Metrological reliability in flow computers using smart meters: test proposal

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Abstract. This article presents the result of a set of tests performed on a flow computer in conjunction with digital signals. These tests are part of a proposal for new evaluation methods for this instrument when connected to smart meters that make use of digital communication, as opposed to existing evaluation methods that focus exclusively on analog communication. The uncertainty of the old and new methods is calculated and presented, as well as a comparison of the complexity of the test platform necessary for its execution.

1. Introduction

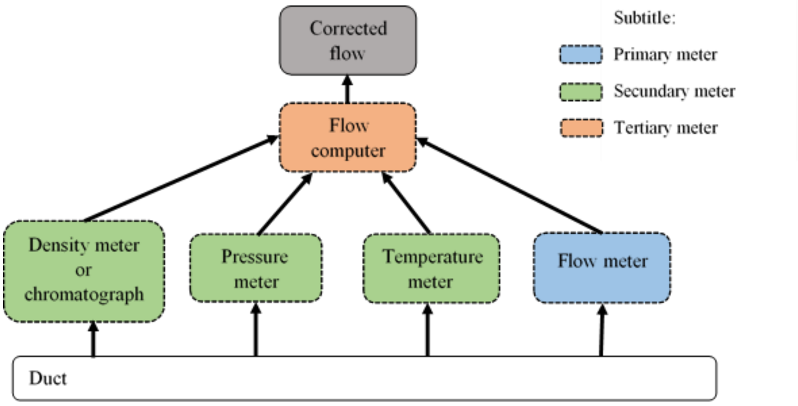
With a production of more than 1 billion barrels of oil and 48 billion cubic meters of natural gas in the year 2021 **[1]**, Brazil stands out as a major world producer of these fluids. These figures rank our country as the 9th largest oil producer and the 30th largest natural gas producer on the entire planet.

For the measurement of these fluids, complex volume measurement systems are used, composed, among others, by fluid specific mass meters, pressure, temperature and the flow meter itself. It is important to remember that, due to the compressible nature of oil and natural gas, their volume varies depending on the pressure and temperature to which they are subjected. It is at this moment that it is necessary to use the last, but perhaps most important, instrument that makes up the measurement system, the flow computer (FC).

This instrument, of a purely electronic nature, communicates with all the other meters and, based on the information received, is capable of converting the volume drained through the flow meter to a previously programmed pressure and temperature. In Brazil, this pressure and temperature are known as basic conditions and determined, by force of law, as 101.325 kPa and 20 °C [2].

The operating diagram of a flow measurement system and its parts can be seen below:

Figure 1: Diagram of operation of a measurement system



Source: Adapted from [3].

At this point, it is important to emphasize that, to carry out its functions, the flow computer communicates with the pressure, temperature and specific mass meters (known as secondary meters) and the flow meter (known as primary) exclusively through electrical signals, which may be analog or digital. Currently, most of the primary and secondary meters make use of analog communication [4], but it is notable the advantages that smart meters have over their older counterparts and these use purely digital communication.

These sensors have features not found in their analog relative [5], such as:

a) Zero, range and span adjustments;
b) Functional diagnostics;
c) Storage of information such as identification code, and settings, among others.

It is here that digital communication is necessary since it is not possible to perform these functions without the bidirectional character that it has.

However, low usage of smart meters, and consequently of digital communication, is observed in the flow measurement systems currently in use. This can be better visualized when analyzing the flow computer approval certificates issued by the National Institute of Metrology, Quality and Technology – and available on its website [6] one can understand the reason, since it cannot be found any of these metering devices approved for use with your digital signal inputs. It should be remembered that, as it is a regulated measuring instrument [7], flow computers must be approved by this Institute before their use.

One of the reasons that can be pointed out to explain the low penetration of this technology is the absence of test methods that guarantee the metrological reliability of flow computers while working with signals of a digital nature. It is worth remembering that the tertiary meter is responsible for connecting all other types of meters to calculate the corrected volume and, therefore, must provide reliable results regardless of the nature of the communication used.

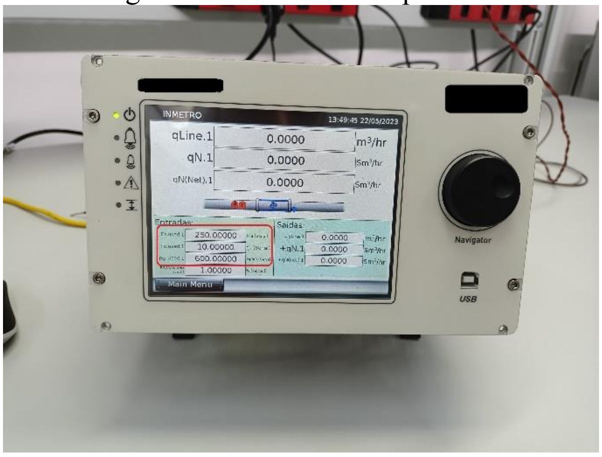
At this point, it can be mentioned that the scientific literature on the subject (mainly based on standards and regulations) is very detailed when describing test methods for flow computers with analog signals, but fails to present forms of evaluation of this meter with the use of digital signals. The regulation itself on which Inmetro is based to evaluate flow computers deals only with test methods using analog signals.

