24th COBEM - 2017

COBEM-2017-1606
GAS FLOW MEASUREMENT UNDER HIGH PRESSURE FLOWING CONDITIONS: ANALYSIS OF THE UNCERTAINTY OF THE REPORTED MEASUREMENT AT STANDARD CONDITIONS.

Marina Duarte Mosckem
Universidade Federal do Espírito Santo, Departamento de Engenharia Mecânica.
Av. Fernando Ferrari, 514, Vitória – ES. 29075-910
email: marinamosckem@gmail.com

Márcio Coelho de Mattos
Universidade Federal do Espírito Santo, Departamento de Engenharia Mecânica.
Av. Fernando Ferrari, 514, Vitória – ES. 29075-910
email: marcio.mattos@ufes.br

Rogerio Ramos
Universidade Federal do Espírito Santo, Departamento de Engenharia Mecânica.
Av. Fernando Ferrari, 514, Vitória – ES. 29075-910
email: ramosrogerio@hotmail.com

Abstract. It is common for regulations to require natural gas flow measurement to be reported on a volumetric basis. Therefore, the measurement should also be reported at a specific pressure and temperature, referred to as standard conditions. In Brazil, petroleum and gas measurements must comply with ANP/Inmetro Ordinance 01/2013, which states the following standard conditions: 1 bar, 20°C. When the flowing conditions are not the same as the standard ones, the measurement must be corrected for the standard condition by means of thermodynamic Equations of State – EOS. Thus, the measurement reported in the standard conditions carries a portion of uncertainty relative to this operation, whose value depends on the temperature and pressure, as well as on the chosen EOS. The main goal of the work is to evaluate this parcel of the uncertainty, especially in critical flowing conditions. Some typical natural gas compositions were selected and the following flowing conditions: 50 bar, 4°C. Results obtained by means of Monte Carlo simulation show that the measurement reported at the standard conditions carries a portion of uncertainty generally greater than 1.0 percentage points, only due to the necessary correction just commented. It is a significantly high value, especially if we take into account that Brazilian regulation states a maximum of 2% for fiscal measurements, for example.

Keywords: Evaluation of Uncertainty. Monte Carlo Simulation. Gas Flow Measurement. Equations of State. Flowing and Standard Conditions.

1. INTRODUCTION

Due to the large volumes extracted and the economic value of petroleum and gas, its regulation gives special attention to the uncertainties, which may reach 1.5% in cases of tax and custody transfer, 2% in appropriation systems and up to 5% in flare burning or venting. Still, due to safety and efficiency, there is a tendency in the technological scenario to replace the topside processes of the platforms for subsea systems for energy generation, processing, flow measurement and subsea pumping in offshore, which leads to conversions at more complex levels and may present uncertainties beyond which they are computed.

Volumetric flow measurement of natural gas must be reported in a thermodynamic state previously established in proper regulation. The pressure and temperature conditions laid down by a regulation are referred to as standard conditions (Sydenham and Thorn, 2005). Therefore, if the measurement is performed under conditions other than the standard ones, the original measurement result shall be corrected for the standard conditions according to the following equation:

$$q_s = \frac{\rho_f}{\rho_s} \cdot q_f = r \cdot q_f \tag{1}$$

where q and ρ refer to the volumetric flow rates and densities, respectively. Subscripts f and s indicate flowing conditions and standard conditions, respectively. Density values ρ_f and ρ_s came from a thermodynamic equation of state like Peng-Robinson (Melhem, 1989) and GERG (Kunz and Wagner, 2012), or from commercial thermodynamic simulators [03].

The expanded uncertainty of q_s can be written as

$$\left(\frac{\Delta q_s}{q_s}\right)^2 = \left(\frac{\Delta q_f}{q_f}\right)^2 + \left(\frac{\Delta r}{r}\right)^2 \tag{2}$$

Therefore, in addition to uncertainty related to the measurement itself (under flowing conditions), the uncertainty of the ratio $r = \rho_f \div \rho_s$ must also be taken into account. The uncertainty of r is also estimated by Monte Carlo simulation.

Even if density is one of the results from the flow measurement itself, under the flowing conditions, it shall be corrected to the standard conditions. Hence, it is necessary to better evaluate what can occur when the flowing conditions are very far from the standard conditions.

2. PROCEDURE

For the accomplishment of this study, two thermodynamic equations of state were selected to be implemented in MATLAB software: Peng Robinson (Savage, 1995) and GERG-2008 (Baladão, 2015).

