Flow Measurement and Instrumentation 74 (2020) 101773

Contents lists available at ScienceDirect

Flow Measurement and Instrumentation

journal homepage: http://www.elsevier.com/locate/flowmeasinst

Fiscal liquid and gaseous hydrocarbons flow and volume measurement: Improved reliability and performance paradigms by harnessing for fourth industrial revolution

Carlos Eduardo R.B. Barateiro [a,*], Claudio Makarovsky [b], José Rodrigues de Farias Filho [b]

[a] *Department of Engineering Estácio de Sá University Macaé, Brazil*
[b] *Department of Engineering Fluminense Federal University Rio de Janeiro, Brazil*

ARTICLE INFO

Keywords:
Fourth industrial revolution
Fiscal measurement
Industrial automation
Flow measurement

ABSTRACT

The oil and gas markets are of fundamental importance to the world's scenario dealing with high value products. Several rules and regulations define the various operating procedures due to environmental, social, political, and financial impacts. Liquid and gaseous hydrocarbon measurement stations are inside this context, either in the transfer of ownership of the product (custody transfer) or for values calculation for tax purposes (fiscal measurement). This is a conservative application in the industry but one that cannot fail to introduce the new features provided by the advances of the fourth industrial revolution. Thus, this article, based on a broad bibliographic research based on a qualitative analysis, addresses the concepts of some technologies already available in the automation market and how they can be applied to these stations to provide a greater reliability through risk reduction.

1. Introduction

Globalization comprises multiple dimensions: economic, political, cultural and social; the economic dimension has been greatly affected by the technological revolution which has spread around the world, with important consequences for business, government, and the labor market (Yalcin, 2008). The oil and gas market, particularly in exploration and production segment have been applying new solutions despite the conservatism of some areas due to the need to comply with specific rules, standards and regulations. As a result, in most of today's digital oil and gas initiatives are yet incremental rather than disruptive [1].

A good example of this resistance to change has been the oil and natural gas production measurement for purposes of fiscal measurement (change of ownership or royalty payment for exploration rights). Projects for new production units using orifice plates in gas flow measurement are still common - a technology that has been commercially available for over 100 years with low rangeability and relatively high uncertainties. However, when analyzing the digitization advantages in these production units, one can understand the limitations of these legacy technologies [2].

As the increase in industrial productivity is the basis of business success and often the reason for its very survival in increasingly globalized markets [3], industrial automation has evolved at an increasing pace, particularly in the last decades and nowadays it has the capacity of being much more than simply a tool for process control, having an impact on project execution, particularly in plant maintenance. In a more in-depth analysis, this is behind the concept of smart factory, more recently called Industry 4.0. A good insight into this relationship between the operational efficiency and the application of recent technologies is in the comparative study conducted by Solomon Associates (2015), an American consulting company, which has performed extensive research with the management staff of over 8000 processing plants in areas such as chemical, petrochemical, refining and operations, allowing the framing of companies in performance quadrants. The framework indicated by this study shows clear performance differences among these organizations: the top quartile companies, when compared to the worst cases: a) spend proportionally much less on maintenance (about US$ 100) than the companies in the last quadrant (about US$ 346); b) have a better performance with an availability index greater than 98% against 86%; c) have 30% lower emissions and 15% less energy use; d) proportionally the projects carried out have a 54% lower cost index and; e) in the construction of the enterprise they consume 49% of the time of those located in the last quadrant.

With this focus, the main objective of this study is to analyze how

* Corresponding author.
E-mail addresses: cerbb@terra.com.br (C.E.R.B. Barateiro), cmakarovsky@id.uff.br (C. Makarovsky), fariasfilho@gmail.com (J. Rodrigues de Farias Filho).

https://doi.org/10.1016/j.flowmeasinst.2020.101773
Received 30 December 2019; Received in revised form 5 June 2020; Accepted 9 June 2020
Available online 26 June 2020
0955-5986/

these modern tools made available by Industry 4.0 technologies can be used in this specific application - the fiscal liquid and gaseous hydrocarbons flow measurement, addressing its advantages/limitations and creating a development framework for the metering systems industry.

