Smart meters and flow computers: A test proposal for metrological reliability

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ABSTRACT
Smart meters are a trend in gas and oil measurement. These meters communicate with flow computers through digital signals, unlike older meters that use analogue signals. Currently, the metrological reliability of flow computers is assessed solely using these analogue signals. This article presents and compares the results of a set of tests performed on a flow computer with analogue and digital signals. The methodology involved simulating secondary meters for pressure and temperature, using both analogue (current and resistive decade) and digital (Modbus TCP/IP protocol) communications, in order to obtain the Volume Conversion Factor calculated by the flow computer. 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 analogue 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 their execution.

1. INTRODUCTION

With a production of more than 1 billion barrels of oil and 48 billion cubic meters of natural gas in 2021 [1], Brazil stands out as a major global 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, comprising, among others, 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 components can be seen in Figure 1.
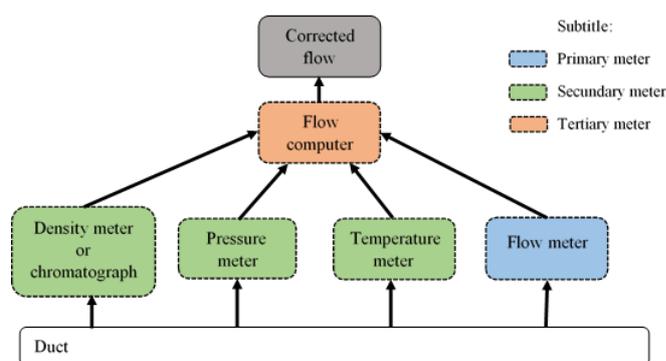

Figure 1. Diagram of operation of a measurement system.

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 the primary meter) exclusively through electrical signals, which may be analogue or digital. Currently, most primary and secondary meters use analogue communication [3], but it is worth noting the advantages that smart meters, which use purely digital communication, have over their analogue counterparts.

These sensors have features not found in their analogue relatives [4], such as:
a) Zero, range, and span adjustments;
b) Functional diagnostics;
c) Storage of information, such as identification code, settings, and more.

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 by analysing the flow computer approval certificates issued by the National Institute of Metrology, Quality and Technology, which are available on its website [5]. One can then understand the reason, since there is no metering device among these that is approved for use with digital signal inputs. It should be noted that, as they are regulated measuring instruments [6], flow computers must be approved by this Institute before they can be used in Brazil.

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 when working with signals of a digital nature. It is worth remembering that the tertiary meter, as flow computers are also known, 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 analogue signals [7]–[13], but fails to present forms of evaluation of this meter with the use of digital 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 analogue 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 analogue 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.

In Figure 2, the flow computer, identified as CV1, used to carry out the tests can be seen.

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) – the factor by which the uncorrected volume must be multiplied to convert it to the base conditions or corrected volume;

Figure 2. CV1 flow computer.

b) Primary meter reading – the ability to read and interpret signals sent by the flow meter;
c) Reading of secondary meters – mainly pressure and temperature;
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.

2. METHODOLOGY

It is important to mention that the VCF evaluation was carried out using two independent methods. At first, it was evaluated with the simulation of sensors using analogue 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 these

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. Analogue signal simulation

The simulation of analogue signals related to pressure was performed by generating an electrical current signal from 4 mA to 20 mA. This simulation was performed with the help of multicalibrator devices.

Regarding the simulation of analogue signals linked to temperature, it should be remembered that it can be carried out using either the same current signal, mentioned above, or a resistance representing a Pt100-type thermoresistance. Thus, a resistive decade was chosen for this simulation, since it presents superior stability in its characteristics compared to the multicalibrators.

Its specifications can be seen in Table 1.

Table 1. Analogue simulation devices and their specifications.

Device	Brand	Model	Range	Accuracy
Multicalibrator	Eurotron	MicroCal 20 DPC	Tension range: from -2 V to 20 V Current range: from 0 mA to 50 mA Resistance range: from 0 Ω to 500 Ω	Tension: ± (0.006 % rdg. + 100 µV) Current accuracy: ± (0.01 % rdg. + 0.4 µA) Resistance: ± (0.008 % rdg. + 20 mΩ)
Resistive decade	Minipa	MDR-611	1 Ω ~ 1111.11 kΩ	x1 Ω ± 0.5 % x10 Ω ~ x10 kΩ ± 0.1 % x100 kΩ ± 0.2 %

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 not only because it is widely used, but also because it is easy to audit and use [3].

This protocol is a specific modality for testing and evaluating the Foundation ™Fieldbus protocol. The software selected for its simulation is "Winterm" [14], and a crossover-type Ethernet cable was used. The 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 [15];
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 an average of 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: that is, 15 decimal places.

2.4. Procedures

Thus, after this configuration, the analogue signals related to temperature and pressure must be varied, and their VCF equivalent must be written down.

If the signal is analogue, 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 define the sources of uncertainty, it is necessary to identify the measurand and, primarily, the equation that gives rise to it. In these tests, the VCF will be observed, and it can be calculated from the general equation of real gases, see equation (1):

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

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, and T_0 is the final temperature.