Thus, to fill this gap in scientific knowledge, a proposal for testing methods for tertiary meters with digital signals will be described. Next, this proposal will be executed together with the test methods currently used with the use of analog signals. The repetition of this evaluation with signals of this nature serves the purpose of establishing a baseline panorama from which it is possible to carry out a comparison between the tests with analog and digital signals.

The test platform, as well as the description of the auxiliary instruments needed in each of the methods, is presented together with the uncertainty associated with each test.

To carry out the tests a flow computer, identified as CV1, was used. As can be seen below.

Figure 2 – CV1 flow computer



Source: own elaboration

2. Methodology

Current scientific literature details many aspects that can be observed and measured to evaluate a flow computer. However, those that are most closely linked to their metrological reliability are:

a) The calculation of its volume conversion factor (VCF) - which is the factor by which the uncorrected volume must be multiplied to convert it to the base conditions or corrected volume;
b) Primary meter reading - the ability to read and interpret signals sent by the flow meter;
c) Reading of secondary meters - pressure and temperature, mainly;
d) Generation of audit reports - the ability to generate reports containing information relevant to the measurement process.

Among these aspects, the one with a direct impact on the measurement result is the VCF, since this is the last factor to multiply the uncorrected volume before its presentation. Thus, in this article, test methods specifically designed to assess VCF will be presented.

It is important to mention that the VCF evaluation was carried out by 2 (two) independent methods. At first, it was evaluated with the simulation of sensors using analog communication, and then digital communication was used. In both methods, it is necessary to simulate the magnitudes of pressure and temperature to which the gas is subjected since the flow computer calculates the VCF from them.

Usually, flow computers do not directly display the calculated VCF on their screens, showing corrected and uncorrected volumes instead. In these cases, it becomes necessary to additionally simulate the primary meter together with the FC. However, the CV1 was specially configured to display the VCF during tests, thus eliminating the need to simulate this meter.

2.1. *Analog signal simulation*

The simulation of analog signals related to pressure was performed with the generation of an electrical current signal from 4 to 20 mA. This simulation was performed with the help of multicalibrator devices. Its specifications can be seen in Table 1 below.

Table 1 - Multicalibrator, Eurotron, MicroCal 20 DPC model and its specifications

	Brand	Eurotron
	Model	MicroCal 20 DPC
	Tension	Range: -2 a 20V Resolution: 100 µV Accuracy: ± (0,006% rdg. + 100 µV)
	Current	Range: 0 a 50mA Resolution: 0,1µA Accuracy: ± (0.01% rdg. + 0.4µA)
	Resistance	Range: 0 a 500Ω Resolution: 10 mΩ Accuracy: ± (0.008% rdg. + 20mΩ)

Source: own elaboration based on the device manual.

Regarding the simulation of analog signals linked to temperature, it should be remembered that it can be carried out using the same current signal, mentioned above, or from a resistance representing a PT 100 type thermo resistance. Thus, a resistive decade was chosen for this simulation, since it presents superior stability in its characteristics than the multicalibrators. Its specifications can be seen in Table 2.

Table 2 – Resistive decade, Minipa, model MDR-611 and its specifications

	Brand	Minipa
	Model	MDR-611
	Resistance range	1 Ω ~ 1111,11 kΩ
	Number of Decades	6
	Accuracy	x1Ω ± 0,5% x10Ω ~ x10kΩ ± 0,1% x100kΩ ± 0,2%
	Contact Resistance	25 ± 5 mΩ
	Insulation resistance	500 MΩ / 500 V DC between panel and circuit

Source: own elaboration based on the device manual.

2.2. Digital signal simulation

For the simulation of digital signals, it is necessary to understand that it can be performed using several different communication protocols. Here, the Modbus TCP/IP protocol was selected because it is not only widely used but also because it is easy to audit and use [4].

This protocol is a specific modality for testing and evaluation of the Foundation TMFieldbus protocol. The software selected for its simulation is "Winterm" [8] and a crossover-type ethernet cable was used. This same software was configured to simulate the digital signals related to the pressure and temperature quantities along with the FC.

2.3. Flow computer setup

The flow computer was configured to work in a natural gas flow measurement system connected to pressure and temperature sensors and a turbine meter. Its settings were:

a) Turbine k-factor = 1.00;
b) Gas composition = Gulf Coast [9];
c) Compressibility calculation method = AGA 8 Detail;
d) Basic conditions = 20° C and 101.325 kPa;
e) Compressibility under baseline conditions = 0.997975204704836

Although the compressibility calculated by the flow computers has, on average, 6 decimal places, it was decided, for educational purposes, to expose it here with the maximum number of decimal places calculated according to the AGA 8 standard, 15 decimal places.

