Manual of Petroleum Measurement Standards Chapter 13 — Statistical Aspects of Measuring and Sampling

Section X— Methods of Evaluating Gas Metering System Uncertainty

1st Edition, 202x

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Introduction

Minimizing gas measurement uncertainty for design or operational maintenance is important to the petroleum industry. A consistent basis for estimating the size and significance of uncertainty of gas quantity transactions is essential for communication among affected parties. Gas measurement systems usually include multiple instruments, and their individual uncertainty contributes to the transaction volume, mass or energy quantity uncertainty.

The purpose of this standard is to define the minimum requirements and typical methods of determining gas measurement system uncertainty so that the uncertainties are understood and consistent with the objectives of parties affected by the measurement operations. The procedures for monitoring instrument performance, and actions to take when uncertainties are outside expectation are left to the agreement among the parties affected by the measurement.

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1 Scope

This standard establishes the basic concepts and procedures to estimate the uncertainty of a gas metering system.

2 Normative References

This document contains no normative references. A list of documents associated with API MPMS Ch 13.X are included in the bibliography.

3 Terms and Definitions

3.1.1

Accuracy

Closeness of agreement between a measured quantity value and a true quantity value of a measurand. The ability to indicate values closely approximating the true value of the measured variable. (adapted from JCGM 200:2012, 2.13)

3.2.1

Confidence Interval

The range within which the true value is expected to lie with a stated confidence level.

3.3.1

Measure and (JCGM 200:2012, 2.3)

Quantity intended to be measured.

3.4.1

Repeatability

A measure of the agreement between the results of successive measurements of the same variable carried out by the same method, with the same instrument, at the same location, and within a short period of time.

3.5.1

Reproducibility

A measure of the agreement between the results of measurements of the same variable where individual measurements are carried out by the same methods, with the same type of instruments, but by different observers, at different locations, and after a long period of time.

3.6.1

Sample

A portion extracted from a population that may or may not contain the constituents in the same proportions as are present in the population.

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3.7.1

Sensitivity Coefficient

A multiplication factor used to determine the relative influence of an inputting parameter or measurand. Mathematically, it is the change in output, y, given a change in one of the inputs x_i in a function:

$y = f(x_1, x_2, \ldots, x_n)$, where i is a positive integer ≤ n.

NOTE Technically the sensitivity coefficient is the partial derivative of y with respect to x_i, but in practice the sensitivity coefficient may be more easily approximated algebraically. (adapted from JCGM 100:2008, 5.1.3)

3.8.1

Standard Deviation

The root mean square deviation of the observed values from the average.

3.9.1

Uncertainty

Non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used. (Adapted from JCGM 200:2012, 2.26)

4. Acronyms and Abbreviations

C_i	sensitivity coefficient for variable i
RTD	resistance temperature detector (also commonly called resistance temperature device)
U	expanded uncertainty
u_i	standard uncertainty of input x_i
q_m	mass flow rate
C_d	Coefficient of discharge
E_v	Velocity of approach factor
Y	Expansibility
d	orifice diameter
g_c	xxx
$\rho_{t,p}$	density at t and p
ΔP	Differential pressure
t	Temperature
p	Pressure
ρ	density
P	pressure

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T	temperature
Z	compressibility
R	Universal gas constant
M_r	molar mass
V_b	standard volume
Vf	flowing volume
Pf	flowing pressure
Pb	base pressure
Tb	base temperature
Tf	flowing temperature
Zb	compressibility at base t and p
Zf	compressibility at flowing t and p
Δy	change in variable y
Δx	change in variable x
h	step size in variable x

5 Significance and General Use

There are various applications for the uncertainty analysis of a gas measurement system that change from system design through to system operation and troubleshooting. This document uses the methods described, and assumes the reader has knowledge of API *MPMS* Chapter 13.3, *Measurement Uncertainty*.

Some assumptions are described in the examples provided that leverage other standards documents. These standards shall govern should any conflict exist between this standard and these standards.

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6 Gas Measurement System Uncertainty

The uncertainty of a gas quantity (mass, volume, energy) determined from a flow metering system is influenced by both hardware and software components. The method used to calculate the uncertainty considers the relative significance of these sources and follows API MPMS Chapter 13.3. The method uses the flow equation that relates the flow metering quantity to the measured or calculated parameters of the system. Figure 1 shows a simplified workflow. For a more detailed description of these grouped steps refer to API MPMS Chapter 13.3.

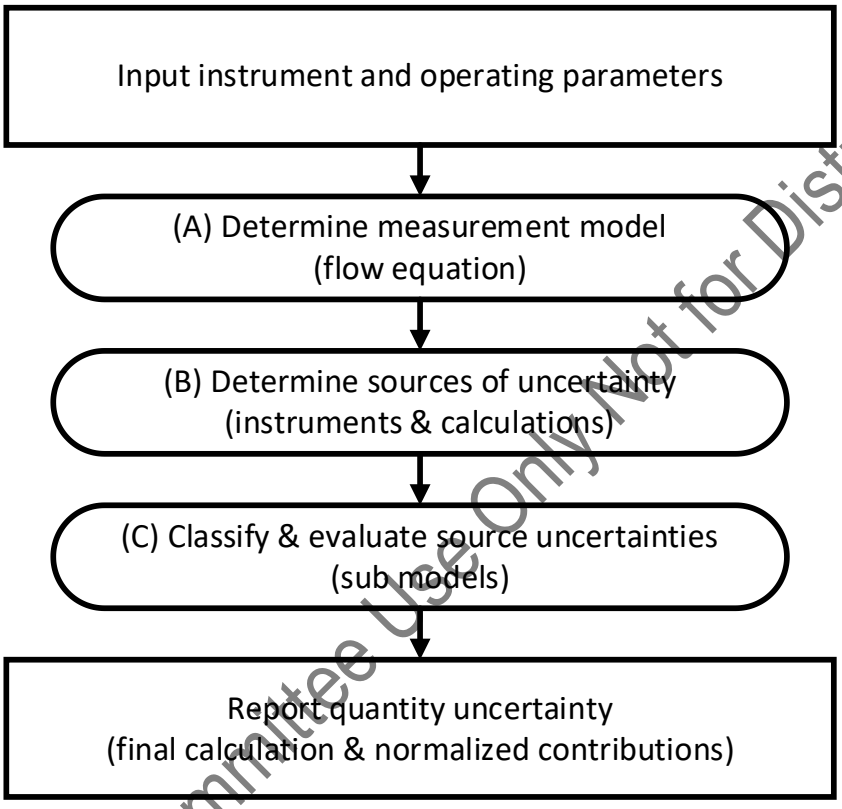

Figure 1- Quantity Uncertainty Determination: Simplified Workflow.

This section describes the implementation of the method using two examples: orifice metering system and linear metering system (ultrasonic, turbine, vortex). Annex A provides additional considerations and the examples described in this section are documented in Annex B.

6.1 Orifice Metering System Mass Flow Example

This section describes a worked example of a mass flow uncertainty calculation for an orifice metering system using assumptions described in API MPMS Ch 14.3.1 and Ch 14.2.2 AGA Report No. 8 Part 1 and 2. A similar approach can be used for volume or energy uncertainty, refer to Annex B.

