Investigation of the causes for the measurement differences between the natural gas measurement systems of a gas distribution company and of a consumer

Kazuto Kawakita[1] and Rubens Silva Telles[2]

[1, 2] IPT-Instituto de Pesquisas Tecnológicas
Centro de Metrologia Mecânica, Elétrica e de Fluidos-CTMetro
Av. Prof. Almeida Prado, 532 - Butantã
05508-901 São Paulo, Brasil

kawakita@ipt.br

Abstract. This paper presents the methodology used, the checked items and the results obtained in an investigation carried out to identify the causes that generated substantial differences between the natural gas volumes measured by two measuring systems, one from a gas distribution company and another from its industrial consumer, both installed in series in a gas pipeline. The investigation showed that the measurement of the volume of gas performed by the gas distributor metering system was influenced by an erroneous measurement of the gas temperature since it was affected by a complex thermodynamic process involving cooling by the Joule-Thomson effect caused by a pressure reducing valve and heating by heat exchange through the pipe walls.

1. Introduction

From an economic point of view, one of the most important activities in the natural gas industry is related to the measurement of the volume of gas produced, processed, transported and commercialized. The reliability in achieving this metrological activity is essential for all companies operating along the entire value chain of this strategic industry for many countries. To obtain this metrological reliability it is necessary to use gas flow measurement systems in most stages of the chain, from production of the gas onshore or offshore or in its importation as a liquefied natural gas, passing through the treatment units, transportation through the long pipelines at last coming to the distribution to final consumers.

Natural gas is a high-value commodity, so it is typical that the parties involved install in all custody transfer stations or delivery points to a major consumer, two independent measuring systems, one operated by the gas supplier and the other by the receiver. Usually, the billing of gas volumes traded is based on the measurement performed by the measurement system from the gas deliverer, although this measurement is continuously being monitored by the measuring system of the receiver.

Nevertheless the sophisticated measurement technology used nowadays, the occurrence of differences between the gas volumes measured by the two measuring systems is quite common, and occasionally these differences go far beyond the limits agreed in the contracts signed by the parties.

The main reason for that is the inherent difficulty in measuring the flow rate of fluids, which is a dynamic phenomenon, dependent on the characteristics of the fluid measured and which can be affected by the different influence quantities impacting the metrological process.

2. Objective

This paper presents the methodology followed, the checked items and the results obtained in an investigation carried out on two natural gas measurement systems, one operated by a natural gas distribution company and the other by an industrial consumer, and that aimed to determine the reasons that caused significant differences between the gas volumes measured by the parties.

Installed in series, the measuring system of the gas distributor used a turbine meter while the industry measuring system was based on a cone type differential pressure flowmeter.

For reasons of secrecy and confidentiality, the names of the companies will be omitted in this work.

3. Characteristics of the measurement systems

The gas measurement system operated by the gas distributor was based on a turbine meter, assembled on a 10 inches diameter horizontal meter tube, also composed of a straight pipe length upstream of the meter, a downstream pipe section, and a flow straightener. The measurement system included a flow computer with integrated sensors/transmitters for measuring the gauge pressure and temperature of the gas. This assembly was mounted as a measurement skid.

Figure 1, below, illustrates schematically the flow measuring system of the gas distributor and its main components.

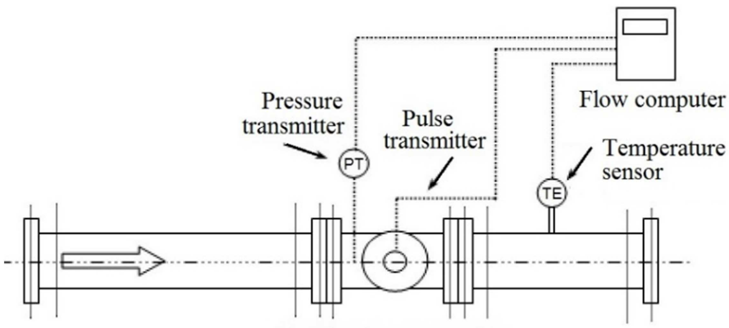

Figure 1. Measuring system of the gas distribution company based on a turbine type gas meter.