Once the equation of state is chosen, the density of the natural gas depends on its temperature, pressure and chemical composition. GERG-2008 (Baladão, 2015) and Peng-Robinson (Chvidchenko, 2008) equations of state were applied to estimate, by means of a Monte Carlo simulation, the gas density at flowing conditions and at standard conditions. The conventional method of calculating uncertainties is ISO GUM. However, the Monte Carlo simulation was applied because the main study is based on propagation of distributions. Figure 1 schematically shows the simulation process.
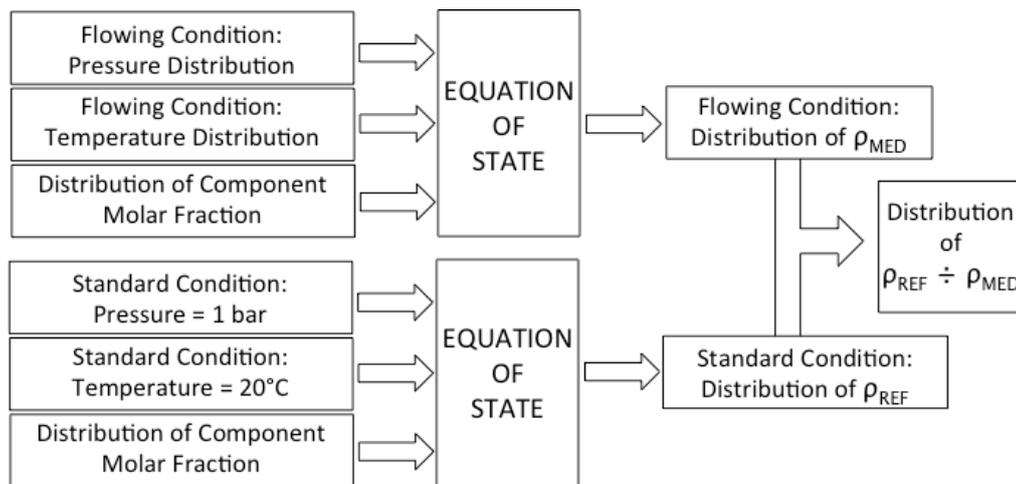

Figure 1. Schematic diagram of the simulation.

The flowing conditions were set to 50 bar pressure and 4 °C temperature. Three chemical compositions were chosen for the gas, with several fractions of methane (95%, 85% and 75%) and 1% of uncertainty for each component, as shown in Table 1.

By applying Monte Carlo simulation, a set of 10,000 gas samples was generated, simulating the variation of the composition during the production process. The pressure was varied around 50 bar with an uncertainty of 1% (0.5 bar). The temperature was varied around 4 °C with an uncertainty of 2.5% (0.1 ° C). Then, it was possible to estimate the mean and the variance of the density at flowing conditions and at standard conditions. With these results it is possible to calculate the portion of uncertainty $\Delta r \div r$.

Table 1. Chemical compositions evaluated.
Averages and standard deviations of the Monte Carlo simulation input.

COMPONENT	COMPOSITION 01			COMPOSITION 02			COMPOSITION 03		
	μ	σ_n	σ_u	μ	σ_n	σ_u	μ	σ_n	σ_u
Methane	95,00	0,4860	0,5210	85,00	0,4338	0,4587	75,00	0,3831	0,4070
COMPONENTES	μ	σ_n	σ_u	μ	σ_n	σ_u	μ	σ_n	σ_u
Nitrogen	1,250	0,1840	0,7000	1,500	0,0925	0,3250	2,500	0,0815	0,3050
Carbon Dioxide	0,100	0,0240	0,1800	0,500	0,0450	0,1800	1,500	0,0400	0,1550
Ethane	3,000	0,4449	1,6000	9,000	0,3770	1,3500	11,00	0,3329	1,2250
Propane	0,500	0,0592	0,4000	3,200	0,1865	0,7450	7,000	0,1645	0,6000
Normal-Butane	0,030	0,0073	0,0550	0,250	0,0225	0,0850	0,800	0,0199	0,0800
Isobutane	0,030	0,0073	0,0550	0,200	0,0054	0,0400	0,400	0,0048	0,0090
Normal-Pentane	0,020	0,0049	0,0250	0,100	0,0054	0,0190	0,600	0,0049	0,0200
Isopentane	0,020	0,0049	0,0250	0,100	0,0054	0,0190	0,500	0,0048	0,0100
Hexane	0,050	0,0122	0,0900	0,150	0,0055	0,0200	0,700	0,3829	0,0400