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

When analysing the final quantities (P_0 and T_0), it should be remembered that the fluid volume in Brazil 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 are defined in advance, 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 [15], where its uncertainty is declared.

In this way, due to the inherent differences between analogue and digital signals, two cause-and-effect diagrams can be assembled, as can be seen in Figure 3.
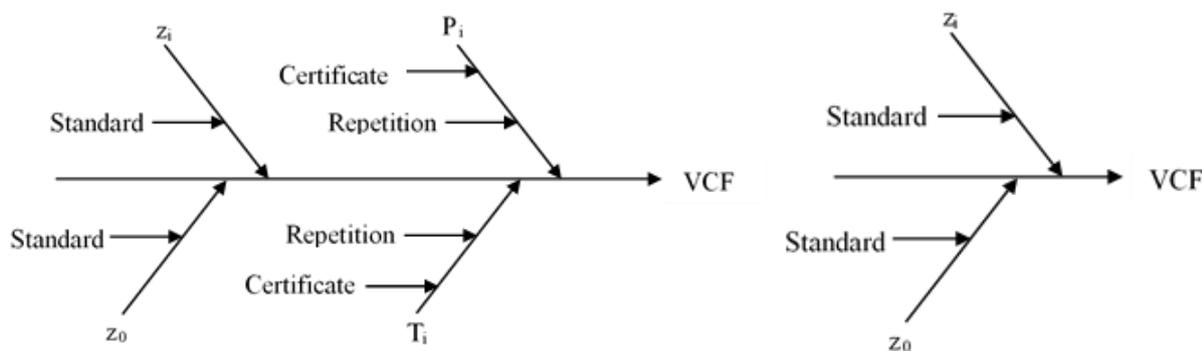

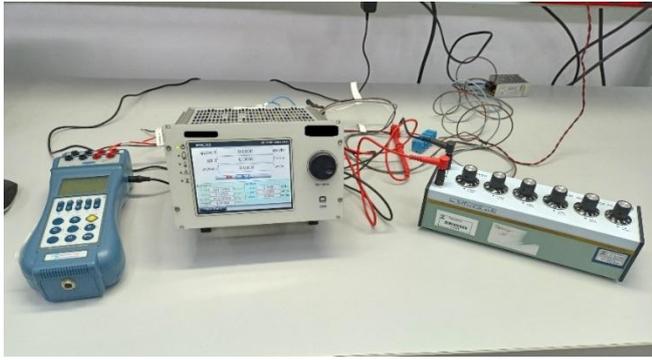Figure 3. Cause-and-effect diagrams for VCF in analogue (left) and digital (right) tests.

Figure 4. Test platform using analogue signals.

Table 2. Collection and calculation of VCF deviation for gases with analogue signals.

Pressure (kPa)	Temp. (°C)	VCF_i	VCF_{ref}	U (× 10⁻³)	$Deviation_i$
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

Figure 5. Test platform using digital signals.

Table 3. Collection and calculation of VCF deviation for gases with digital signals.

Pressure (kPa)	Temp. (°C)	VCF_i	VCF_{ref}	U (× 10⁻³)	$Deviation_i$
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

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, Rio de Janeiro, between 5 and 16 June 2023.

3.1. Analogue tests

The assembly of the test platform using analogue signals can be seen in Figure 4, along with the results in Table 2, where *Pressure* (kPa) is the 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, and $Deviation_i$ can be calculated with (2):

$$Deviation_i = \left| \frac{(VCF_i - VCF_{ref})}{VCF_{ref}} \right| \times 100 \% . \qquad (2)$$

3.2. Digital tests

The assembly of the test platform using digital signals can be seen in Figure 5, along with the results in Table 3.

4. CONCLUSIONS

The presentation of this test method, as well as its results, demonstrates its feasibility for evaluating the metrological reliability of flow computers with digital signals of the Modbus TCP/IP type. These methods are added to the existing ones for evaluation with analogue signals, however, it was possible to observe clear advantages of the former over the latter:

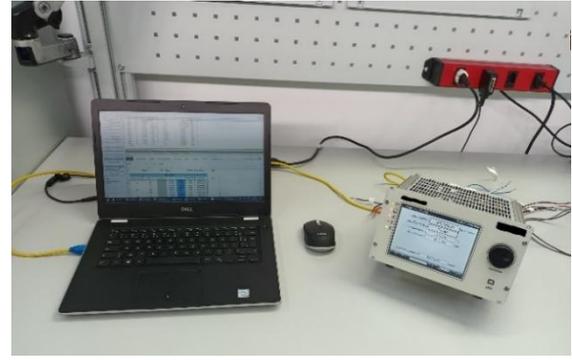a) Decreased number of instruments and work patterns required;

b) Digital FC inputs do not need to be calibrated as opposed to analogue 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 analogue 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, in both the FC and the related software. This required not only time but also specific training.

This proposal proved to be cheaper, with faster execution time and smaller uncertainty, providing the necessary tools for validating the measurements in FCs connected to smart meters.

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