In its turn, the natural gas flow measuring system installed in the industrial plant gate was composed of a cone type flow meter, assembled on a 10 inches horizontal pipe, completed by straight pipe sections upstream and downstream of the meter. This measurement system included also a flow computer associated to an integrated sensor/transmitter for measuring the gauge pressure, differential pressure and temperature of the gas.

Figure 2, below, illustrates schematically the flow measurement system of the industry and its main components.

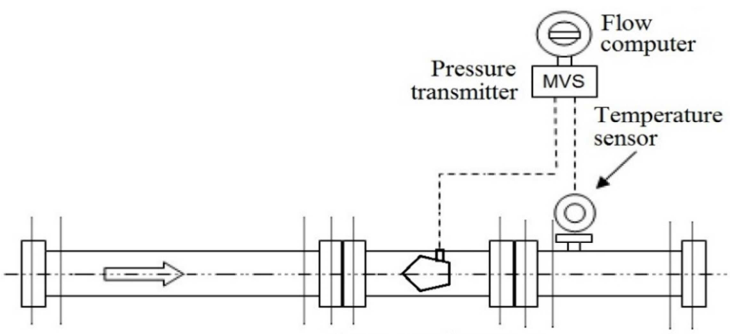

Figure 2. Gas measurement system of the industry based on a cone type flowmeter.

4. Methodology

From the metrological point of view, the inspections of the gas flow measurement systems were carried out in order to assess the reliability of the natural gas volumes measured by the systems in accordance with the requirements and procedures set out in the reference standards.

The reference documents used in this study were the AGA Report No. 7 [1], the AGA Report No. 8 [2], the GUM guide [3] and the ISO 5168 standard [4].

Considering the case of two natural gas measurement systems, one based on a cone type differential pressure meter and the other on a turbine meter, the inspection was carried out by checking the construction, installation and operation parameters of the components of each system.

4.1. Inspection of the primary elements

The gas distributor metering system was visually inspected in order to check if the meter tube upstream and downstream straight pipe sections, and also the turbine meter body itself were assembled according to the requirements defined in the AGA Report No. 7 standard.

Although there is no technical standard to be followed in case of installation and use of cone type meters, a visual inspection of the meter tube of the industry measurement system was also carried out in order to analyze the compliance with the manufacturer's installation instructions for this type of meter.

Additionally, the inspection evaluated if the installation positions of the pressure and temperature sensors/ transmitters were in compliance to the assembling requirements of the reference standard for a turbine type measuring system.

4.2. Calibration of the secondary elements

As a second step of the inspection, calibrations of the gauge pressure, differential pressure and temperature sensors and transmitters of the industry and of the gas distributor measurement systems were carried out using standards calibrated and certified by ISO 5167 accredited laboratories.

Calibrations of the sensors and transmitters of both measurement systems were performed in closed loop, i.e., applying input signals in the pressure and temperature sensors and then reading the parameters values directly in the flow computers.

4.3. Inspection of the flow computers

Inspection of the two flow computers intended to verify the various parameters entered in their configuration, such as measurement units, base pressure and temperature conditions, local barometric pressure, set points of the electronic transmitters for gauge pressure, differential pressure and temperature quantities, composition and properties of the natural gas, technical reference standards, among others.

Additionally, the gas volumes calculated by the flow computers were checked in order to validate the calculation algorithms used by these equipment.

4.4. Assessment of the measurement uncertainty

As a final part of the inspection process, the measurement uncertainties associated to the volumes of gas measured by both systems were estimated for real operating conditions. For this, the contributions of the uncertainties of each factor (gauge pressure, differential pressure, temperature, gas composition, meter factor, among others) we considered in the assessment of the overall uncertainty.

