

FLOW MEASUREMENT UNCERTAINTY OF NATURAL GAS METERING STATION IN GAS PROCESSING UNITY

Valmir Ruis, N. M. Taira

*IPT-Institute for Technological Research
Flow Laboratory*

José M. Câmara Brito

Petrobrás - Petróleo Brasileiro S.A.

DTSE - GEMAC

Process Engineer

Rodovia Amaral Peixoto km 188

27970-020 / Cabiunas - Macaé - RJ - BRAZIL

ABSTRACT:

Orifice plates are the most common flow meters used in Brazil to measure natural gas in metering stations in processing units.

This article presents the results of analysis of the present situation of gas flow metering stations according to metrological and dimensional criteria of AGA Report #3. The uncertainty analysis was made following the guidelines of the ISO Guide for Uncertainty in Measurement (ISO GUM).

1 INTRODUCTION

This work is part of the tasks developed by a quality program regarding the measured values and totalized daily volumes of natural gas in processing units of Petrobras. An evaluation of the situation of Macaé is described to see if it conforms to the AGA Report n° 3 [1] and AGA Report n° 8 [2].

The uncertainty evaluation was made using the recommendations of the ISO GUM [3], combining the calibration values, process data and AGA values.

2 METODOLOGY FOR THE UNCERTAINTY ANALYSIS

Considering the generic case where an output quantity Y is a function of several input quantities $x_1, x_2, x_3, \dots, x_n$, the uncertainty $u(y)$ of the dependent variable Y will be:

$$u_c^2(y) = \sum_{i=1}^n \left[\frac{\partial f}{\partial x_i} \right]^2 u^2(x_i) , \quad (1)$$

Where $u(x_i)$ is the uncertainty in the determination of x_i .

Defining the sensitivity coefficient as $c_i \equiv \frac{\partial f}{\partial x_i}$, the uncertainty of a quantity y due to the variable

x_i is given by:

$$u_i(y) \equiv |c_i| u(x_i) \quad (2)$$

Therefore, using the root mean square method the global uncertainty will be:

$$u_c^2(y) = \sum_{i=1}^n [c_i u(x_i)]^2 \equiv \sum_{i=1}^n u_i^2(y) \quad (3)$$

Technically it applies only to random independent uncertainties but can also be used in the case of systematic uncertainties.

This method can be applied to determine the uncertainty of flow measurement using orifice plate. According to AGA Report #3, the mass flow rate in an orifice plate is given by equation 4

$$q_m = \frac{C\varepsilon A_o}{\sqrt{(1-\beta^4)}} \sqrt{(2\rho\Delta p)} \quad (4)$$

The corresponding volumetric flow rate at base condition is:

$$Q_v = \frac{q_m}{\rho_b} \quad (5)$$

Where:

q_m is the mass flow rate,
 Q_v is the volumetric flow rate,
 C is the discharge coefficient,
 ε is the expansion coefficient,
 A_o is the orifice area,
 β is the diameter ratio,
 ρ is the specific mass at operation condition,
 ρ_b is the specific mass at base condition, and
 Δp is the pressure differential.

Applying equation 4 in equations 1, 2 and 3, the uncertainty of mass flow rate in an orifice plate is given by:

$$u(q_m) = \sqrt{u_C^2 + u_\varepsilon^2 + u_\beta^2 + u_d^2 + u_D^2 + u_{\Delta p,a}^2 + u_{\Delta p,b}^2 + u_{\rho,a}^2 + u_{\rho,b}^2} \quad (6)$$

In this equation,

- U_c Uncertainty in the discharge coefficient (from Aga 3)
- U_ε :Uncertainty of the gas expansion factor (from Aga 3)
- U_d : Uncertainty in the measurement of the orifice plate internal diameter (from measurement report)
- U_D : Uncertainty of the pipe internal diameter (from drawing design)
- $U_{\rho,a}$:Uncertainty of the specific mass due to variation of pressure and temperature (from data of process measurement).
- $U_{\rho,b}$:Uncertainty of the specific mass due to the variation in the natural gas composition (from chromatography of the natural gas).
- $U_{\Delta p,a}$: Uncertainty in the measurement of the differential pressure (from certificate of calibration of the instrument).
- $U_{\Delta p,b}$: uncertainty in the measurement of the differential pressure (from data of process measurement)

3 Data obtained from the metering station

The global uncertainty is calculated using equation 6. This section presents an uncertainty analysis for a real case using the numerical values given below.