6.1.2 (A) Determine the Measurement Model

API MPMS Chapter 14.3.1 provides the orifice metering system calculation:

$$q_m = C_d E_v Y (\pi/4) d^2 \sqrt{2 g_c \rho_{t,p} \Delta P} \quad (1)$$

and AGA Report No. 8 provides the density calculation:

$$\rho = \frac{M_r P}{ZRT} \quad (2)$$

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6.1.3 (B) Determine Sources of Uncertainty

An example of mapping the uncertainty sources is shown in Figure 2. Some sources of uncertainty are determined using sub-models and their sources of uncertainty are described in more detail in section 6.3 Pressure, Temperature and Differential Pressure and section 6.4 Gas Property Uncertainty.

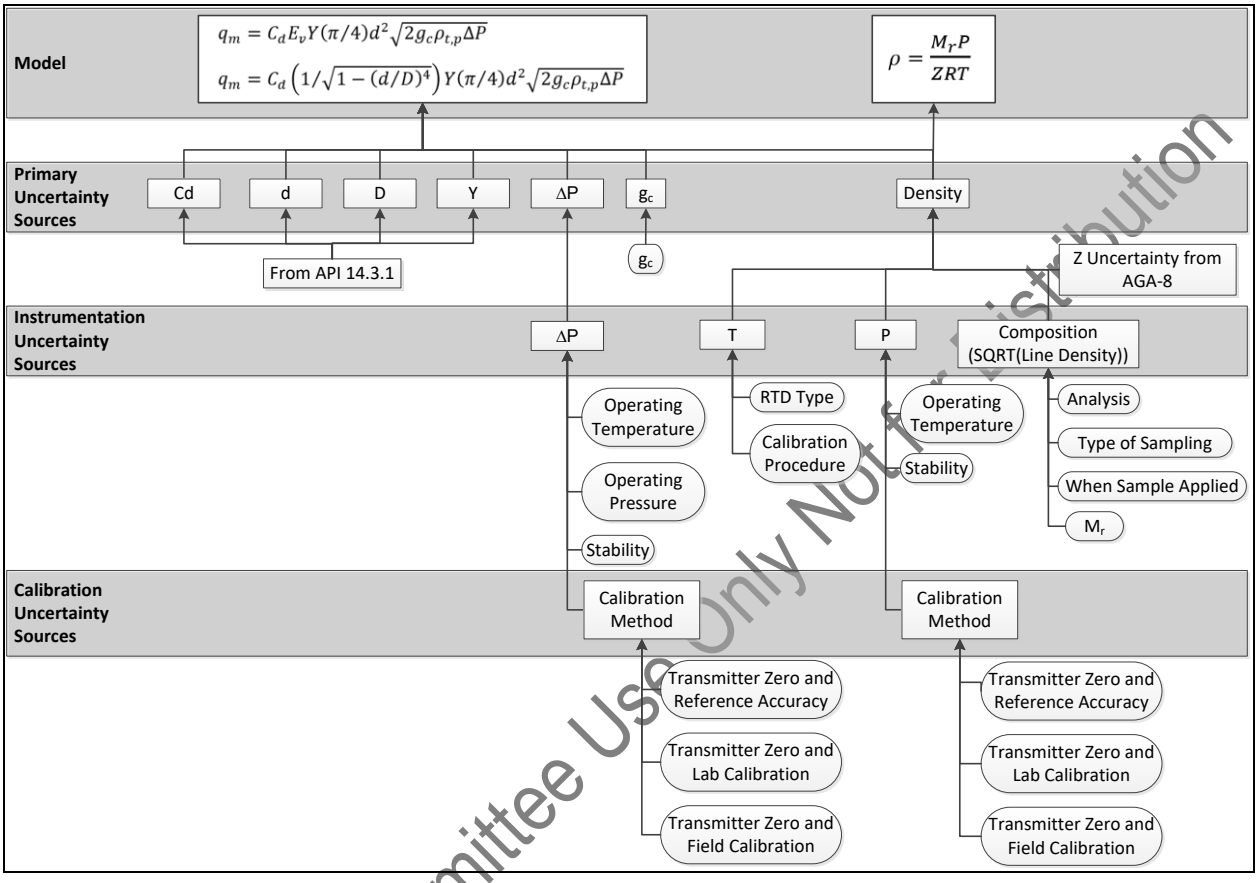

Figure 2 – Sources of Orifice Meter System: Mass Uncertainty

6.1.4 (C) Classify and Evaluate Source Uncertainties

The estimated source uncertainties and distribution types are determined for each source in the model as shown in Figure 3. Some of these source uncertainties are pre-determined in the sub models described in sections 6.3 and 6.4.

In this example the Cd uncertainty comes from API MPMS Chapter 14.3 which includes installation tolerances in the stated Cd uncertainty, and the density uncertainty comes from AGA Report No. 8.

		Input variable	Operating Condition	Uncertainty	Units	Uncertainty %	Distribution Type	Standard uncertainty (u)	Sensitivity coefficient (c)	Correlation coefficient (r)	Variance (u * c)^2	% Contribution
	Orifice	*Cd	0.52		β	0.50%	95 % Normal	0.25%	1.00		6.25E-06	73.7%
		d	2.000	0.0010	inch	0.05%	95 % Normal	0.03%	2.16		2.92E-07	3.44%
		D	3.826	0.0010	inch	0.03%	95 % Normal	0.01%	-0.16		4.45E-10	0.0%
		Y	0.9984		-	0.02%	95 % Normal	0.01%	1.00		8.81E-09	0.1%
	DP	DP	50	0.0051	"H2O	0.51%	95 % Normal	0.26%	0.50		1.65E-06	19.5%
Density	P	P	250.00	0.2063	PSI	0.08%	95 % Normal	0.04%	0.50		4.26E-08	0.5%
	T	T	50.00	0.4200	F	0.08%	95 % Normal	0.04%	-0.50		4.24E-08	0.5%
	EOS	Z				0.10%	95 % Normal	0.05%	0.50		6.25E-08	0.7%
	Sqrt(Line Density)	Comp	0.8097			0.07%	95 % Normal	0.04%	1.00		1.32E-07	1.6%
										Sum of variances, uc(qm)^2	8.48E-06	
										Relative Combined Standard Uncertainty, u_c(qm)	0.29 %	
										Relative Expanded Uncertainty (95% confidence level, k=2), k u_c(qm)	0.58 %	

*Note: API 14.3.1 uses β to determine the Cd uncertainty.

Figure 3 – Orifice Meter System: Mass Uncertainty Summary.

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6.2 Linear Metering System Volumetric Flow Example

This section describes a worked example of a base volume uncertainty calculation for an ultrasonic metering system using the gas equation.

6.2.1 (A) Determine the Measurement Model

$$V_b = V_f \frac{P_f}{P_b} \frac{T_b}{T_f} \frac{Z_b}{Z_f} \qquad (3)$$

This section describes the model for base volume uncertainty. A similar approach can be used for mass or energy uncertainty, both documented in Annex A.

6.2.2 (B) Determine Sources of Uncertainty

An example of mapping the uncertainty sources is shown in Figure 4. Some sources of uncertainty are determined using sub-models and their sources of uncertainty are described in more detail in sections 6.3 and 6.4.