5. Results

5.1. Results of visual inspection of the primary elements

It was observed that in the gas distributor measurement system, the upstream and downstream straight pipe lengths complied with the installation requirements of the reference standard.

Likewise, the installation positions of the pressure taps and temperature thermowell met the requirements of the standard.

However, as can be seen in figure 3, the measurement skid of the gas distributor included valves, reducers and 90º bends in perpendicular planes at the inlet of the straight pipe section upstream of the turbine meter. This set up can induce disturbances in the flow and which could cause measurement errors according to item 7.1.7 of the AGA Report No. 7 standard.

The most common disturbances in these situations are the asymmetry in the gas velocity profile and the helical flow of the gas, frequently known as swirl. It is well known that the turbine flowmeter performance is affected, to a greater or lesser extent, by these effects, but the exact amount is difficult to quantify, requiring for this experimental tests on laboratory test benches.

Figure 3. The gas distributor measurement system with turbine meter.

The physical inspection of the measurement system of the industry showed no abnormality of installation since it included long straight pipe sections upstream and downstream of the cone type meter, complying with the manufacturer's instructions for its installation.

Figure 4. Measuring system of the industry with a cone type flowmeter.

5.2. Calibration results of the secondary elements

The gauge pressure, differential pressure and temperature sensors and transmitters were calibrated in closed loop with the flow computer.

It was detected during the preliminary calibration of the instruments that the gauge pressure transmitter installed in measurement system of the gas distributor showed an indication error of -1.8 % of the span. Under request of the gas distributor agent, the instrument was calibrated, but not adjusted, i.e., it was kept under the same conditions found during the inspection mainly for preserving its status for necessary corrections.

5.3. Flow computer inspection results

The parameters of the setup menus and the gas composition inserted into the two flow computers were verified.

During the inspection of the flow computer of the industry measurement system, it was detected that the natural gas composition parameterized in it was different from that parameterized in the flow computer of the gas distributor measuring system. Under request of the industry agent the gas composition configuration was update in its flow computer.

It was checked that the flow computer of the gas distributor measurement system performed the calculations of gas volumes correctly. However, the flow computer of the industry's measurement system showed deviations of up to about 0.55 % compared to the volumes calculated by checking program used.

Results of the verification of the flow computers calculation algorithms of the gas measurement systems of industry and gas distributor are presented respectively in tables 1 and 2 below.

Table 1. Results of the verification of the industry flow computer calculation algorithm.

		Differential pressure [mmH2O]			**Deviation [%]**		
		250	**300**	**2 275.3**			
Gauge pressure [kPa]		**200**	**300**	**400**			
Temperature [ºC]	**0**	5 440.80	6 933.63	21 013.35	**0.342**	**0.058**	**0.335**
		5 459.47	**6 937.63**	**20 943.30**			
	10	5 346.15	6 811.78	20 640.27	**0.218**	**0.049**	**0.442**
		5 357.80	**6 808.45**	**20 549.50**			
	20	5 256.76	6 696.83	20 288.76	**0.095**	**0.155**	**0.545**
		5 261.78	**6 686.43**	**20 178.10**			

Table 2. Results of the verification of the gas distributor flow computer calculation algorithm.

		Gauge pressure [kPa]			**Deviation [%]**		
		400	**400**	**600**			
Uncorrected flowrate		**120**	**160**	**160**			
Temperature [ºC]	**0**	6 261,773	8 349,031	11 855,494	**0,014**	**0,014**	**0,016**
		6 262,620	**8 350,160**	**11 857,370**			
	10	6 030,125	8 040,167	11 408,390	**0,014**	**0,014**	**0,016**
		6 030,940	**8 041,250**	**11 410,200**			
	20	5 815,612	7 754,149	10 995,448	**0,014**	**0,014**	**0,016**
		5 816,400	**7 755,200**	**10 997,190**			

5.4. Results of the measurement uncertainty assessment

Based on the information and data collected during the inspection of the metering systems, it was possible to estimate the uncertainty associated with the measured volumes of natural gas, but only for the measurement system of the industry. This measurement system, operating under normal conditions of process parameters, is capable of obtaining uncertainties of approximately 1.6 % of the measured volume, considering a confidence level of approximately 95 %.