Base temperature (°C) = 20
 Base pressure (psia) = 14,696
 Local atmospheric pressure (psi) = 14,7 (admitted, at sea level)
 Tube diameter (mm) = 431,8
 Bore diameter (mm) = 239,34
 $\beta = d/D$ = 0,554

Gas properties:
 Viscosity (cP) = 0,0129
 Isentropic coefficient (Cp/Cv) = 1,3

During the measurements, the flow rates were determined using the fixed gas composition, according to table 1.

Table 1- Gas composition used in the flow rate determination.

Component	Molar Fraction (%)	Component	Molar Fraction (%)
N ₂	0,7599	NC5	0,3800
CO ₂	0,3800	C6	0,4300
H ₂ S	0,0000	C7	0,0000
H ₂ O	0,0000	C8	0,0000
He	0,0000	C9	0,0000
C1	78,662	C10	0,0000
C2	10,549	O2	0,0400
C3	6,0694	CO	0,0000
iC4	0,8999	H2	0,0000
nC4	1,5998	Argon	0,0000
iC5	0,2300		

This was done because there is no "on line" chromatograph. Every day, 3 gas samples are collected and analysed in the Laboratory chromatograph, and this data is used to determine the daily average composition of the gas.

The correction of the daily volume totalization is made by using the average value of the specific mass of the gases obtained from the 3 collected samples . Table 2 shows some compositions taken during the evaluation process and used in the uncertainty calculation.

Table 2 - Natural gas composition

Date	03/Nov	03/Nov	03/Nov	07/Nov	07/Nov	07/Nov	11/nov	11/nov	11/nov
hour	2:00	10:00	18:00	2:00	10:00	18:00	2:00	10:00	18:00
Product	% molar								
O2	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
N2	0,832	0,791	0,601	0,764	0,700	0,621	0,781	0,626	0,588
CO2	0,402	0,406	0,405	0,405	0,406	0,411	0,381	0,399	0,388
C1	83,238	82,031	82,518	82,600	82,455	82,518	82,676	81,690	83,924
C2	8,750	9,213	8,670	8,692	9,001	8,949	8,726	8,563	7,992
C3	4,304	4,985	5,097	4,975	4,995	4,848	4,955	5,095	4,584
iC4	0,581	0,627	0,659	0,628	0,608	0,668	0,628	0,681	0,605
nC4	1,219	1,288	1,327	1,279	1,261	1,323	1,264	1,449	1,237
Neo C5	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
iC5	0,231	0,217	0,248	0,224	0,201	0,219	0,203	0,355	0,228
nC5	0,263	0,256	0,279	0,264	0,224	0,255	0,230	0,404	0,264
C5 ⁺	0,181	0,187	0,197	0,17	0,147	0,189	0,157	0,739	0,19

Since a fixed composition is used in the daily totalization, as it is shown in table 2, and this composition in reality is not fixed as table 3 shows, this variation of composition should be taken into account in the uncertainty evaluation.

The operating condition was considered constant for both cases (this is a reasonable assumption since the operating conditions are very stable throughout a day and are continuously measured):

Absolute pressure = 5,108 MPa
 Temperature = 22,94 °C

Figure 1 shows the variation of the specific mass for several gas compositions obtained in 25 days of measurements under the above temperature and pressure conditions.