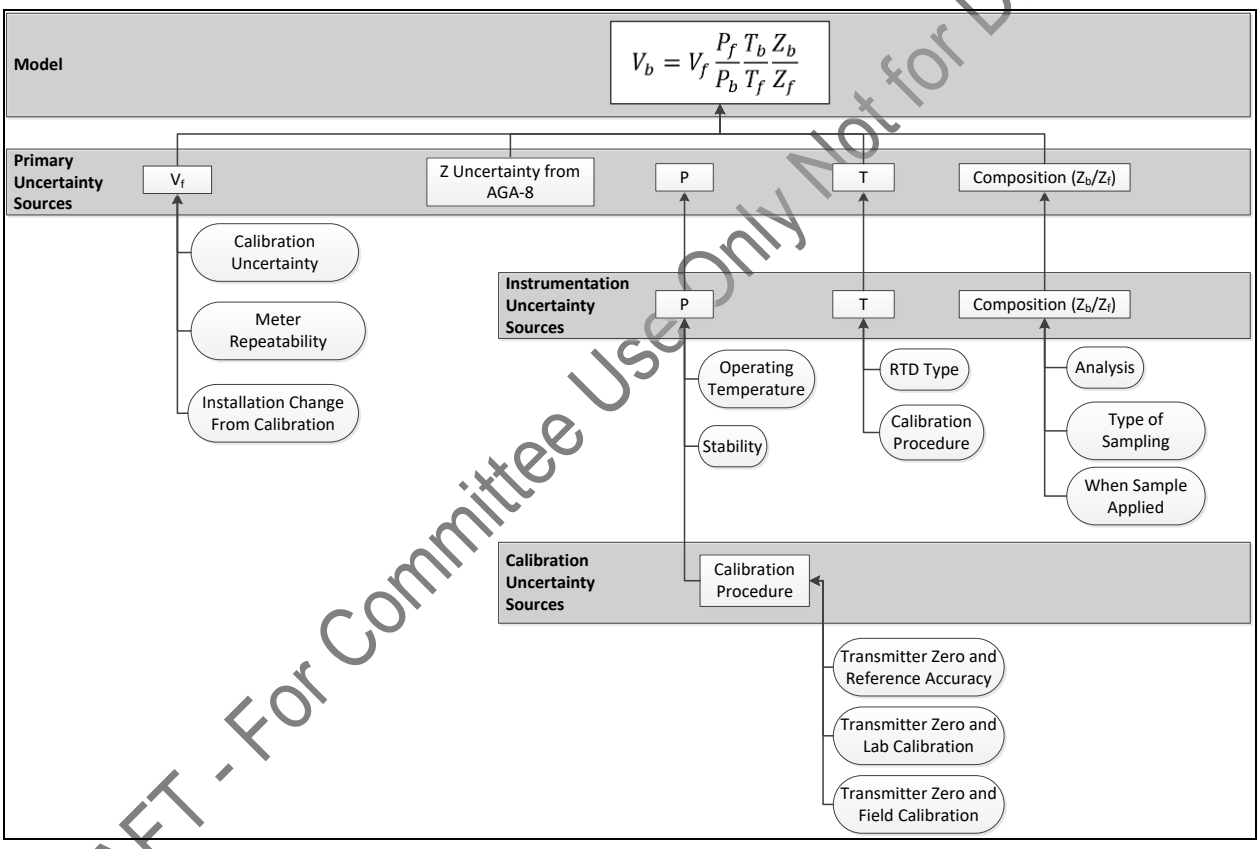

Figure 4 – Sources of Linear Meter System: Standard Volume Uncertainty.

6.2.3 (C) Classify and Evaluate Source Uncertainties

The estimated source uncertainties and distribution types are determined for each source in the model as shown in Figure 5. Some of these source uncertainties are predetermined in the sub models described in sections 6.3 and 6.4.

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		Input variable	Operating Condition	Uncertainty	Units	Uncertainty %	Distribution Type	Standard uncertainty (*u*)	Sensitivity coefficient (*c*)	Correlation coefficient (*r*)	Variance (u * c)^2	% Contribution
	Linear Meter	*Calibration*				0.25%	95 % Normal	0.13%	1.00		1.56E-06	33.6%
		Repeatability				0.10%	95 % Normal	0.05%	1.00		2.50E-07	5.37%
		Installation				0.30%	95 % Normal	0.15%	1.00		2.25E-06	48.32%
Volume Correction	P	*P*	*250.00*	0.2063	PSIA	0.08%	95 % Normal	0.04%	1.00		1.70E-07	3.7%
	T	*T*	*50.00*	0.4200	F	0.08%	95 % Normal	0.04%	1.00		1.70E-07	3.6%
	EOS	*Z*				0.10%	95 % Normal	0.05%	1.00		2.50E-07	5.4%
	Z_{base} / $Z_{flowing}$	*Comp*				0.01%	95 % Normal	0.01%	1.00		4.06E-09	0.1%
										Sum of variances, uc(qstd)*2	4.66E-06	
										Relative Combined Standard Uncertainty, uc(qstd)	0.22	%
										Relative Expanded Uncertainty (95% confidence level, k=2), k Uc(qstd)	0.43	%

Figure 5 – Linear Meter System Standard Volume Uncertainty Summary.

6.3 Pressure, Temperature and Differential Pressure

Pressure, temperature and differential pressure sensors and transmitters often have performance specifications that are described in different ways. This section uses an example specification, and the sub-models may be adjusted to reflect different specification information as needed.

Example sub-models and operating conditions, specification, and calibration approaches for pressure, temperature and differential pressure are shown in Figure 6, Figure 8, and Figure 10 respectively.

The Calibration method section describes three options:

- Transmitter Zero and Manufacturer Reference Accuracy - zero adjustment and slope/linearity reference accuracy specification.
- Transmitter Zero and Lab Calibration - zero and slope/linearity input collected under laboratory conditions.
- Transmitter Zero and Field Calibration - zero and slope/linearity input collected under field conditions and may have a lower calibration accuracy than the laboratory approach.

The calculated uncertainty estimates for pressure, temperature and differential pressure are shown in Figure 7, Figure 9, and Figure 11 respectively.

Transmitter operation		
Static Pressure (Reading)	250	PSIA
Transmitter URL	1000	PSIA
Transmitter Span	500	PSIA

Transmitter specification		
Op. Temp. - Span and Zero Uncertainty		
Specification Per degree F	50	F
Ambient Temperature (F)	70	F
Ambient Temperature Variability (±F)	21	F
Variability (% of Specification)	42.00%	
Stability		
Specification Per 12 Months	12	month
Transmitter Zeroed Every 12 Months	12	month
Stability (% of Specification)	100.00%	

Calibration method		
Transmitter Zero and Reference Accuracy	Ref. Accuracy	
Transmitter Zero and Lab Calibration	0.02%	Reading
Transmitter Zero and Field Calibration	0.10%	Span

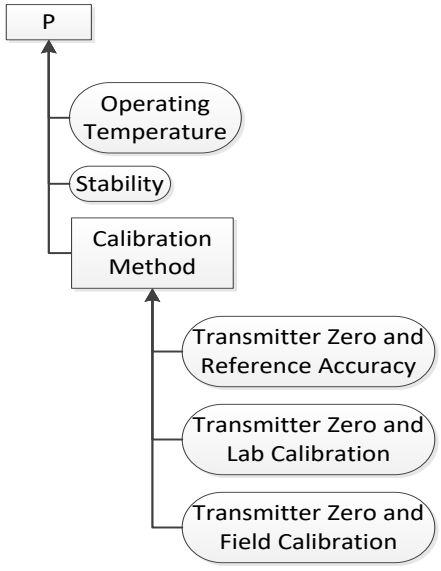

Figure 6 – Pressure Transmitter Operating Conditions, Specification and Calibration Method.