Attention should be drawn to the information on methane whose cells are shaded in the table. The methane fraction is calculated from the closure of the sum of the molar fractions by 100%. Thus, its fraction does not have the same distribution of the other variables. If the other variables have a uniform distribution, for example, the distribution of the methane fraction is similar to that shown in Figure 2. It is for this reason that information on the fraction of methane is shown prominently. As pointed out, in the case of uniform distribution, the amplitude of the respective range of variation is given for the other fractions instead of the standard deviation.
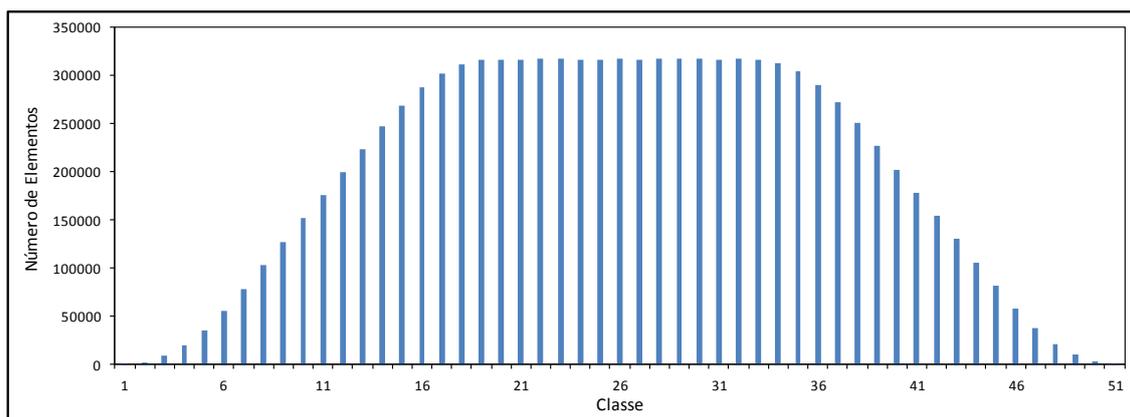

Figure 2. Typical distribution of methane fraction if the other fractions are evenly distributed and the methane fraction is obtained by the closing of the balance sheet.

3. RESULTS

This section presents the results of the simulation considering: three different chemical compositions, normal and uniform distribution, 95% confidence and eight different situations.

Situation	Density ratio			
	GERG-2008 Equation		Peng-Robinson Equation	
	μ	Δ_{95}	μ	Δ_{95}
Flowing conditions	2,793681e+00	*****	2,876770e+00	*****
Standard conditions	4,171415e-02	*****	4,174418e-02	*****
01	2,793693E+00 ± 3,6589e-02	1,3097%	2,876820e+00 ± 3,8170e-02	1,3268%
02	2,793710E+00 ± 2,1912e-02	0,0784%	2,876770e+00 ± 2.3362e-02	0,0812%
03	2,793699E+00 ± 1,3919e-02	0,4982%	2,876780e+00 ± 1,5277e-02	0,5311%
04	2,793673E+00 ± 3,6719e-02	1,3144%	2,876834e+00 ± 3,8280e-02	1,3306%
05	2,793657E+00 ± 3,9358e-02	1,4088%	2,876895e+00 ± 4,1075e-02	1,4277%
06	2,793669E+00 ± 1,4138e-02	0,5061%	2,876803e+00 ± 1,5474e-02	0,5379%
07	2,793700E+00 ± 3,9515e-03	1,4144%	2,876929e+00 ± 4,1280e-02	1,4349%
08	4,171015E-02 ± 2,0132e-06	0,0048%	4,174419e-02 ± 2,1924e-06	0,0053%
	Density ratio for situation 07 and 08			
	4,171015E-02 ± 2,0132e-06	0,0048%	4,174419e-02 ± 2,1924e-06	0,0053%

Situation 1: Variable pressure (50 ± 0.5 bar), constant temperature (4 °C), constant chemical composition
Situation 2: Constant pressure (50 bar), variable temperature (4 ± 0.1 °C), constant chemical composition
Situation 3: Constant pressure (50 bar), constant temperature (4 °C), variable chemical composition
Situation 4: Variable pressure (50 ± 0.5 bar) and temperature (4 ± 0.1 °C), constant chemical composition
Situation 5: Variable pressure (50 ± 0.5 bar) and chemical composition, constant temperature (4 °C)
Situation 6: Variable temperature (4 ± 0.1 °C) and chemical composition, constant pressure (50 bar)
Situation 7: Variable pressure (50 ± 0.5 bar), temperature (4 ± 0.1 °C) and constant chemical composition
Situation 8: Variable chemical composition, constant pressure and temperature at standard conditions
Gas composition: Methane: 75% | Ethane: 11% | Propane: 7% | N-butane: 0.80% | Isobutene: 0.40%|
N-pentane: 0.60% | Isopentano: 0.50% | Hexane: 0.70% | N_2: 2.50% | CO_2: 1.50%
(variation according Table 1)

The results obtained for the different situations treated allow us to conclude that:
- The uncertainty of the pressure in the measurement condition is the most relevant variable for the uncertainty of the density ratio. The density uncertainty predicted for situation 01 is much greater than the density uncertainty predicted in situations 02 and 03.
- After the variable related to the pressure in the flowing condition, the uncertainty of the chemical composition appears as an important parameter to contribute to the uncertainty of the density ratio.
- The temperature uncertainty is the one that less contribute to the uncertainty of the density ratio, with a very small contribution. Although it is not categorically stated that such a contribution is negligible, it is in

this sense that the data point out. The contribution of this parameter in the density uncertainty, for example, is only perceptible in the order of thousandth per cent.