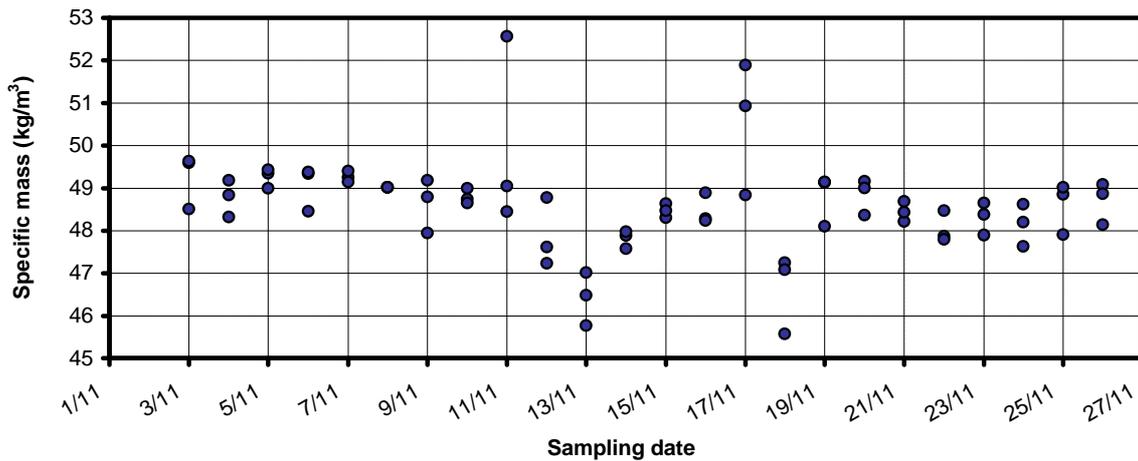


Figure 1 - Variation of the specific mass in 25 days.

Adopting the uncertainty of the specific mass as the standard deviation of each set of daily analysis, it is possible to calculate the combined uncertainty for 2 cases:

1st Case - This case is based in the gas composition of November 3.
 A typical case

standard deviation = 0,633 kg/m³
 Average specific mass = 48,591 kg/m³

$$U_p = S_p / \sqrt{n}$$

$$U_p = 0,633 / \sqrt{3}$$

$$U_p = 0,365 \text{ kg/m}^3 \quad \text{or} \quad U_p = 0,75\%$$

2nd Case - This case is based in the gas composition of November 11.
 The worst case, considering the highest standard deviation found in the analysed period

standard deviation = 2,29 kg/m³
 Average specific mass = 48,59 kg/m³

$$U_p = S_p / \sqrt{n}$$

$$U_p = 2,29 / \sqrt{3}$$

$$U_p = 1,32 \text{ kg/m}^3 \quad \text{or} \quad U_p = 2,72\%$$

4 RESULTS - Flow measurement uncertainty calculation

Tables 3 and 4 present the uncertainty calculation according to ISO GUM, for the 2 cases analysed before.

TABLE 3- Evaluation of the uncertainty in the flow measurement for the first case.

Variable Quantity	Estimate x_i	Standard uncertainty $u(x_i)$		Degree of freedom	Probabilities distribution	Sensitivity coefficient	$ci [Xi]^{-1}$	Uncertainty	Individual Contribution (%)
C	0,6030	$U_C/2$	0,00129	infinite	Normal	q_m/C	79,161	0,1026	21
ϵ	0,9981	$U_\epsilon/2$	0,00125	infinite	Normal	q_m/ϵ	47,825	0,0060	0,1
β	0,5543	$U_\beta/\sqrt{3}$	0	infinite	Rectangular	1	1	0,0000	0
d (m)	0,2393	$U_d/\sqrt{3}$	6,93E-5	infinite	Rectangular	$(q_m/d)*[2/(1-\beta^4)]$	440,46	0,0305	1,9
D (m)	0,4318	$U_D/\sqrt{3}$	5,77E-4	infinite	Rectangular	$(q_m/D)*[2\beta^4/(1-\beta^4)]$	23,047	0,0133	0,4
ρ (kg/m ³)	48,591	$U_\rho/2$	0,1030	infinite	Normal	$q_m/2\rho$	0,4912	0,0506	5
ρ (kg/m ³)	48,591	$S_\rho/\sqrt{3}$	0,366	2	Rectangular	$q_m/2\rho$	0,4912	0,1795	65
ΔP (Pa)	28959	$U_{\Delta P}/2$	71	infinite	Normal	$q_m/(2\Delta P)$	0,0008 2	0,0585	7
ΔP (Pa)	28959	$S_{\Delta P}/\sqrt{3}$	7	2	Rectangular	$q_m/(2\Delta P)$	0,0008 2	0,0059	0
q_m (kg/s)	47,734	S_{q_m}/\sqrt{n}	0	30	Normal	1	1,0209 5	0,0000	0

