Metrological reliability in flow computers using digital transducers: a literature review

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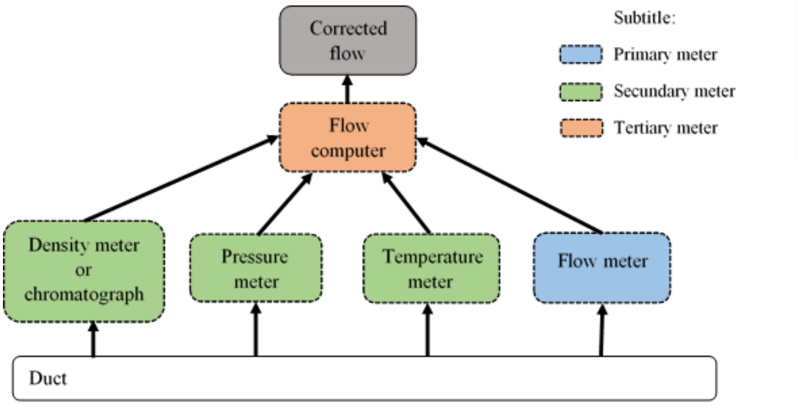
Abstract. This article presents a bibliographic review conducted in several standards applicable to the measurement of fluids (such as oil and natural gas) in which it sought to identify criteria and test methods that could be used to assess the metrological reliability of flow computers (FC) with the use of digital transducers. The articles of these standards that fit into this category were briefly highlighted and suggestions for new forms of evaluation are made at the end.

1. Introduction

In 2021, more than 1 billion barrels of oil and 48 billion cubic meters of natural gas were produced in Brazil [1]. These impressive numbers place our country as the 9th largest oil producer in the world and the 4th largest natural gas producer in Latin America.

In our country, as required by law, these fluids are measured in volume according to Joint Resolution ANP/Inmetro No. 1, of June 10, 2013 [2]. This makes it necessary that the measurement systems, used in the measurement of the aforementioned fluids, make use of flow computers to compensate for the effects of pressure and temperature in their transport. These are characterized by being purely electronic calculating devices that work together with other transducers that have the objective of identifying the magnitudes associated with the fluid to be measured, normally uncorrected flow (measured through a flow meter), temperature (thermo resistive sensor), pressure (piezoelectric type sensor) and specific mass (density meter for oil and chromatograph for natural gas). The operating diagram of a measurement system can be seen in Figure 1.

Figure 1: Diagram of operation of a measurement system



Source: Adapted from [3].

It is important to emphasize that the communication between the primary and secondary meters and the tertiary meter (flow computer) occurs purely through electrical signals, which can be analog or digital. However, it is by using communication in its digital format that these transducers have several advantages over the analog model, including reduction of cabling used in the transmission of information, bidirectional communication between the transducer and the flow computer and reduction of uncertainty [4].

Despite these advantages, this method of communication between transducer and flow computer has its use extremely reduced in fiscal and custody transfer measurements in the oil and gas sector. When analyzing the approval ordinances for calculating devices issued by the National Institute of Metrology, Quality and Technology - Inmetro (responsible for approving flow computers) and available on its website [5], one can understand the reason, since none of these metering devices can be found approved for use with their digital signal inputs.

However, with the advent of public consultation No. 1 of 2022 [6], the National Agency for Petroleum, Natural Gas and Biofuels (ANP) made public its proposal to revise the regulation for technical measurement of oil and natural gas (RTM), approved by Joint Resolution ANP/Inmetro No. 1, of 2013. Among the various changes brought about by this new proposal is the requirement to use digital communication between the flow computer, the meters and the instruments (item 10.2.2 of the draft) for measurement systems with a flow greater than 5,000 m³/day for liquids or 1,000,000 m³/day for gases.

This change in current legislation makes it urgent for manufacturers, users and regulatory bodies to work to ensure the metrological reliability of flow computers in the use of digital transducers.

2. Bibliographic Review

To understand the state of the art in the evaluation of flow computers, standards, recommendations and regulations issued by the following national and international bodies were evaluated: American Petroleum Institute (API), International Organization of Legal Metrology (OIML), Associação Brasileira de Normas Técnicas (ABNT), National Institute of Metrology, Quality and Technology (Inmetro) and French Standardization Association (AFNOR). The objective was to find documents that dealt with the evaluation of this meter with the use of digital communication with the transducers, through test methods and applicable criteria. The result of the research, as well as the summary of the evaluation of each of the documents, can be seen below.

2.1. API MPMS CHAPTER 21.2 [7]

This standard deals with the flow measurement of liquids using electronic measurement systems with positive displacement or turbine-type meters. It is of interest in this topic as it features specific sections on tertiary meters, specifically flow computers.