For this, Section 2 of this paper presents the overall Fourth Industrial Revolution concepts and an overview on Fiscal Flow and Volume Measurement - both necessary to understand the scope of the research. The paper consolidates the experience of the authors, who have been working in the areas of fiscal measurement and custody transfer for over 30 years and the research project carried out within the University. This project considered the technical solutions existing in the automation and instrumentation market and, for that, a major literature review was carried out. The results obtained in the qualitative research are presented in Section 3 and Section 4, with a summary in its conclusion.

2. Flow measurement and industry 4.0

The theoretical framework of this paper is based on the following areas of knowledge: Fiscal Flow Measurement Aspects, Industry 4.0 Concept and Oil and Gas 4.0 Era.

2.1. Fiscal Flow measurement aspects

Custody transfer measurement in the oil and gas business has been described in many ways. It has been called an accuracy in measurement that both the buyer and seller can agree upon and it has been called the best that can be achieved to meet contract conditions [4]. Fiscal Flow Measurement must not be confused with Custody Transfer; in fact, fiscal measurement is a more general term meaning "measurement for money" that includes both allocation and custody transfer flow measurement. Allocation is the numerical distribution of products between two parties according to their equity share. Custody transfer is a contract driven concept: it means that there is a contractual obligation between buyer and seller which may require adherence to accuracy, repeatability, linearity, or uncertainty standards as defined by measurement standards [5].

These measurement standards can be divided into two broad groups: a) those that originate from entities formed by industry players such as the American Petroleum Institute (API) or; b) from local metrological organisms such as the National Institute of Metrology (INMETRO) from Brazil.

Typically, these regulations define some aspects that must be followed by production field operators to ensure complete and accurate results [6]:

- Pressure and Temperature Measurement.
- Uncorrected Fluid Flow and Volume Measurement.
- Fluid Analysis.
- Algorithms for Gas and Oil.
- Data, Alarm & Event Logs Control.
- Uncertainty Calculation and Control.
- Calibration and Proving.
- Model Approval.
- Audit and Traceability.

2.1.1. Pressure and Temperature Measurement

The temperature and pressure of the measured gas and liquid affect the performance of the meter, due to a mechanical effect caused by the expansion or contraction of the its body and components, when the operating temperature and/or pressure are different from the calibration conditions. The variation of the temperature and pressure affects the physical properties of the measured fluid, such as its vapor pressure, density and viscosity [7].

Another important aspect in measuring pressure and temperature is establishing a standard condition to allow comparisons to be made among different sets of data. The most used standards are based on National Institute of Standards and Technology (NIST) which consider a temperature of 293.15 K (20 °C) and an absolute pressure of 101.325 kPa - this standard is also called normal temperature and pressure (abbreviated as NTP) (McNaught and A. Wilkinson (1997). Some countries, however, use The International Standard Metric Conditions which considers 288.15 K (15.00 °C) and 101.325 kPa - this standard is also called standard temperature and pressure (abbreviated as STP) (ISO, 1996).

It is worth mentioning that the ambient temperature variation also affects the performance of most flow meters. Many technologies for the uncorrected flow measurement already include a system to compensate for these effects. When this functionality is not available, its effects must be considered in the uncertainty calculation.

2.1.2. Uncorrected Fluid Flow and Volume Measurement

The regulations allow the fluid measurement in its operating conditions by two techniques: with inline measurement (closed ducts) or through calibrated tanks - these measurements are called uncorrected or actual. Not all measurement technologies are acceptable under these regulations because of the uncertainty class. Typically for closed liquid pipelines the use of Transit Time Ultrasonic Meters, Coriolis effect Mass Meters, turbines and positive displacement are approved. For in-line gas, Transit Time Ultrasonic Meters, Coriolis effect Mass Meters, turbines and pressure differential orifices are accepted. For tanks, non-contact radar type or traditional float type meters are allowed [6].