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Input variable	Value	Uncertainty %	Units	Uncertainty (PSI)	Variation %	Adjusted Operating Uncertainty	Distribution Type	Standard uncertainty (u) (PSI)	Sensitivity coefficient (c)	Correlation coefficient (r)	Variance (u * c)^2	% Contribution
Ambient Temp. - Span and Zero Uncertainty												
% Span	500	0.0625%	Span	0.3125	42.00%	0.1313	99 % Normal	0.044	1		1.91E-03	18.0%
Zero (% URL)	1000	0.0125%	URL	0.1250	42.00%	0.0525	99 % Normal	0.018	1		3.06E-04	2.9%
% Reading	250		Reading	0.0000	--	0.0000	99 % Normal	0.000	1		0.00E+00	0.0%
Stability												
% Span	500		Span	0.0000	100.00%	0.0000	99 % Normal	0.000	1		0.00E+00	0.0%
Zero (% URL)	1000	0.0250%	URL	0.2500	100.00%	0.2500	99 % Normal	0.083	1		6.94E-03	65.3%
% Reading	250		Reading	0.0000	--	0.0000	99 % Normal	0.000	1		0.00E+00	0.0%
Transmitter Zero and Lab Calibration												
Transmitter Reference Accuracy												
% Span	500	0.0750%	Span	0.3750	--		99 % Normal	0.000	1		0.00E+00	0.0%
Zero (% URL)	1000		URL	0.0000	--		99 % Normal	0.000	1		0.00E+00	0.0%
% Reading	250		Reading	0.0000	--		99 % Normal	0.000	1		0.00E+00	0.0%
Calibration												
Procedure	250	0.0200%	Reading	0.0500	--	0.0500	95 % Normal	0.025	1		6.25E-04	5.9%
Equipment % Span	500		Span	0.0000	--	0.0000	99 % Normal	0.000	1		0.00E+00	0.0%
Equipment Zero (% URL)	1000		URL	0.0000	--	0.0000	99 % Normal	0.000	1		0.00E+00	0.0%
Equipment % Reading	250	0.0350%	Reading	0.0875	--	0.0875	99 % Normal	0.029	1		8.51E-04	8.0%
Other _____												
% Span	500		Span	0.0000	--		99 % Normal		1			
Zero (% URL)	1000		URL	0.0000	--		99 % Normal		1			
% Reading	250		Reading	0.0000	--		99 % Normal		1			
										Sum of variances, $\Sigma(u * c)^2$	1.06E-02	
										Combined Standard Uncertainty for Energy Rate Composition Uncertainties, $SQRT(\Sigma(u * c)^2)$	0.1032	PSI
										Expanded Uncertainty (95% confidence level, k=2), $k * SQRT(\Sigma(u * c)^2)$	0.2063	PSI
										Expanded Relative Uncertainty (95% confidence level, k=2)	0.08%	

Figure 7 – Pressure Transmitter Estimated Uncertainty Summary.

Operating condition		
Operating Temperature	50	F

RTD Type				
	Zero Uncertainty		Slope Uncertainty	
RTD Type A	0.27	F	0.0020	Per °F Diff
RTD Type B	0.54	F	0.0050	Per °F Diff

Calibration Method		
RTD Reference Accuracy	Ref. Accuracy	
RTD Zero and Lab Calibration	0.10	°F
RTD Zero and Field Calibration	0.50	°F

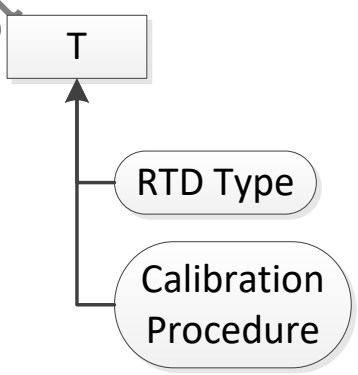

Figure 8 – Temperature RTD Type and Calibration Method.

Input variable	Value	Uncertainty	Units	Uncertainty (F)	Distribution Type	Standard uncertainty (u) (F)	Sensitivity coefficient (c)	Correlation coefficient (r)	Variance (u * c)^2	% Contribution
RTD Reference Accuracy										
RTD Reference Accuracy										
RTD Type B										
Zero (32° F)	32	0.540	°F	0.5400	99 % Normal	0.180	1	1	4.41E-02	85.7%
Temperature Difference from Zero	18.00	0.005	Per °F Diff	0.0900	99 % Normal	0.030	1			14.3%
Calibration										
Procedure		Ref. Accuracy			95 % Normal		1			
Equipment		0.500	°F		99 % Normal		1			
% Span			Span		99 % Normal		1			
Zero (% URL)			URL		99 % Normal		1			
% Reading			Reading		99 % Normal		1			
								Sum of variances, $\Sigma(u * c)^2$	4.41E-02	
								Combined Standard Uncertainty for Energy Rate Composition Uncertainties, $SQRT(\Sigma(u * c)^2)$	0.2100	F
								Expanded Uncertainty (95% confidence level, k=2), $k * SQRT(\Sigma(u * c)^2)$	0.4200	F
								Expanded Relative Uncertainty (95% confidence level, k=2)	0.08%	

Figure 9 – Temperature Estimated Uncertainty Summary.

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Transmitter operation		
Differential Pressure (Reading)	50	" H2O
Transmitter URL	250	" H2O
Transmitter Span	100	" H20

Transmitter specification		
Op. Temp. - Span and Zero Uncertainty		
Specification Per degree F	50	F
Ambient Temperature (F)	70	F
Ambient Temperature Variability (±F)	21	F
Variability (% of Specification)	42.00%	
Op. Pressure - Span and Zero Uncertainty		
Specification Per psi	1000	psi
Operating Pressure	800	psi
Operating Pressure Variability (±)	200	psi
Variability (% of Specification)	20.00%	
Stability		
Specification Per 12 Months	12	month
Transmitter Zeroed Every 12 Months	12	month
Stability (% of Specification)	100.00%	

Calibration method		
Transmitter Zero and Reference Accuracy	Ref. Accuracy	
Transmitter Zero and Lab Calibration	0.02%	Reading
Transmitter Zero and Field Calibration	0.25%	Span

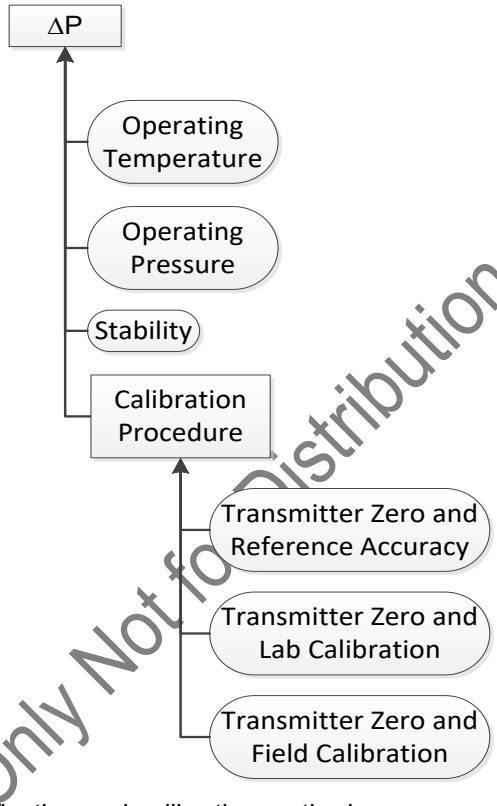

Figure 10 – Differential Pressure operating conditions, specification and calibration method