Most of the requirements presented in this standard apply to flow computers regardless of the form of communication with the secondary meters. When the differentiation of requirements arises due to the nature of the signal, most of them refer to analog communication, but some specific ones can be extracted for digital:

a) The set of secondary and tertiary meters must present an uncertainty of ±0.25% and is influenced by the type of communication between them (analog or digital);
b) The flow computer must be checked for reading false pulses (the interpretation of this requirement can also be expanded regarding the reading of false values emitted by intelligent transducers);
c) Determines rounding rules to be implemented in the FC and its maximum error of 0.01%;
d) It should be possible to use the FC to assist in the calibration of digital transducers.

Additionally, the standard explains that the use of digital transducers is preferable, as it eliminates the analog/digital conversion, which, by itself, is already a source of uncertainty.

Of all the elements presented by the standard, perhaps the one with the greatest impact on the evaluation of flow computers with digital signals would be the stipulation of the rounding rule to be used in this meter and the determination of its maximum error, since, as will be seen later, other standards stipulate this error as the only acceptable one in this case.

Procedures for calibrating analog sensors are suggested with a certain level of detail, such as the number of points and the need for adjustments. The calibration procedure for digital sensors only mentions the need to use a flow computer in the process, but does not make more detailed comments.

2.2. OIML R 117 – 2019 [8]

This recommendation, issued by the International Organization of Legal Metrology (OIML), lists requirements applicable to measurement systems for liquids other than water and their parts. Additionally, such requirements are presented in such a way that those uniquely applicable to flow computers can be identified.

This document presents two approaches for checking flow computers: the first with secondary meters associated with the CV and the second with the instrument verified separately using a signal simulator.

In the first case, the nature of the communication signal between the secondary and tertiary meters is disregarded, and metrological performance requirements are presented, which include the errors associated with the set.

The second approach is the only one that presents a requirement applicable only to flow computers associated with digital meters: that failures must be restricted to rounding errors.

Other requirements and tests applicable to digital communication are mentioned, but no others focused on CVs. In particular, item 3.7.4 recommends that secondary and tertiary meters be installed at a distance of no more than 1 (one) meter, which seems to be a requirement aimed at the use of analog transducers since digital ones are not limited in any way by the distance over which the signal is transmitted (assuming manufacturers' recommendations are followed). There is no mention of tests or procedures aimed at tertiary meters using digital signals.

2.3. OIML R 140 – 2007 [9]

Once again, OIML focuses on the topic of measurement systems, this time the measured fluids are gaseous. As addressed by R117, this document also presents elements that can be used for the metrological evaluation of flow computers.

The use of two approaches for the evaluation of flow computers, in the same format presented by R117, is resumed. However, it is necessary to better detail the treatment of the maximum permissible errors (MPE) of these approaches.

Both approaches recommend that associated instrument errors are also evaluated, in addition to the flow computer. The most relevant point is that the sum of the MPEs of these two elements is notably higher than the rounding error that is stipulated by R117 of 0.01% (in the case of 4 significant figures) for the application of the second approach (FC evaluated without associated meters). It can be concluded that the evaluation of the metrological performance of flow computers using digital signals without associated meters is considerably more permissive, in terms of MPE, in R140 than it is in R117.

As in R117, there is no mention of tests or procedures aimed at tertiary meters using digital signals. Mention is made that is unnecessary to verify the calculation of gas characteristics in the FC when associated with meters transmitting digital signals, but nothing more.

2.4. ABNT NBR 14978 - 2020 [10]

This standard deals with flow computers used in gas measurement and is divided into 5 (five) parts:

a) Part 1 – Terminology, classification, measurement ranges and stipulated operating conditions;
b) Part 2 – PTZ type;
c) Part 3 – Flow computers;
d) Part 4 – Installation, commissioning, validation and measurement monitoring;
e) Part 5 – Measuring instruments and associated gauges.

First of all, it is important to clarify that, in addition, to flow computers, this standard deals with PTZ-type volume converters and that this type of device is not the focus of this article.

The first and second parts do not present elements of great relevance to the subject addressed in this article. However, in part three one can find requirements, which although they do not deal with the use of digital meters, can be used in this theme.

It is recommended that, in flow calculations for differential pressure gauges, a sampling frequency of at least once per second be used. This requirement is relevant, as many digital communication protocols have bandwidth limits on data transmission and will not necessarily be able to meet this frequency.

Additionally, it is stipulated that an integrity test is performed on the data transmitted between the flow computer and the associated instruments and that incorrect data is flagged and not used. Finally, it determines that the transmitted data is protected from tampering. These requirements are relevant because communication protocols have additional functions, in addition to data transmission, that could perform the previously determined functions.