2.1.3. Fluid Analysis

Fluid characteristics need to be monitored because they are used to obtain corrected flow or volume values either through the direct parameters in the compensation equations (algorithms) or indirectly, because they affect direct parameters. Also, the regulations define the need for these analyses to control undesirable contaminants in the fluid. For liquid hydrocarbons, specific mass, determination of the volume fraction of water and sediment (BSW), boiling point, determination of sulfur content, shrinkage factor and solubility ratio are typically analyzed. For gases, the gas composition, specific mass, calorific value, inert gas and contaminant contents. When large quantities are involved, the measurements of these variables are usually inline through sampling systems [6].

2.1.4. Algorithms for Gas and Oil

Specific algorithms for fluid density correction are used to perform pressure and temperature compensation calculations. For liquid hydrocarbons, API density correction tables [8] with the quantity obtained through ISO 4267 [9] or API Manual of Petroleum Measurement Standards Chapter 21 [10] are typically used. For gas, ISO specifications are used, depending on the measurement technology: a) ultrasonic flow meter: ISO 17089 [11]; Coriolis effect mass flow meters: ISO 10790 [12]; c) turbines: ISO 9951 [13] and d) differential pressure orifices: ISO 5167 [14]. However, the use of algorithms depends on the regulation to be followed. For example, in many countries it is common to follow the AGA (American Gas Association) recommendations for natural gas metering systems [15–18].

Algorithms calculate the average normal or standard flow rate value but how these values are totalized (with period reset) or accumulated (without reset) as defined by specific regulations. Typically, these are based on API Manual of Petroleum Measurement Standards Chapter 21 [10].

Both compensation and totalize/accumulation algorithms operate on a specific equipment called a flow computer which is permanently responsible for algorithm running and values storage. In order to reduce the uncertainties calculation, it typically operates with double precision floating decimal point [10] - this is the main reason why Programmable Logic Controllers (PLC), despite having the algorithms developed for hydrocarbon measurement, are not used in fiscal measurement, since they operate with single precision.

2.1.5. Data, Alarm & Event Logs Control

One of the most important functions of the flow computer is storing the measurement data (average, total and accumulated values) but it also records alarms (such as out of range temperature or pressure) and events (system power failure time and/or start-up time). The equipment typically should be capable of storing data for up to 35 days on a time basis and at least the last 250 alarm/event logs [19]. All this information is deleted in the FIFO (first in, first out) method.

2.1.6. Uncertainty Calculation and Control

All measurement regulations specify the maximum tolerable uncertainty conditions for the fiscal measurement application. It is the responsibility of the field operator to maintain the updated calculation memorials whenever a change occurs in any of the factors that may cause errors in the systems. Typical error sources are the uncertainties of primary elements (flow meters); and uncertainties of secondary elements (pressure, temperature sensors), flow computer uncertainties (algorithm, parameters), variations in environment conditions (temperature, moisture) and variations in process conditions (variables with large fluctuations), etc. The procedures for calculating uncertainties should normally follow the ISO/IEC GUIDE 98–3 (ISO, 2008).

2.1.7. Calibration and Proving

Proving is the process of checking a flow meter against a reference device, in order to evaluate the difference between them. After several runs, notes are taken of the differences in the measured values of each device (operational and reference), and with that it is possible to calculate the factor called "K" – this "K" factor is used to calibrate the operational meter. Calibration is whatever is necessary to adjust the meter to match the reference device, thus ensuring accurate measurement performance [20].

Measurement regulations define the maximum calibration frequency of primary and secondary meters according to the equipment type, application and technology. For example, according to Brazilian regulations, a Coriolis effect mass meter or a Time Transit ultrasonic meter need to be calibrated every six months for fiscal measurement, and those with other technologies, every 3 months [6].

2.1.8. Model approval

Model approval is testing and verification by the local metrology authority to ensure that the measuring equipment meets the technical requirements defined by a specific regulation. These tests are specific, considering electronic device firmware to ensure the performance of its algorithms. These tests mainly consider the primary meters and the flow computers [6].