2.4. *Procedures*

Thus, after this configuration, the analog signals related to temperature and pressure must be varied and their VCF equivalent must be written down following the order shown in the table below.

Table 1 - Collection and calculation of VCF deviation for gases

Pressure (kPa.a)	Temp. (°C)	VCF_i	VCF_{ref}	U	$Deviation_i$
	0	VCF_1	2,65959	U_1	$Deviation_1$
250	100	VCF_2	1,93806	U_2	$Deviation_2$
	200	VCF_3	1,52614	U_3	$Deviation_3$
	0	VCF_4	5,35367	U_4	$Deviation_4$
500	100	VCF_5	3,88337	U_5	$Deviation_5$
	200	VCF_6	3,05337	U_6	$Deviation_6$
	0	VCF_7	10,84828	U_7	$Deviation_7$
1000	100	VCF_8	7,79540	U_8	$Deviation_8$
	200	VCF_9	6,11080	U_9	$Deviation_9$

Source: own elaboration.

Where:
Pressure (kPa.a) = Simulated absolute pressure;
Temp. (°C) is the simulated temperature;
VCF_i is the Volume Conversion Factor informed by the flow computer;
VCF_{ref} is the Reference Volume Conversion Factor calculated with the help of validated software;
U is the associated uncertainty;

$$Deviation_i = \left|\frac{(VCF_i - VCF_{ref})}{VCF_{ref}}\right| \times 100$$

If the signal is analog, it is necessary to wait at least 30 (thirty) seconds before reading each point, so that the signal can reach stability.

2.5. *Sources of uncertainty*

To clearly define the sources of uncertainty, it is necessary to identify the measurand and, mainly, the equation that gives rise to it. In these tests, the volume conversion factor will be observed and it can be calculated from the general equation of real gases, as can be seen in equation 1.

$$VCF = \frac{P_i}{P_0} \times \frac{z_0}{z_i} \times \frac{T_0}{T_i}, \quad (1)$$

Where:
P_i is the initial pressure;
P_0 is the final pressure;
z_i is the initial compressibility factor;
z_0 is the final compressibility factor;
T_i is the initial temperature;
T_0 is the final temperature.

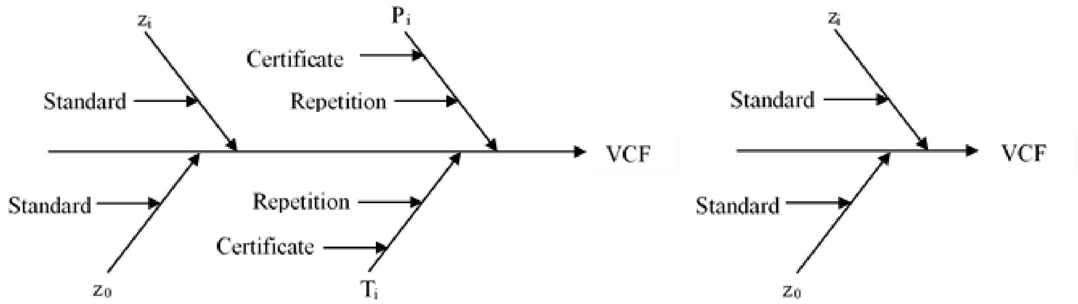
Regarding the initial magnitudes (P_i and T_i) it is important to detail that, when they are analog, they are the result of a simulated and duly calibrated signal, therefore, they carry with them the uncertainty associated with their calibration certificate. Digital signals, due to their inherent characteristics, do not have associated uncertainty.

When analyzing the final quantities (P_0 and T_0) it should be remembered that, in Brazil, the fluid volume must be converted to a pressure and temperature as determined by legislation (101.325 kPa and 20° C) [2], therefore, they are not measured, but previously defined even before the tests are carried out. Thus, there is no uncertainty associated with the final values of these quantities.

The fluid compressibility factor is a characteristic of the fluid calculated as a function of its composition, temperature and pressure. Different methods for its calculation vary according to the nature of the measured fluid and whether it is in its liquid or gaseous form. For natural gases, it can be calculated by the AGA 8 standard [9], where its uncertainty is declared.

In this way, due to the inherent differences between analog and digital signals, two cause-and-effect diagrams can be assembled, as can be seen below.

Figure 2 – Cause-effect diagram for VCF in analog (left) and digital (right) tests



Source: own elaboration.