Part 4 is of special interest as it deals with the process of validating flow computers. This stage is divided into 3 (three) tasks: verification of the general configuration, the digital input signal versus the output calculation and the review of the diagnostic data. Here we have an explicit mention of the need to compare the information that arrives via a digital protocol and what the FC is reporting as a result of the measurement.

It is also mentioned that smart meters (which communicate via digital signals) may need to undergo zero adjustment and eventually, it may be necessary to use a flow computer to assist in this task.

Finally, the standard ends this subject by recommending the monitoring of the gas volume conversion factor as the only way to evaluate the metrological performance of flow computers.

2.5. ABNT NBR 16020 – 2011 [11]

Like the ABNT NBR 14978 standard, this document also focuses on the measurement of fluids with flow computers, however, it deals only with liquids.

This standard presents a calibration and verification procedure for flow computers as detailed as API 21.2. Here it is recommended to check and calibrate the analog and digital inputs of the FC, but without mentioning the procedures for this second case.

The verification procedure, within the scope of this standard, has the main objective of identifying problems in the measurement process. This procedure deals, within the scope of the flow computer, exclusively with the pulse input channels. Here it is described how the pulse frequency or its accumulated value can be used in this process. Pulse inputs are of particular interest in this topic since they can be considered digital signal inputs.

The calibration of smart meters may require the use of a flow computer to perform the correction functions since many of these transmitters are not capable of performing this function separately.

This document gives the flow computer a central role in the verification of the system since it treats all the information provided by it as the final value of all quantities measured by the measurement system.

The major focus of evaluating the metrological reliability of the flow computer comes from comparing the values calculated by it and previously validated calculation spreadsheets. No differentiation is made as to the nature of the input signal. Perhaps the greatest difference between this document with the others is present in this topic since here an error is admitted for the volume conversion factor of 0.03%, while any error in the reading by the flow rate computer is considered negligible for the following magnitudes:

a) Temperature;
b) Pressure;
c) Specific mass.

It is worth remembering that other standards admit a rounding error in these cases (generally around 0.01%). This creates a paradoxical position where ABNT NBR 16020 is, at the same time, more rigid in the evaluation of flow computers with secondary meters and more permissive in the evaluation of the final measured value. Measurement data integrity and inviolability requirements are similar to those presented by ABNT NBR 14978.

Finally, it recommends only HART or Field-bus as digital communication protocols.

2.6. Inmetro Ordinance No. 298, of July 8, 2021 [12]

This ordinance issued by Inmetro contains technical and metrological requirements applicable to flow computers used in the measurement of oil and natural gas. Because it was issued in the form of a regulation, rather than a rule, it has a mandatory character applicable to all these instruments used in Brazil.

Among the most notable technical requirements, it is possible to mention the mandatory storage device capable of saving metrologically relevant data changes and the ability to indicate all parameters used in the volume conversion calculation.

However, it is in the metrological requirements that great detail can be found. These contain the complete list of tests to which these devices must be submitted, they are as follows:

a) The volume conversion factor for pulsed output meters;
b) Volume flow for differential pressure gauges;
c) Pulse count;
d) Validation of the gas characterization algorithm (gases only);
e) Conversion factor due to temperature and pressure (oil only);
f) Double pulses (oil only)

It is important to mention that for each of these tests, maximum permissible errors are presented, broken down according to the nature of the signal read by the FC. While with the use of analog transmitters, the maximum errors vary from 0.015% (Conversion factor due to temperature and pressure) to 0.05% (Volume conversion factor for pulsed output gas meters), in the case of digital ones it is restricted to 0.01%, regardless of the essay applied.

Additionally, it is stipulated that, in any of the tests described, if analog and digital signals are used simultaneously, the maximum error to be observed will be that applicable to the use of the meter with digital transducers.

It is important to point out that this document does not have requirements or maximum errors applicable to the reading, by FC, of input quantities, such as temperature, pressure or specific mass, as opposed to the provisions of other standards. This absence is particularly interesting if one considers that, in this bibliographic review, this is the only document to present the tests to be applied to tertiary meters, discriminating them by type of fluid. The presence of maximum errors separated according to the input signal is a fact of great relevance, even if in the end this error, for digital signals, is the one, presented in other standards, restricted to rounding errors (0.01%).

This can be considered the most complete document for the evaluation of flow computers, since it presents, simultaneously, types of tests, approval requirements, requirements for the audit trail and sealing and requirements for electromagnetic compatibility.

2.7. NF EN 12405:2021 [13]

This standard deals with the measurement of gases through the use of conversion devices. It is divided into 3 (three) parts, with the most relevant being part 3 (flow computer).