Standard uncertainty combined = 0,2234

Coverage factor = 2,6

Uncertainty expanded $U(E_t) = 0,556$ kg/s

Result: $q_m = 47,734 \pm 0,6203$ kg/s or 1,3 %

TABLE 4- Evaluation of the uncertainty in the flow measurement for the second case.

Variable Quantity	Estimate x_i	Standard uncertainty $u(x_i)$		Degree of freedom	Probabilities distribution	Sensitivity coefficient	$ci [Xi]^{-1}$	Uncertainty	Individual Contribution (%)
C	0,6030	$U_C/2$	0,00129	infinite	Normal	q_m/C	79,161	0,102	2
ϵ	0,9981	$U_\epsilon/2$	0,00125	infinite	Normal	q_m/ϵ	47,824	0,00596	0
β	0,5543	$U_\beta/\sqrt{3}$	0	infinite	Rectangular	1	1	0	0
d (m)	0,2393	$U_d/\sqrt{3}$	6,93E-5	infinite	Rectangular	$(q_m/d)*[2/(1-\beta^4)]$	440,46 0	0,03051	0
D (m)	0,4318	$U_D/\sqrt{3}$	5,77E-4	infinite	Rectangular	$(q_m/D)*[2\beta^4/(1-\beta^4)]$	23,047	0,0133	0
ρ (kg/m ³)	48,591	$U_\rho/2$	0,1200	infinite	Normal	$q_m/2\rho$	0,491	0,0589	1
ρ (kg/m ³)	48,591	$S_\rho/\sqrt{3}$	1,322	2	Rectangular	$q_m/2\rho$	0,491	0,6494	96
ΔP (Pa)	28959	$U_{\Delta P}/2$	71	infinite	Normal	$q_m/(2\Delta P)$	0,0008 2	0,0585	1
ΔP (Pa)	28959	$S_{\Delta P}/\sqrt{3}$	7	2	Rectangular	$q_m/(2\Delta P)$	0,0008 2	0,0059	0
q_m (kg/s)	47,734	S_{q_m}/\sqrt{n}	0	30	Normal	1	1,0209	0,0000	0

Standard uncertainty combined = 0,6636

Coverage factor = 4,3

Uncertainty expanded $U(E_t) = 2,855$ kg/s

Result: $q_m = 47,734 \pm 2,855$ kg/s or 6,0 %

5 Final Comments

The main sources of uncertainties can be observed from the results presented previously. More attention should be paid to these sources if the global uncertainty should be reduced. It is evident that not only the sensibility coefficient but also the measurement uncertainty of a quantity determine the global uncertainty (equation 2).

The previous results show that the main component of the global uncertainty is the uncertainty of the gas specific mass. The uncertainty of the specific mass may be divided into two factors: (1)

That due to the uncertainty of pressure, temperature and chromatography of the natural gas composition and (2) That due to the change in composition throughout a day.

The first factor will always be present and is often discussed in the literature. The same is not true for the second factor. In this case, the uncertainty is a result of ignorance of the correct composition during the volume totalization. This factor may be reduced to almost zero if an in line chromatograph is used and may be substantially reduced if composition analysis are made more often.

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REFERENCE

- [1] AGA Report n° 3 *Part 1 - September 1990 (General Equations and Uncertainty Guidelines)*.
- [2] AGA Report n° 8 (Compressibility Factors of Natural Gas and Other Related Hydrocarbon Gas)
- [3] ISO GUM - International Standard Organisation - Guide to the expression of Uncertainty in Measurement).