Input variable	Value	Uncertainty %	Units	Uncertainty (" H2O)	Variation %	Adjusted Operating Uncertainty	Distribution Type	Standard uncertainty (*u*) (" H2O)	Sensitivity coefficient (*c*)	Correlation coefficient (*r*)	Variance (u * c)^2	% Contribution
Ambient Temp. - Span and Zero Uncertainty												
% Span	100	0.0625%	Span	0.0625	42.00%	0.0263	99 % Normal	0.009	1		7.66E-05	0.5%
Zero (% URL)	250	0.0125%	URL	0.0313	42.00%	0.0131	99 % Normal	0.004	1		1.91E-05	0.1%
% Reading	50		Reading	0.0000	--	0.0000	99 % Normal	0.000	1		0.00E+00	0.0%
Op. Pressure - Span and Zero Uncertainty												
Zero (% URL) per 1000 psi	250	0.0500%	URL	0.1250	20.00%	0.0250	99 % Normal	0.008	1		6.94E-05	0.4%
% Reading	50	0.1000%	Reading	0.0500	--	0.0500	99 % Normal	0.017	1		2.78E-04	1.7%
Stability												
% Span	100		Span	0.0000	100.00%	0.0000	99 % Normal	0.000	1		0.00E+00	0.0%
Zero (% URL)	250	0.0250%	URL	0.0625	100.00%	0.0625	99 % Normal	0.021	1		4.34E-04	2.6%
% Reading	50		Reading	0.0000	--	0.0000	99 % Normal	0.000	1		0.00E+00	0.0%
Transmitter Zero and Field Calibration												
Transmitter Reference Accuracy												
% Span	100	0.0750%	Span	0.0750	--	#N/A	99 % Normal		1			
Zero (% URL)	250		URL	0.0000	--	#N/A	99 % Normal		1			
% Reading	50		Reading	0.0000	--	#N/A	99 % Normal		1			
Calibration												
Procedure	100	0.2500%	Span	0.2500	--	0.2500	95 % Normal	0.125	1		1.56E-02	94.5%
Equipment % Span	100		Span	0.0000	--	0.0000	99 % Normal	0.000	1		0.00E+00	0.0%
Equipment Zero (% URL)	250		URL	0.0000	--	0.0000	99 % Normal	0.000	1		0.00E+00	0.0%
Equipment % Reading	50	0.0350%	Reading	0.0175	--	0.0175	99 % Normal	0.006	1		3.40E-05	0.2%
Other _____												
% Span	100		Span	0.0000	--		99 % Normal		1			
Zero (% URL)	250		URL	0.0000	--		99 % Normal		1			
% Reading	50		Reading	0.0000	--		99 % Normal		1			
										Sum of variances, $\Sigma(u * c)^2$	1.65E-02	
										Combined Standard Uncertainty for Energy Rate Composition Uncertainties, $SQRT(\Sigma(u * c)^2)$	0.1286	" H2O
										Expanded Uncertainty (95% confidence level, k=2), $k * SQRT(\Sigma(u * c)^2)$	0.2572	" H2O
										Expanded Relative Uncertainty (95% confidence level, k=2)	0.51%	

Figure 11 – Differential Transmitter Estimated Uncertainty Summary.

6.4 Gas Property Uncertainty

Composition is often used to determine gas properties which are used to determine mass, volume, and energy quantities in a gas measurement system. The sub-model associated with gas properties via composition is described in this section and follow the process summarized in Figure 12.

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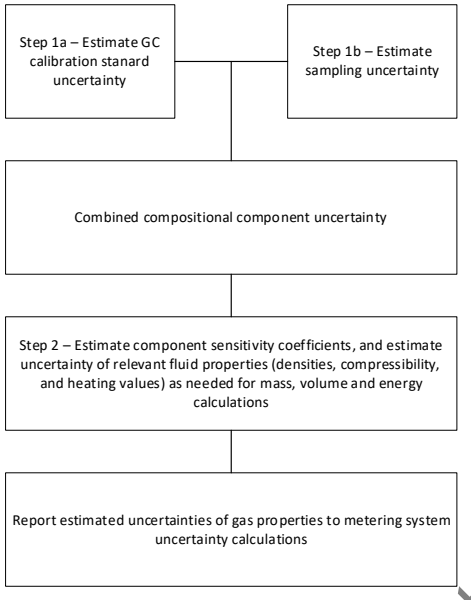

Figure 12 – Gas Property Uncertainty Calculation Steps.

6.4.1 Step 1 – Estimate GC Calibration Standard & Sample Uncertainty

Gas chromatographs are a common way to determine the composition of a gas stream; however, they are not the only analytical method commonly used in determining the entire composition of the gas stream. In the interest of simplicity, this example only including the uncertainty of a chromatograph. In practice, the uncertainty of all analytical devices should be included. The calibration gas component uncertainties are typically provided in the form of a calibration gas certificate, on a per component basis. Figure 13 shows an example in step 1a.

The sample uncertainty can be determined based on an evaluation of sampling statistics and an assessment of component variance. The assumptions used to assess the variance may depend on the system in place including the stability of the process, and frequency of sampling. For example, a system using a gas chromatograph that is collecting, analyzing and averaging a large number of samples over a period, the average composition may be assumed to introduce minimal or no additional variance or component uncertainty.

In a system that uses composite or spot sampling, the component variance may be estimated using history, for example, or an estimate of maximum and minimum component variation. The example shown in Figure 13 Step 1b, assumes the use of history (12 samples) and Figure 14 shows the 12-sample data with average and two standard deviation variances. Combining the calibration standard uncertainty (step 1a) with the sampling composition uncertainty (step 1b) provides the combined uncertainty for the compositional components.

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Combined calibration standard and sample composition uncertainty						
Step 1a - Estimate the GC calibration standard uncertainty				Step 1b - Sampling uncertainty			Combined Uncertainty
Component	mole %	normalized mole %	GC Cal Standard Uncertainty	Component Uncertainty	Uncertainty Period Samples	Adjusted Component Uncertainty	
methane	95.2299	95.2299	0.0243	0.6355	12	0.1835	0.1850
ethane	2.1114	2.1114	0.0200	0.4580		0.1322	0.1337
propane	0.8182	0.8182	0.0082	0.1361		0.0393	0.0401
isobutane	0.1262	0.1262	0.0013	0.0171		0.0049	0.0051
butane	0.2165	0.2165	0.0022	0.0389		0.0112	0.0114
isopentane	0.0593	0.0593	0.0006	0.0105		0.0030	0.0031
pentane	0.0531	0.0531	0.0005	0.0104		0.0030	0.0030
hexane	0.0336	0.0336	0.0003	0.0091		0.0026	0.0026
heptane	0.0162	0.0162	0.0002	0.0058		0.0017	0.0017
octane	0.0044	0.0044	0.0000	0.0023		0.0007	0.0007
helium	0.0222	0.0222	0.0002	0.0027		0.0008	0.0008
carbon dioxide	0.2757	0.2757	0.0028	0.0573		0.0165	0.0168
nitrogen	1.0334	1.0334	0.0103	0.1641		0.0474	0.0485
	100.00000	100.00000					