In terms of safety, it is determined that the flow computer detects if any of the electrical input signals are outside its operational limits. This condition can eventually be extrapolated to determine whether the flow computer is capable of determining whether the digital communication protocol is the one programmed by the operator. The data transmission rate is stipulated at a minimum of 4800 bits per second. This is important data, as many digital communication protocols have limits on their transmission speed.

Mandatory specific functions for flow computers are cited. The most relevant are, regarding the use of digital transmitters, the following:

a) Comparison of data sent by the turbine for fault detection (meter-meter comparison);
b) Transducer response test (Timeout check);
c) Verification of temperature and pressure measurements;
d) Cross-checking of measurements.

Great importance is given to the use of digital protocols in the communication between primary and tertiary meters. Primary meters often transmit their readings in digital protocols and pulses simultaneously. This redundancy allows monitoring of the health of the meter by the flow computer, which is why it has become a mandatory function.

The audit trail is described in greater detail with emphasis on measurement data, metrologically and non-metrologically relevant parameters, events and status. Parameters specific to digital communication to be stored by the audit trail are not presented.

MPEs are differentiated according to their association with their secondary meters. Whether they are type 1 (secondary meters associated with FC) or type 2 (FC without associated meters). For the scope of this work, only type 2 is considered. In this case, this document presents MPE values considerably higher than other standards. Just for comparison purposes, the most restrictive maximum permissible error is 0.1% and it is applied to the reading of the temperature, pressure signal and calculation of the FC volume conversion factor. It is worth remembering that this error is 10 times greater than that estimated for the rounding error (0.01%). Additionally, in the tests and MPE, there is no differentiation regarding the nature of the electrical signal read by the tertiary meter, be it analog or digital.

The conformity assessment tests for this device show:

a) Requirements for repeatability;
b) Types of tests;
c) Approval requirements;
d) Audit trail requirements;

e) Requirements for electromagnetic compatibility and other influencing factors.

In the first place, it is necessary to clarify that throughout the standard, no differentiation is indicated regarding the nature of the electrical signal of the transmitters. This calls into question whether the authors of this document even had the inherent differences in these signals in mind when developing these requirements. Judging by MEPs being more permissive than other standards, the most likely conclusion is that the answer is no.

Second, of all the tests presented, only those on accuracy, alarm operation, optional functionality and repeatability could be used to evaluate flow computers with digital transmitters, since the scope of this work does not cover the evaluation of electromagnetic compatibility and other influencing factors. Despite this, it is important to mention that all tests are described in great detail in the appendix in addition to presenting their complete procedure.

3. Comparison of Standards and Conclusion

The expansion of the use of digital transmitters in the measurement of oil and natural gas is an element that will cause a great impact on this market. In addition to eliminating errors associated with their analog counterpart, they have several other advantages that even facilitate the introduction of this market in Industry 4.0, such as bidirectional communication and long distances with the flow measurement system.

However, one cannot forget that the metrological reliability of measuring devices, especially the flow computer, cannot be left behind in this process. To this end, the literature on the subject was evaluated as a way to identify tests that could be used for this purpose.

Each of these studied norms presented rich elements for the evaluation of the metrological reliability of flow computers. It can be mentioned in the introduction, by API 21.2, of the rounding error is the oldest evaluation requirement present in the literature regarding flow computers with the use of digital transducers. The OIML recommendations present two approaches for evaluating flow computers, although without defining specific tests for the use of digital communication. The documents issued by ABNT add the need for integrity tests of the signals received by the flow computer in addition to the minimum sweep speed of the secondary meters. While the AFNOR standard presents detailed test procedures, although, is apparently, focused on the evaluation of analog signals.

Special attention should be given to Inmetro Ordinance No. 298, of July 8, 2021. This standard is presented as the most complete on the subject, by stipulating types of tests, approval requirements, requirements for the audit trail and sealing and requirements for electromagnetic compatibility.

By presenting specific MPE for the use of digital transmitters in each of the tests described, Inmetro Ordinance No. 298 suggests that these tests are suitable for evaluating the metrological reliability of CVs using these meters. However, as one of those responsible for the development of this document, I can say that these tests were developed or adapted from other standards taking into account only the use of analog signals.

Over the 8 years that this regulation was in force (also considering the previous regulation, Inmetro ordinance n° 499, of October 2, 2015 [14]) 21 flow computers were approved for use in Brazil [5], but none of these had their approval extended to the use of digital transmitters, despite the absence of legal impediment.

This demonstrates that even the only standard, currently in force, dealing with all aspects of the assessment of the metrological reliability of flow computers was not applied in terms of digital communication with secondary meters due to the lack of a technical basis for their tests. Thus, there is a need, in our scientific literature, for the development of new test methods, requirements and evaluation criteria for flow computers with digital transmitters.

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