This measurement uncertainty assessment was developed based on the methodology presented in the GUM 2008 - *Evaluation of measurement data – Guide to the expression of uncertainty in measurement* [3] and ISO 5168: 2005 [4]. In this uncertainty estimation, besides the uncertainty contributions arising from the calibration of the cone type meter, other sources of uncertainty were considered such as the uncertainties associated with the calibration of the secondary elements, the natural gas expansion and compressibility factors and the differences detected in the flow computer calculation algorithm.

On the other hand, the uncertainty estimation associated to the volume of gas measured by the gas distributor metering system was not performed because it was not possible to estimate the uncertainty contributions in the measurement of the gas temperature in the meter due to the conditions found at the site. These restrictions are mainly due to the unfeasibility to assess the resulting uncertainties from:

(a) the effects caused by the expansion of gas due to the abrupt reduction of its pressure in the pressure reducing valve;

(b) the rates of gas heat exchange with the walls of the pipe, which depend on the environmental conditions at the moment (night or day, winter or summer), and

(c) the effects of disturbances in the flow at the turbine meter inlet, due to the physical configuration of the pipes upstream of the meter in the measuring skid.

Table 3 shows the results of the measurement uncertainty assessment performed for the gas measurement system of the industry.

Input quantity X_i	Value x_i	Std. unc. u(x_i)	Sensibility coefficient	Uncertainty	Contribution (%)
Discharge coefficient	0.82920	0.0014	1.934E+00	0.002681	4.7 %
Apr. Velocity factor	1.51613	6.02566E-05	1.058E+00	0.000064	0.0 %
Expansion coefficient	0.9968	8.04002E-05	1.609E+00	0.000129	0.0 %
Geometric dimension	0.22144 m	0.000005 m	1.449E+01	0.000072	0.0 %
Differential pressure	2921 Pa	42.315 Pa	2.746E-04	0.011619	89.0 %
Gas density	3.739 kg/m³	0.0144 kg/m³	2.145E-01	0.003080	6.3 %
Flow computer	1.604 kg/m³	0.0044 kg/m³	1.000E+00	0.004374	12.6 %
Mass flowrate Q_m	**7.13 kg/s**	**Comb. std. unc. u_c (Q_m) =**		**0.0123 kg/s**	**100 %**
Coverage factor k = 2,00					
Expanded uncertainty U (Q_m) = 0.02464 kg/s					

Input quantity X_i	Value x_i	Std. unc. u(x_i)	Sensibility coefficient	Uncertainty	Contribution (%)
Mass flowrate Q_m	1.604 kg/s	0.0123	1.2988	0.015997	86.9 %
Gas density (base cond.)	0.770 kg/m³	0.0023	-2.7058	-0.006114	13.1 %
Volum. flowrate Q_{vb}	**180 000 m³/day**	**Comb. std. unc. u_c (Q_{vb}) =**		**0.01716 m³/s**	**100 %**
Coverage factor k = 2.00					
Expanded uncertainty U (Q_{vb}) = 2966 m³/day (1.6 %)					

The declared expanded uncertainty is based on a combined standard uncertainty multiplied by a coverage factor k = 2.00 under a confidence level of approximately 95 %.

Obs.: Q_{vb} is the volumetric flowrate of gas at base conditions of 20 ºC & 101.325 kPa.

Table 3. Measurement uncertainty estimation for the measurement system of the industry.

As can be seen from the calculation, the industry measurement system enabled gas volume measurements with an associated uncertainty of approximately 1.6 %.

5.5. Measuring differences between the two measurement systems

The hourly rate volumes of gas measured by the two measurement systems were converted to the base conditions of 20 °C and 101.325 kPa, typically used in the gas industry.

The flow computer of the measurement system operated by the gas distribution company calculated and stored the average gas pressure values, average temperature, uncorrected volume and corrected volume computed in a hourly basis.