Figure 13 – Calibration gas and sample composition component uncertainties

Step 1b - Sampling uncertainty															
	1	2	3	4	5	6	7	8	9	10	11	12	Average	1σ	2σ
methane	95.3716	95.1960	95.2279	94.5459	95.3604	94.6505	95.5369	95.4151	95.3482	95.1576	95.5035	95.4447	95.2299	0.3178	0.6355
ethane	2.0436	2.0993	2.1231	2.4185	2.0505	2.7171	1.9348	1.9705	2.0233	1.9948	1.9664	1.9951	2.1114	0.2290	0.4580
propane	0.8023	0.8475	0.8517	1.0149	0.8195	0.7823	0.7563	0.7825	0.8073	0.7942	0.7754	0.7850	0.8182	0.0680	0.1361
isobutane	0.1181	0.1283	0.1276	0.1507	0.1236	0.1201	0.1186	0.1237	0.1297	0.1259	0.1236	0.1243	0.1262	0.0086	0.0171
butane	0.2106	0.2294	0.2237	0.2718	0.2156	0.2029	0.1976	0.2085	0.2153	0.2088	0.2051	0.2080	0.2165	0.0195	0.0389
isopentane	0.0566	0.0633	0.0593	0.0743	0.0582	0.0556	0.0544	0.0589	0.0596	0.0574	0.0571	0.0572	0.0593	0.0052	0.0105
pentane	0.0510	0.0580	0.0532	0.0678	0.0519	0.0495	0.0483	0.0527	0.0525	0.0510	0.0509	0.0508	0.0531	0.0052	0.0104
hexane	0.0310	0.0383	0.0339	0.0460	0.0315	0.0318	0.0290	0.0341	0.0315	0.0327	0.0322	0.0309	0.0336	0.0046	0.0091
heptane	0.0140	0.0195	0.0165	0.0239	0.0147	0.0154	0.0128	0.0165	0.0152	0.0150	0.0152	0.0152	0.0162	0.0029	0.0058
octane	0.0035	0.0057	0.0042	0.0071	0.0039	0.0050	0.0029	0.0047	0.0046	0.0036	0.0040	0.0039	0.0044	0.0011	0.0023
helium	0.0223	0.0228	0.0216	0.0251	0.0232	0.0214	0.0218	0.0239	0.0224	0.0206	0.0208	0.0208	0.0222	0.0014	0.0027
carbon dioxide	0.2742	0.2782	0.2750	0.2888	0.2692	0.3610	0.2538	0.2570	0.2626	0.2607	0.2621	0.2654	0.2757	0.0286	0.0573
nitrogen	1.0013	1.0137	0.9823	1.0652	0.9778	0.9873	1.0326	1.0524	1.0277	1.2778	0.9836	0.9988	1.0334	0.0821	0.1641
	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000		

Figure 14 – Sampling Uncertainty from History

6.4.2 Step 2 – Estimate Gas Property Component Uncertainty and Sensitivity Coefficients

Composition affects the calculation of density, compressibility and heating value. Due to the interrelationship between composition and the correlation between density, compressibility and heating value, partial differentiation may use to estimate each composition's relative sensitivity using the following equation:

$$\text{Relative Sensitivity: } c = \frac{\Delta y/y}{\Delta x/x} = \frac{(f(x+h)-f(x))/f(x)}{h/x} \quad (4)$$

For example, for the calculation of mass flow in the orifice metering mass flow example in 6.1, sqrt (line density) is needed. Figure 15 shows the example of using (4) to calculate the per component sensitivity coefficients.

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step size, h 1.00E-04

Calculating Sensitivity Coefficients (Ci) by numerical differentiation with respect to each input:

	methane	ethane	propane	isobutane	butane	isopentane	pentane	hexane	heptane	octane	helium	carbon dioxide	nitrogen
methane	95.2299	95.2298	95.2298	95.2298	95.2298	95.2298	95.2298	95.2298	95.2298	95.2298	95.2298	95.2298	95.2298
ethane	2.1114	2.1115	2.1114	2.1114	2.1114	2.1114	2.1114	2.1114	2.1114	2.1114	2.1114	2.1114	2.1114
propane	0.8182	0.8182	0.8183	0.8182	0.8182	0.8182	0.8182	0.8182	0.8182	0.8182	0.8182	0.8182	0.8182
isobutane	0.1262	0.1262	0.1262	0.1263	0.1262	0.1262	0.1262	0.1262	0.1262	0.1262	0.1262	0.1262	0.1262
butane	0.2165	0.2165	0.2165	0.2165	0.2166	0.2165	0.2165	0.2165	0.2165	0.2165	0.2165	0.2165	0.2165
isopentane	0.0593	0.0593	0.0593	0.0593	0.0593	0.0594	0.0593	0.0593	0.0593	0.0593	0.0593	0.0593	0.0593
pentane	0.0531	0.0531	0.0531	0.0531	0.0531	0.0531	0.0532	0.0531	0.0531	0.0531	0.0531	0.0531	0.0531
hexane	0.0336	0.0336	0.0336	0.0336	0.0336	0.0336	0.0336	0.0337	0.0336	0.0336	0.0336	0.0336	0.0336
heptane	0.0162	0.0162	0.0162	0.0162	0.0162	0.0162	0.0162	0.0162	0.0163	0.0162	0.0162	0.0162	0.0162
octane	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0044	0.0045	0.0044	0.0044	0.0044
helium	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0222	0.0223	0.0222	0.0222
carbon dioxide	0.2757	0.2757	0.2757	0.2757	0.2757	0.2757	0.2757	0.2757	0.2757	0.2757	0.2757	0.2758	0.2757
nitrogen	1.0334	1.0334	1.0334	1.0334	1.0334	1.0334	1.0334	1.0334	1.0334	1.0334	1.0334	1.0334	1.0335
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Refprop Strings for Numerical Di	methane;ethane;prop	methane;ethane;prop	methane;ethane;prop	methane;ethane;propa	methane;ethane;propa	methane;ethane;propane	methane;ethane;propane	methane;ethane;propa	methane;ethane;propa	methane;ethane;propa	methane;ethane;propa	methane;ethane;propane	methane;ethane;propa ne;isobutane;butane;n
Component	*methane*	*ethane*	*propane*	*isobutane*	*butane*	*isopentane*	*pentane*	*hexane*	*heptane*	*octane*	*helium*	*carbon dioxide*	*nitrogen*
Line Density (x+h)	*0.8097*	*0.8097*	*0.8097*	*0.8097*	*0.8097*	*0.8097*	*0.8097*	*0.8097*	*0.8097*	*0.8097*	*0.8097*	*0.8097*	*0.8097*
SQRT(Line Density)	*0.8998*	*0.8998*	*0.8998*	*0.8998*	*0.8998*	*0.8998*	*0.8998*	*0.8998*	*0.8998*	*0.8998*	*0.8998*	*0.8998*	*0.8998*
Relative Sensitivity	-2.92E-02	8.98E-03	7.14E-03	1.66E-03	2.86E-03	1.05E-03	9.36E-04	7.40E-04	4.28E-04	1.36E-04	-9.89E-05	2.24E-03	3.09E-03

Figure 15 Example table: calculation of sensitivity coefficients for sqrt(line density).

In the example described in 6.2 Linear Metering System Volumetric Flow Example, Zb/Zf is needed. Figure 16 shows the example of using (4) to calculate the per component sensitivity coefficients.

