination of gas measurement uncertainty has been and is addressed in numerous industry articles and standards publications. Three such articles and publications that were referenced in the preparation of this paper are: (1) Norman and Jepson, (2) Tiemstra, Rans, and Backus, (3) AGA Report No.3 Part 1 – 1990. However, for the purposes of evaluation, this paper will not concern itself with the influence of the interdependence of variables. But will utilize the calculation procedure given in A.G.A. Report No. 3 (API MPMS 14.3, ANSI 2530, GPA 8185-90) Part I – 1990 to determine the orifice meter measurement uncertainty and will apply the same metrology to the positive meter (turbine, rotary, or diaphragm meter) measurement uncertainty.

The uncertainty for a single meter run is evaluated from the random and systematic uncertainty of the primary element (orifice, turbine, rotary, or diaphragm meter) and its instrumentation. The uncertainty of the primary element includes the

uncertainty associated with the flow coefficient, expansion factor, diameter of the meter run, diameter of the orifice plate bore, and calibration of the positive meters.

For an Individual meter run:

$$U_{TM} = U_{RM} + U_{SM} \quad (\text{Equation 1})$$

Where

U_{TM} - Total meter run uncertainty
 U_{RM} - Meter run random uncertainty

$$U_{RM} = \sqrt{\sum(U_{Ri})} \quad (\text{Equation 2})$$

U_{SM} - Meter run systematic uncertainty –

$$U_{SM} = \sqrt{\sum(U_{Si})} \quad (\text{Equation 3})$$

The percent random uncertainty contributed by each variable, U_{Ri} , is defined as follows:

$$U_{Ri} = (X_i \times A_i)^2 \quad (\text{Equation 4})$$

The sensitivity coefficient of each variable at the point of evaluation, X_i , can be determined by calculating the results for the conditions of evaluation, R , and the change in the result, ΔR , produced independently by the accuracy variation of each variable at the conditions of evaluation and substituting into the following equation:

$$X_i = \left(\frac{\Delta R}{R} \right) \quad (\text{Equation 5})$$

The percent accuracy of each variable at the point of evaluation, e.g. average differential pressure, is determined as follows:

For variables whose accuracy is stated as function of its full-scale value, the percent accuracy is the value of the accuracy at full scale, A_F , divided by the value of the variable at the conditions of evaluation, V_{CE} .

$$A_i = \left(\frac{A_F}{V_{CE}} \right) \times 100 \quad (\text{Equation 6})$$

As an example, assume that one of the variables is a differential pressure value whose accuracy is stated as 0.1% of full scale, its full scale is 100 and the point of evaluation is 50. The percent accuracy of the variable at the point of evaluation, A_i , would be:

$$A_i = \left(\frac{0.001 \times 100}{50} \right) \times 100 = 0.2\% \quad (\text{Equation 7})$$

The sensitivity coefficient of the variable at the point of evaluation, X_i , could be determined by calculating the results, R , using the point of evaluation value of 50, then calculating the change in results, ΔR , using the point of evaluation value, 50, changed by 0.2%. These two numbers would be inserted into the equation for X_i to determine the sensitivity coefficient of the variable at the point of evaluation.

For variables whose accuracy is stated as a function of reading, the percent accuracy is the same though out its range.

The systematic uncertainty of each variable is determined using the accuracy of the calibration standards as an estimate of its contribution to the total systematic uncertainty (U_{SM}).

$$U_{Si} = (X_i \times A_i)^2 \quad (\text{Equation 8})$$

The accuracy of the calibration standards (A_i) are expressed as a percent of reading so they can be substituted directly into the U_{Si} equation along with the sensitivity coefficients (X_i) calculated for the appropriate element to determine the systematic uncertainty contribution by each variable.

The total systematic uncertainty is determined using the USM equation.

$$U_{SM} = \sqrt{\sum(U_{Si})} \quad (\text{Equation 9})$$

However, since the criteria applied for the determination of the sensitivity coefficient can vary and is specific to an application, the sensitivity coefficients used for the orifice meter uncertainty were chosen from A.G.A. Report No.3 (API MPMS 14.3, ANSI 2530, GPA 8185-90), Part 1 – 1990 and similar sensitivity coefficient were developed for the positive meters. The use of these particular sensitivity coefficients can result in a small understatement of the uncertainty estimates resulting from not accounting for the interdependence of some of the elements.