The multivariable transmitter, which had a unit to totalize the gas volumes measured, sent these values to a supervisory system in the gas distributor's control room. This supervisory system also received the values totalized by the measurement system of the gas distributor.

During the inspection period, data of gas hourly volume measurements for different days were collected, from which significant differences between the two volumes computed by the two measurement systems were identified. In fact, along the period analyzed, differences of up to 5 % were observed between the gas hourly volumes totalized by these two measurement systems.

Table 4 shows the gas hourly volumes measured by the industry measurement system and the gas distributor system and the percentage differences for a particular day.

Table 4. Hourly volumes of gas measured by the two measurement system and the differences.

Hour	Hourly volume of gas measured by the industry measuring system [m³]	Hourly volume of gas measured by the gas distributor measuring system [m³]	Percentage difference [%]
00:00	6 709.11	6 966.58	3.84
01:00	6 930.47	7 173.85	3.51
02:00	6 672.09	6 928.17	3.84
03:00	6 463.44	6 726.61	4.07
04:00	6 621.70	6 872.58	3.79
05:00	6 739.50	6 994.28	3.78
06:00	6 655.45	6 943.12	4.32
07:00	6 797.46	7 043.78	3.62
08:00	6 706.10	6 976.76	4.04
09:00	6 519.92	6 631.93	1.72
10:00	6 716.59	6 739.39	0.34
11:00	6 604.67	6 558.60	-0.70
12:00	6 741.12	6 716.46	-0.37
13:00	6 709.22	6 621.88	-1.30
14:00	6 827.17	6 711.34	-1.70
15:00	6 690.56	6 580.43	-1.65
16:00	6 589.48	6 480.57	-1.65
17:00	6 444.30	6 342.79	-1.58
18:00	6 548.35	6475.01	-1.12
19:00	6 551.96	6 602.19	0.77
20:00	6 353.72	6 499.35	2.29
21:00	6 499.98	6 674.18	2.68
22:00	6 639.01	6 840.80	3.04
23:00	6 576.51	6 817.78	3.67
00:00	6 711.96	6 924.58	3.17

Figure 5 shows the results of hourly volumes of gas at reference conditions measured by the gas measurement systems of the industry and the gas distributor, and also the temperature and pressure of the gas measured by the measuring system of the gas distributor along the same day.