Component	*methane*	*ethane*	*propane*	*isobutane*	*butane*	*isopentane*	*pentane*	*hexane*	*heptane*	*octane*	*carbon monoxide*	*carbon dioxide*	*nitrogen*
Z_f	*0.9605*	*0.9605*	*0.9605*	*0.9605*	*0.9605*	*0.9605*	*0.9605*	*0.9605*	*0.9605*	*0.9605*	*0.9605*	*0.9605*	*0.9605*
Z_b	*0.9978*	*0.9978*	*0.9978*	*0.9978*	*0.9978*	*0.9978*	*0.9978*	*0.9978*	*0.9978*	*0.9978*	*0.9978*	*0.9978*	*0.9978*
Z_b/Z_f	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388	1.0388
Relative Sensitivity	-3.68E-03	1.68E-03	1.19E-03	2.56E-04	4.63E-04	1.64E-04	1.43E-04	1.09E-04	6.29E-05	1.95E-05	-2.64E-05	9.18E-05	-4.73E-04

Figure 16 Example table: calculation of sensitivity coefficients for Zb/Zf.

6.4.3 Step 3 - Report the Estimated Uncertainty of Gas Properties

The sensitivity coefficients described in the Step 2 are used in figures Figure 17 and Figure 18 to determine the composition uncertainty for the orifice mass flow and linear meter volume flow calculations respectively. The outputs (0.07% and 0.01% respectively) are used as the inputs for the composition contribution in Figure 3 and Figure 5 respectively.

Input variable		Uncertainty	Units	Calculated Uncertainty	Distribution Type	Standard Uncertainty (u)	Sensitivity Coefficient (c)	Variance (u * c)^2	% Contribution
Pressure	250.00								
Temperature	50.00								
methane	*95.2299*	0.1850	mol%	0.194%	95 % Normal	0.0972%	-0.0292	8.02E-10	0.6%
ethane	*2.1114*	0.1337	mol%	6.333%	95 % Normal	3.1664%	0.0090	8.09E-08	61.3%
propane	*0.8182*	0.0401	mol%	4.905%	95 % Normal	2.4523%	0.0071	3.07E-08	23.2%
isobutane	*0.1262*	0.0051	mol%	4.041%	95 % Normal	2.0205%	0.0017	1.12E-09	0.9%
butane	*0.2165*	0.0114	mol%	5.284%	95 % Normal	2.6420%	0.0029	5.70E-09	4.3%
isopentane	*0.0593*	0.0031	mol%	5.189%	95 % Normal	2.5943%	0.0010	7.39E-10	0.6%
pentane	*0.0531*	0.0030	mol%	5.730%	95 % Normal	2.8648%	0.0009	7.20E-10	0.5%
hexane	*0.0336*	0.0026	mol%	7.888%	95 % Normal	3.9440%	0.0007	8.52E-10	0.6%
heptane	*0.0162*	0.0017	mol%	10.492%	95 % Normal	5.2459%	0.0004	5.05E-10	0.4%
octane	*0.0044*	0.0007	mol%	14.814%	95 % Normal	7.4070%	0.0001	1.02E-10	0.1%
helium	*0.0222*	0.0008	mol%	3.689%	95 % Normal	1.8443%	-0.0001	3.33E-12	0.0%
carbon dioxide	*0.2757*	0.0168	mol%	6.080%	95 % Normal	3.0398%	0.0022	4.62E-09	3.5%
nitrogen	*1.0334*	0.0485	mol%	4.692%	95 % Normal	2.3460%	0.0031	5.26E-09	4.0%
Total	*100.0000*								
Line Density	*0.809689*	g/mol							
SQRT(Line Density)	*0.900*								
							Sum of variances, $\Sigma(u * c)^2$	1.32E-07	100.0%
							Combined Standard Relative Uncertainty for Mass Rate Composition Uncertainties, SQRT($\Sigma(u * c)^2$)	0.04%	
							Expanded Relative Uncertainty (95% confidence level, k=2), k * SQRT($\Sigma(u * c)^2$)	0.07%	

Figure 17 – Composition Uncertainty Summary Table for Orifice Meter Mass.

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Input variable		Uncertainty	Units	Calculated Uncertainty	Distribution Type	Standard Uncertainty (u)	Sensitivity Coefficient (c)	Variance (u * c)^2	% Contribution
Pressure	0.00								
Temperature	0.00								
methane	*95.2299*	0.1850	mol%	0.194%	95 % Normal	0.0972%	-0.0037	1.28E-11	0.3%
ethane	*2.1114*	0.1337	mol%	6.333%	95 % Normal	3.1664%	0.0017	2.82E-09	69.4%
propane	*0.8182*	0.0401	mol%	4.905%	95 % Normal	2.4523%	0.0012	8.58E-10	21.1%
isobutane	*0.1262*	0.0051	mol%	4.041%	95 % Normal	2.0205%	0.0003	2.67E-11	0.7%
butane	*0.2165*	0.0114	mol%	5.284%	95 % Normal	2.6420%	0.0005	1.50E-10	3.7%
isopentane	*0.0593*	0.0031	mol%	5.189%	95 % Normal	2.5943%	0.0002	1.82E-11	0.4%
pentane	*0.0531*	0.0030	mol%	5.730%	95 % Normal	2.8648%	0.0001	1.69E-11	0.4%
hexane	*0.0536*	0.0026	mol%	7.888%	95 % Normal	3.9440%	0.0001	1.86E-11	0.5%
heptane	*0.0162*	0.0017	mol%	10.492%	95 % Normal	5.2459%	0.0001	1.09E-11	0.3%
octane	*0.0044*	0.0007	mol%	14.814%	95 % Normal	7.4070%	0.0000	2.10E-12	0.1%
helium	*0.0222*	0.0008	mol%	3.689%	95 % Normal	1.8443%	0.0000	2.37E-13	0.0%
carbon dioxide	*0.2757*	0.0168	mol%	6.080%	95 % Normal	3.0398%	0.0001	7.79E-12	0.2%
nitrogen	*1.0354*	0.0485	mol%	4.692%	95 % Normal	2.3460%	-0.0005	1.23E-10	3.0%
Total	*100.0000*								
Z_f	*0.960524*								
Z_b	*0.997829*								
Z_b/Z_f	*1.0388389834*								
							Sum of variances, $\Sigma(u * c)^2$	4.06E-09	100.0%
							Combined Standard Relative Uncertainty for Volume Rate Composition Uncertainties, $SQRT(\Sigma(u * c)^2)$	0.01%	
							Expanded Relative Uncertainty (95% confidence level, k=2), $k * SQRT(\Sigma(u * c)^2)$	0.01%	

Figure 18 – Composition Uncertainty Summary Table for Linear Meter Volume.

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Annex A: Informative Considerations for Gas Measurement System Uncertainty

Quantification of the uncertainty of a measurement system has multiple uncertainty sources. Some may be more impactful than others, and the evaluation of the source uncertainty impact may be system specific. Some common sources are listed below with guidance on quantifying them.

Note: the uncertainty examples in this document do not consider all the sources listed below.

Flow Meters and Flow Elements

Sources of uncertainty in a flow meter or flow element are technology specific:

Source	Guidance
Calibration	Uncertainties arise from the calibration process of the flow meter or flow element. For example, a flow meter or element may be calibrated using a dynamic calibration that correlates its response to measured flow rates, or a static calibration that measures its dimensions or response under static conditions. Uncertainty in calibration may be described from: • Uncertainty of the reference equipment measurement used for the calibration (test equipment). • • Applied correction factors or curve fits, such as a meter adjustment curve. In the case of a dynamic flow calibration, the reference equipment uncertainty and repeatability is generally provided by the flow facility at the time of calibration. In the case of static or dimensional calibration, calibration uncertainty is determined from the reference instruments used, and the measured repeatability. In either case a correction factor or curve is sometimes determined post calibration. In cases where dynamic or static/dimensional calibration is not available, for example, during design, specification from the manufacturer or published test results may be used.
Linearity	Uncertainty due to the non-linear response. For example, a flow meter may have a calibration curve at a discrete number of flow rates or a fixed calibration adjustment, and non-linear response that hasn't been accounted for may still be present.
Long Term Reproducibility Stability / Drift)	An uncertainty due to potential drift in a measurement over time, from when it was installed or last calibrated. Sources of stability or drift uncertainty can include: • Fouling of the meter or pipework • Degradation of components; either physical or electronic • Mechanical wear of meter moving parts Drift is sometimes quantified by the manufacturer and more often estimated through operational experience.