Differential Meter Uncertainty

The variable elements of a gas orifice meter measurement uncertainty calculation are as follows:

- Differential Pressure, dp
- Static Pressure, P_f
- Flowing Temperature, T_f
- Gas Relative Density, G_r
- Gas Compressibility Factor, Z_f & Z_b (F_{pv})
- Orifice Meter Coefficient of Discharge, C_d
- Orifice Bore Diameter, d
- Meter Tube inside Diameter, D
- Expansion Factor, Y
- Differential Pressure Calibrator, d_{pc}
- Static Pressure Calibrator, P_{fc}
- Flowing Temperature Calibrator, T_{fc}
- Gas Relative Density Calibrator, G_{rc}

To calculate the measurement uncertainty for a multiple meter run station, the variables that are independent on a per run basis are differential pressure, static pressure, temperature, and meter run tolerances. The variables common to all runs in the station are the relative density (specific gravity), gas composition, and calibration standards.

The total percent measurement uncertainty for a meter station is as follows:

$$U_{TS} = U_{RS} + U_{SS} \quad (\text{Equation 10})$$

Where

- U_{TS} - Total orifice meter station uncertainty
- U_{RS} - Total orifice meter station random uncertainty
- U_{SS} - Total orifice meter systematic uncertainty

The total orifice meter station random uncertainty is given as:

$$U_{RS} = \sqrt{\sum \left(\frac{U_{Ri}}{\sqrt{n}} \right)^2 \Big|_{\text{per Run}} + \sum (U_{Ri})^2 \Big|_{\text{per Station}}} \quad (\text{Equation 11})$$

Where n is the number of meter runs. And the total orifice meter station systematic uncertainty, U_{SS} , as:

$$U_{SS} = \sqrt{\Sigma(U_{SM})^2}_{per\ Run} \quad (\text{Equation 12})$$

Since there are numerous combinations of equipment, operating conditions, and calculation methods existing for orifice metering, it is impossible to establish a single base line uncertainty relationship. The most practical approach is to provide uncertainty ranges for the most typical orifice metering combinations.

Positive Meter Uncertainty (Turbine, Rotary, and Diaphragm)

The variable elements of a gas positive meter measurement uncertainty calculation are as follows:

- Static Pressure, Pf
- Flowing Temperature, Tf
- Gas Relative Density, Gr
- Gas Compressibility Factor, Zf & Zb
- Positive Meter Linearity, PM_L
- Positive Meter Calibrator, PM_{pc}
- Static Pressure Calibrator, P_{fc}
- Flowing Temperature Calibrator, T_{fc}
- Gas Relative Density Calibrator, G_{rc}

To calculate the measurement uncertainty for a multiple meter run station, the variables that are independent on a per run basis are positive meter calibration or proof, static pressure, and temperature. The variables common to all runs in the station are the relative density (specific gravity), gas composition, and calibration standards.

The total percent measurement uncertainty for a meter station is as follows:

$$U_{TS} = U_{RS} + U_{SS} \quad (\text{Equation 13})$$

Where

- U_{TS} - Total orifice meter station uncertainty
- U_{RS} - Total orifice meter station random uncertainty
- U_{SS} - Total orifice meter systematic uncertainty

The total positive meter station random uncertainty is given as:

$$U_{RS} = \sqrt{\Sigma\left(\frac{U_{Ri}}{\sqrt{n}}\right)^2}_{per\ Run} + \Sigma(U_{Ri})^2}_{per\ Station} \quad (\text{Equation 14})$$

Where n is the number of meter runs. And the total positive meter station systematic uncertainty, U_{SS}, as:

$$U_{SS} = \sqrt{\Sigma(U_{SM})^2}_{per\ Run} \quad (\text{Equation 15})$$

Since there are numerous combinations of equipment, operating conditions, and calculation methods existing for positive metering, it is impossible to establish a single uncertainty relationship. The most practical approach is to provide uncertainty ranges for the most typical positive metering combinations.