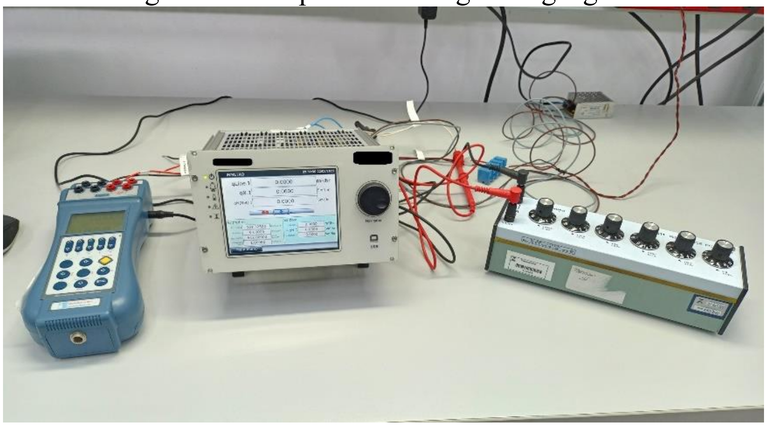
3. Results

These tests were carried out in the flow computer laboratory located at the Inmetro Innovation and Metrology Campus, in Xerém, Duque de Caxias - RJ, between June 5 and 16, 2023.

3.1. Analog tests

The assembly of the test platform using analog signals can be seen in the following figure.

Figure 3– Test platform using analog signals



Source: own elaboration.

The following results were obtained:

Table 2 - Results obtained in tests with analog signals

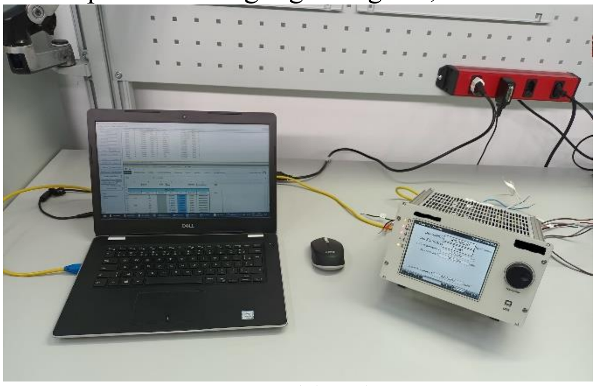
Pressure (kPa.a)	Temp. (°C)	VCF_i	VCF_{ref}	U (x10^{-3})	$Deviation_i$
250	0	2,66084	2,65959	3,85327	0,047
	100	1,93902	1,93806	6,14356	0,049
	200	1,52642	1,52614	7,78248	0,018
500	0	5,35220	5,35367	8,64724	-0,028
	100	3,88291	3,88337	12,42577	-0,012
	200	3,05309	3,05337	15,58035	-0,009
1000	0	10,84490	10,84828	19,47429	-0,031
	100	7,79730	7,79540	26,55868	0,024
	200	6,11280	6,11080	31,40652	0,033

Source: own elaboration.

3.2. Digital tests

The assembly of the test platform using digital signals can be seen in the following figure.

Figure 4 – Test platform using digital signals, Modbus TCP/IP type



Source: own elaboration.

The following results were obtained:

Table 3 - Results obtained in tests with digital signals

Pressure (kPa.a)	Temp. (°C)	VCF_i	VCF_{ref}	$U (x10^{-3})$	$Deviation_i$
250	0	2,65960	2,65959	3,76123	0,0002
	100	1,93806	1,93806	6,12869	0,0001
	200	1,52614	1,52614	7,78182	0,0000
500	0	5,35367	5,35367	7,57124	0,0001
	100	3,88337	3,88337	12,28029	0,0000
	200	3,05337	3,05337	15,56917	0,0002
1000	0	10,84828	10,84828	15,34178	0,0000
	100	7,79540	7,79540	24,65122	0,0000
	200	6,11080	6,11080	31,15910	0,0000

Source: own elaboration.

4. Conclusion

The presentation of this platform and test method, as well as results, it is demonstrated the feasibility of tests for the evaluation of metrological reliability in flow computers with digital signals of the Modbus TCP/IP type. These methods are added to the existing ones for evaluation with analog signals, however, it was possible to observe clear advantages of the first over the second:

a) Decrease amount of instruments and work patterns required;

b) Digital FC inputs do not need to be calibrated as opposed to analog inputs;

c) Fewer sources of uncertainty, which is reflected in a slightly lower general uncertainty for the digital test;

An additional advantage is related to the test time, since when using analog signals in tests, one must wait for the signal to stabilize before reading, which does not occur in the test method with digital signals.

The disadvantage of this method is due to the need to configure the communication ports both in the FC and in the “Winterm" software. This required not only time but specific training (provided here by the company Conaut).

Overall, this platform and test method proved to be cheaper, with faster execution time and smaller uncertainty, and provides the necessary tools to validate the measurement in FC connected to smart meters.

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Acknowledgments

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