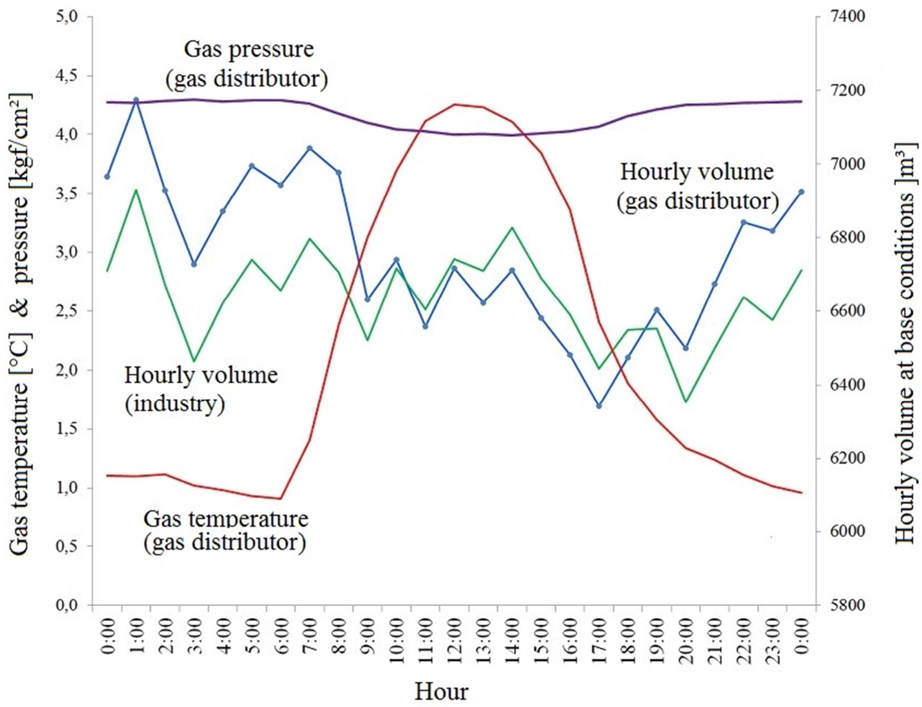

Figure 5. Hourly volumes of gas at reference conditions measured by the two gas measurement systems and the temperature and pressure of the gas measured by the measuring system of the gas distributor.

6. Analysis

An important fact observed during the inspection of the gas distributor measurement system is that the metering skid in question included a pressure reducing valve that operated reducing the pressure of the gas received via the pipeline from 35 kgf/cm² to 4 kgf/cm² in one single step. The Joule-Thomson cooling effect due to the abrupt expansion of the gas caused a great reduction in its temperature, as evidenced by the high rate of water vapor from ambient air condensed on the pipe walls downstream the pressure reducing valve.

After this cooling process downstream the valve, the gas flowed along the pipe exchanging heat with the pipe walls, and getting warm gradually reaching the turbine flow meter at a temperature not yet fully stabilized. This thermodynamic process includes internal temperature gradients in each cross section, as illustrated in the computational simulation of the gas temperature levels shown in figure 6.

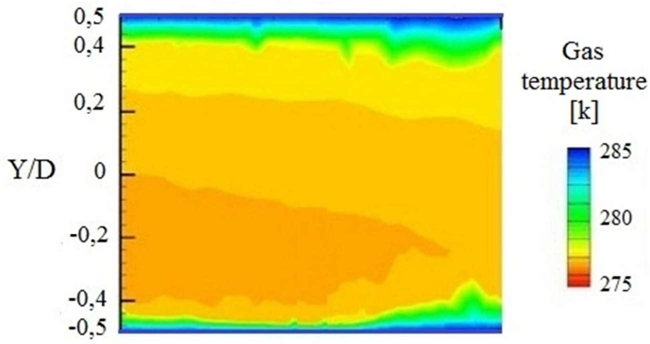

Figure 6. Gas temperature gradients inside the pipe.

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This rate of heat transfer depends on environmental conditions (air temperature, wind, sunlight) at the moment, so that the measurement result is also influenced by these factors. Thus, the temperature measured by the sensor installed after the turbine may not exactly represent the average gas temperature in the flow. Again, the estimation of this effect influenced by multiple parameters is by no means a simple phenomenon and would require for that extensive simulation tests in a laboratory test bench.

7. Conclusion

The study made it possible to observe that the behavior of the measured parameters and influence quantities shown in table 3 and figure 5 repeated in a similar way along other days. These results indicated that the measurement of the volume of gas carried out by the gas distributor metering system was influenced by an erroneous measurement of the gas temperature. This fact is evidenced in figure 5 by the line of the gas temperature variation, where it is observed a sharp increase of this temperature in the early hours of the day and also a decrease in it during the afternoon and a relatively stable situation overnight, indicating a correlation of the measured temperature of the gas with the ambient temperature.

Thus, a hypothesis that could explain this behavior of the gas measurement system of the gas distributor is that the gas cooling effect due to its expansion in the pressure reducing valve is more efficiently mitigated by the heat exchange between the gas and the pipe during the day than during the night. Thus, an underestimation of the gas temperature overnight tends to result in a calculation of a larger density for the natural gas and, consequently, an overestimation of the gas volume totaled in this period. This fact caused a larger difference between the volumes measured by the two measurement systems during the night period.

In view of the issue addressed in this article, a warning should be made to the responsibles for the measurement management in the gas industry since there are many natural gas measurement systems installed excessively close to pressure reducing valves and that may be suffering from this same problem reported herein.

References

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