Energy Determination Uncertainty

The measurement of total energy received or delivered is customarily the product of the measured volume and the heating value (Hv) per unit volume. The heating value per unit volume is typically an inferred measurement resulting from a chromatographic analysis of a representative sample of the gas being received or delivered. In addition to heating value per unit volume, relative density (specific gravity) used in the determination of volume is also obtained from the chromatographic analysis. Industry standards, which address the performance of chromatographic analysis, the calculation of heating value per unit volume, and relative density of a gas sample, are:

- (4)ASTM D 1945 (GPA 2261) - Standard Test Method Analysis of Natural Gas by Gas Chromatography
- (5)ASTM D 3588 (GPA 2172) - Standard Practice for Calculating Heat Value, Compressibility Factor, and Relative Density(Specific Gravity) of Gaseous Fuels

The industry standards, ASTM D 1945 (GPA 2261) and ASTM D 3588 (GPA 2172) provide a precision statement for repeatability and reproducibility as a function of the mole fraction of each component in the gas mixture. The repeatability is the expected precision within a laboratory using the same equipment and the same analyst. The reproducibility is the expected precision when different laboratories using different equipment and different analysts use the same method. Tables 1 and 2 provide the given repeatability and reproducibility tolerances which are subject to periodic revision.

Component Mole %	Repeatability %
0 to 0.1	0.01
0.1 to 1.0	0.04
1.0 to 5.0	0.07
5.0 to 10	0.08
Over 10	0.10

Table 1 - ASTM D 1945 Precision Repeatability Criteria

Component Mole %	Reproducibility %
0 to 0.1	0.02
0.1 to 1.0	0.07
1.0 to 5.0	0.10
5.0 to 10	0.12
Over 10	0.15

Table 2 - ASTM D 1945 Precision Reproducibility Criteria

The individual component reproducibility tolerances were combined using the square root of the sum of the squares method as shown in ASTM D 3588 (GPA 2172) to obtain a precision statement. This is a common methodology employed when determining the tolerance of calculated values containing random individual elemental tolerances. Chromatographic analysis and the calculations of Hv and relative density performed using industry standards, ASTM D 1945 (GPA 2261) and ASTM D

3588 (GPA 2172), will produce heating value results to within $\pm 0.25\%$ and relative density results to within 0.003 relative density units for a typical pipeline lean natural gas having the following composition:

Mixture Component	Mole %
Methane	96.5222
Ethane	1.8186
Propane	0.4596
Isobutane	0.0977
n-Butane	0.1007
Isopentane	0.0473
n-Pentane	0.0324
n-Hexane	0.0664
Nitrogen	0.2595
Carbon Dioxide	0.5956

BTU/Ft³ 1036.06 **Ideal Gross Hv per Real Ft³ @14.73 & 60F**
0.582 **Real Relative Density @14.73 & 60F**

Table 3 – Typical Pipeline Lean Gas Analysis

Since the ASTM D 1945 repeatability and reproducibility criteria originated from a statistical examination of inter-laboratory test results, it includes the influences of properly prepared calibration gas standards. The Hv and relative density precision values assume that the sampling methods and sampling systems utilized provide a representative sample of the flowing gas stream for analysis.

System Balance Influence

Engineering departments can use metering station uncertainty information in selecting the type of equipment to be use in a meter station. Equipment can be selected to meet a system balance expectation or uncertainty. It can be used by gas control departments to estimate when the uncertainty of a meter station's measurement is increasing. It can be used to help manage lost and unaccounted-for numbers. If all one type of equipment is installed on the inlet and all of another type on the outlet, the metering system may not produce the desired system balance results. It can be used by maintenance to understand on which pieces of equipment to concentrate their efforts. In fact since system balance requires strict adherence to the physical laws and whereas custody transfer is an agreement between parties involved, the system balance accuracy is the most demanding

References

- (1) Calculation defines uncertainty of unaccounted-for gas, Norman, R and Jepson, P., Oil & Gas Journal Report April 6, 1987
- (2) Comparison of Orifice and Turbine meter Accuracy, Tiemsyra, P., Rans, R., and Bacus, H., American Gas Association Distribution/Transmission Conference April, 1991, Nashville, Tennessee
- (3) Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids, Part 1 - 1990, General equations and uncertainty guidelines. American Gas Association Report No. 3, Third Edition, Arlington, VA, October 1990.
- (4) Standard Test Method Analysis of Natural Gas by Gas Chromatography - ASTM D 1945-96 (GPA 2261-95)
- (5) Standard Practice for Calculating Heat Value, Compressibility Factor, and Relative Density (Specific Gravity) of Gaseous Fuels - ASTM D 3588-98 (GPA 2172-96)