- Lesser than the temperature uncertainty contribution is the variation of the density of the gas in the standard condition due to the variation of the chemical composition. In this case, the contribution is negligible compared to the other components of uncertainty. Furthermore, their contribution is imperceptible if the uncertainty of the density ratio is expressed to the nearest tenth of a thousandth per cent. This is because the density of the gas in the reference condition is much smaller than its density in the measurement condition.

The computational cost of the calculations involved in the Monte Carlo simulation may be asked. The most important thing to note in this subject is the big difference between the simulation times when adopting differents equation of state, in this case, GERG-2008 and Peng-Robinson. For one million samples, for example, the times of the various Monte Carlo simulations using GERG-2008 were always longer than 50 hours on a DEL XPS 8900 computer (Intel i6700, 3.43 GHz, 16 GB RAM). For the same number of samples, but adopting the Peng-Robinson equation, the simulation times, in the same computer, did not exceed 20 minutes.

4. CONCLUDING REMARKS

Results from the Monte Carlo simulation shows that:

Table 3. Results - Density Ratio.

Composição 01 Distribuição Normal	5,922171e+01 ± 1,6272e-06	1,1757%	6,060907e+01 ± 7,2173e-01	1,1908%
Composição 01 Distribuição Uniforme	5,922484E+01 ± 7,0405e-01	1,1888%	6,060975e+01 ± 7,2926e-01	1,2032%
Composição 02 Distribuição Normal	6,196034E+01 ± 7,8982e-01	1,2747%	6,362238e+01 ± 8,1743e-01	1,2848%
Composição 02 Distribuição Uniforme	6,203642e+01 ± 7,9592e-01	1,2830%	6.362247e+01 ± 8,2175e-01	1,2916%
Composição 03 Distribuição Normal	6,694979e+01 ± 9,5029e-01	1,4194%	6,891627e+01 ± 9,8633e-01	1,4312%
Composição 03 Distribuição Uniforme	6,697890E+01 ± 9,4737e-01	1,4144%	6,891807e+01 ± 9,8891e-01	1,4349%

- It should be noted that high-pressure and low-temperature flow measurements are a natural consequence of the tendency in the technological scenatio initially commented.

- The conversion of natural gas measurement from the flowing conditions to the standard conditions generates an extra portion of uncertainty in the final measurement. In the context of this study, an increase of more than 1 percentage point in measurement uncertainty was found.

- Faced with the restrictions of the regulation, the results of this study show their relevance especially when it comes to tax measurement, transfer of custody and appropriation.

- Regarding the uncertainty, the results show that the application of EOS GERG-2008 or PR has a very limited effect, of the order of hundredths of a percentage point. However, the difference in the density ratio prediction is very significant (PR higher than 2% in relation to GERG-2008).

- The hypothesis on the distribution of the molar fractions of the gas, if normal or uniform, has little significance on the variability of the density ratio. The variable that shows the greatest significance is the pressure.

- In addition, the results show that there is a tendency in increasing the uncertainty of the conversion of the measurement when there is decrease in the fraction of methane present in the chemical composition.

5. REFERENCES

Baladão, Luis Fernando. Avaliação da Equação de Estado GERG-2008 para o Gás Natural; Dissertação de Mestrado. Universidade Federal do Rio Grande do Sul. 2015. 124 p.

Chvidchenko, V. Estudo Comparativo do Desempenho das Equações de Estado CPA, SRK e PR na Modelagem de Sistemas de Interesse para a Indústria do Gás Natural. Dissertação de Mestrado. Universidade Federal do Rio de janeiro. 2008. 171 p.

Kunz, O. & Wagner, W. The GERG-2008 Wide-Range Equation of State for Natural Gases and Other Mixtures: An Expansion of GERG-2004; Journal of Chemical and Engineering Data, 2012. 57 (11), pp 3032–3091.

Melhem, Georges A. A modified Peng-Robinson Equation of State; Fluid Phase Equilibria, Volume 47, August 1989, pp. 189-237.

Savage, P. E. Spreadsheets for Thermodynamics Instruction. Chemical Engineering Education. University of Michigan. ChE Division, p.262-269, 1995.

Sydenham, Peter H. & Thorn, Richard. Handbook of Measuring System Design. Chichester, England: Wiley. 2005.

6. ACKNOWLEDGEMENTS

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.