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Flow Calculation Uncertainty	Uncertainty in the parameters used for flow calculation. For example: • Discharge coefficient for differential pressure devices is derived from experimental data and therefore has an associated uncertainty. If using a fixed temperature in the flow calculation, any variation in process temperature will contribute to uncertainty. For uncertainty in flow calculation parameters such as discharge coefficients refer to standards governing the flow meter type. Uncertainties in other fixed parameters such as process variables can be assessed by inspecting the variability of the process.
Installation effects	An installation effect is something that contributes to uncertainty in the meter reading as a result of installation in the process. For example, this could include • Flow disturbances resulting from upstream pipework • Pipe stresses • Pipe alignment • Non-steady flow • Pulsating Flow • Swirling, or disturbed flow, Type of flow conditioning utilized • Deviations from calibration conditions: Operating pressure and temperature, ambient temperature or fluid properties. • Fluid phase(s) • Actual volumetric flow rate verses Reynolds Number verses standard volumetric flow rate • Variation in viscosity – Assumptions of value and variability about that value.
	Quantifying installation effect uncertainties can often be difficult. The user may be able to draw on the following: • Published technical data and papers. • Type-approval certification for the specific flow meter model may outline maximum permissible effects. • Flow measurement standards for the specific flow meter (E.g. AGA9, API Ch14.3.) Knowledge of the specific process will also be beneficial in estimating installation effects, for example.

Pressure, Temperature and Differential Pressure Instrumentation

Uncertainty in process pressure and temperature measurements contributes to uncertainty in physical properties of the gas such as density and compressibility. This contributes to uncertainty in calculated quantities such as standard volume or mass. In some cases, pressure or temperature variation may impact quantity uncertainty through mechanical changes.

In the case of differential pressure, uncertainty feeds into flow rate via the flow equation for the differential pressure device. In the absence of further information, the manufacturer's specification is generally used to assess pressure and temperature instrumentation uncertainty.

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Typical sources of uncertainty in instrumentation include:

- Linearity – Uncertainty due to the non-linear response of an instrument.
- Repeatability – A measure of the agreement between the results of successive measurements of the same variable carried out by the same method, with the same instrument, at the same location, and within a short period of time.
- Hysteresis – The difference between the indications of a measuring instrument when the same value of the quantity measured is reached by increasing or decreasing the quantity. In operation, hysteresis is normally small. In calibration, hysteresis can introduce calibration bias due to the larger size of hysteresis loop that can occur if the test points are applied in an always increasing or always reducing direction without small random adjustment around the test point.
- Zero Drift - An uncertainty due to potential drift in a measurement overtime, from when it was installed or last calibrated. Modern intelligent transmitters primarily have a zero drift that can be detected and adjusted in the field.
- Slope stability is usually small and is usually similar in size to the test equipment stability. This makes it difficult to detect and impractical to manage in the field.
- Vibration – Some instruments can be affected by high-vibration environments. If so, uncertainty is generally specified by the manufacturer.
- Orientation – Some instruments can be affected by the orientation in which they are installed. Often this is correctable bias and not a source of uncertainty.
- Ambient Temperature Effects – An additional uncertainty due to change in ambient temperature from the ambient temperature at which the instrument was calibrated.
- Static Pressure Effects (for differential pressure transmitters only) – An additional uncertainty due to operating a differential pressure instrument at a different static pressure from the static pressure at which it was calibrated.
- Analogue to Digital and Digital to Analogue signal conversion accuracy – The applicability of these uncertainties depend on the communication protocols being used to transmit the measurement.

In the case of gauge pressure instrumentation, the atmospheric pressure and associated variation should also be considered. In the case of temperature measurement, the class of the temperature sensing element should be considered in conjunction with the transmitter, if applicable. In operations, knowledge of the site maintenance practices may be used to characterize the uncertainty of the instrument:

- Verification Tolerance – the pass/fail tolerance applied to the verification check, can be assessed as a rectangular distribution.
- Test Equipment Uncertainty – the uncertainty of the test equipment used to perform the verification check.
- Verification Frequency – this can be used to assess probable uncertainty due to drift between calibrations, in combination with the manufacturer's specification.

Gas Composition

The uncertainty of a gas composition is generally a combination of sampling and analysis methods.

Sampling methods are designed for specific conditions, for example, well mixed, single-phase gas. Deviation from these design assumptions can impact performance. Additional typical sources of sampling uncertainty may include:

- Process variability (chemical or flow)
- Sample system equipment – Sampling probe and tubing, container
- Sample handling - The activities associated with transport, conditioning, storage, transfer and preparation of a sample or samples for analysis.

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- Sample interval – The actual flow rate and variability of the gas composition of that flow determines sampling frequency. The variation of standard volumetric flow rate quantities must be modelled against the gas composition variability to determine the type of sampling and the sample interval to keep the reported gas volumes with-in allowable uncertainty values.

Analytical methods

- Calibration Gas Uncertainty – The calibration gas target composition has uncertainty associated with each component of the mixture. The accuracy of the component quantity is listed by the supplier for that bottle. The calibration gas also can be affected by settling by density separation and stratification. Mixing and/or heating may be required to ensure a homogeneous sample gas is provided.
- Validation Repeatability (for example ASTM D1945).
- Normalization – Any given gas composition when totalized against mole percentage will not equal 100% due to changes in atmospheric pressure changing the injection sample size. In order to report the composition in percent the adjustment of each component must be adjusted so the total composition equals 100%. Consider if the adjustment process is causing excessive normalization and if this may be causing a bias .
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Fluid Property and Gas Quality Calculations

Uncertainty in the equation of state or base calculation method should be considered. Equations of state are usually based on empirical data and their uncertainty described due to curve-fitting or extrapolation of this experimental data. This type of uncertainty is often referred to as “Method Uncertainty” as it is the uncertainty inherent in the calculation method itself. Method uncertainty must be treated separately, in addition to the uncertainty of any inputs to these calculations. For example:

Calculation of gas density and compressibility using AGA8 Detail Characterization method. Sources of uncertainty will include those associated with the measurement of line pressure, temperature and gas composition as well as the method uncertainty of the AGA8 calculation itself.

Annex B

(Informative)

See the Table Gas Mass Volume Energy Guide

Annex Example Tables Gas Mass Volume Energy Aug_19_2026.xlsm

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Bibliography

The following documents are directly referenced in this recommended practice.

[1] API *MPMS* Chapter 13.3, Measurement Uncertainty

[2] API MPMS Ch 14.2.2 Calculating Thermodynamic Properties of Natural Gas and Other Related Hydrocarbon Gases Using GERG-2008 Equation (AGA Report No. 8 Part 2)

[3] API MPMS Ch 14.3.1 Concentric, Square-Edged Orifice Meters – General, Equations and Uncertainty Guidelines (AGA Report No. 3 Part 1)

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