2.1.9. Audit and Traceability

The production field operator must ensure full traceability to the measurement data so that the conditions and verifications of the errors impact on the calculated values can be reproduced at any time. Since flow computers have limited memory capacity, automatic or manual systems for collecting data stored on these devices must be provided. All data must be protected against unwanted breaches. Periodic audits should be established for the verification and treatment of nonconformities. Typically, regulations require compliance with standard ISO 10012 [21].

2.2. Industry 4.0 concept

The Industry 4.0 phenomenon was first mentioned in Germany in 2011 as a proposal for the development of a new concept of economic policy based on high technology strategies [22]. In fact, it is defined as "the integration of complex physical machinery and devices with networked sensors and software, used to predict, control and plan for better business and societal outcomes" (Industrial Internet Consortium, 2013) and as "Intelligent Industry or Industry 4.0 as the technological evolution from embedded systems to cyber physical systems and represents the fourth industrial revolution on the way to an Internet of Things, Data and Services" as defined by Germany Trade and Invest [23]. Decentralized intelligence helps creating an intelligent network of objects and independent process management with the interaction of the real and virtual worlds representing a crucial new aspect of the manufacturing and production process strategies [22].

Roser [24] mentions how they arrived at the current stage of industrial development: a) the first industrial revolution with steam engines; b) the second industrial revolution with the use of electricity; c) the third industrial revolution with computers, networks, robotics in manufacturing and connectivity and; d) the current fourth industrial revolution (Industry 4.0) with concepts such as Cyber Physical Systems, technology convergence (IT), Internet of Things, Big Data, cloud, advanced robotics, artificial intelligence (AI) and cognitive science.

However, we have a subtle difference between Industry 4.0 and the Industrial Internet: Industrial Internet was seen as the third wave of industrial innovation rather than a fourth revolution in the industry (I-Scoop, 2010). It shows just how revolutionary terms are like the three industrial waves of Internet innovation, respectively:

a) The Industrial Revolution. The real combination of the first and second revolution in the view of Industry 4.0.
b) The Internet Revolution: "computing power and the emergence of distributed information networks".
c) The Industrial Internet: what is called the fourth industrial revolution in Industry 4.0.

Today, the concept of four industrial revolutions, however, has gained wide acceptance, and so the general term of Industry 4.0 was adopted here [25]. Many of the technologies considered in the Industry 4.0 concept are often considered separately. But together they integrate into the physical and virtual worlds. This change allows for a powerful new way of organizing global operations: bringing the interconnection and speed of software to the production of machines on a large scale. Under the Industry 4.0 model, product design and development take place in simulated laboratories and use digital manufacturing models. The products themselves take on a tangible form only after most design and engineering problems have been solved. The networks of machines that engendered industrial society become highly flexible systems granting technology, responding quickly not only to human commands, but to their own perceptions and self-direction [26].

According to Mamad [27]; Industry 4.0 is based on some fundamental concepts: a) Intelligent factory; b) Cyber physical systems; c) Self-organization; d) New distribution and acquisition systems; e) New systems to develop products and services; f) Adapting to human needs and; g) Corporate Social Responsibility.

Three aspects of digitization form the heart of an Industry 4.0 approach in accordance with Thames and Schaefer [28]: a) The complete digitization of the operations of a company; b) The redesign of products and services to be incorporated with customized software and; c) Closer interaction with customers.

In fact, Geissbauer et al. [26] mention that industrial enterprises are moving towards greater digital value creation, from isolated products to digital ecosystems by: a) Enhanced Digital Products; b) Complete Solution/Service Provider. C) Focus on Data analysis; and d) Integrated Digital Ecosystem Provider.

Finally, it is necessary consider two other important aspects cited by I-Scoop (2010)): the horizontal integration of Internet Technologies (IT) among the various production and business planning processes and the vertical integration of IT systems at various hierarchical levels of production and production.

The fourth industrial revolution is rapidly expanding: in 2015, PricewaterhouseCoopers interviewed more than 2000 companies from 26 countries in the industrial production sectors, including aerospace and defense; automotive; Chemicals; electronics; engineering and construction; forest products, paper and packaging; industrial manufacturing; metals; and transportation and logistics. In this global survey of Industry 4.0, a third of the respondents said their company had already achieved advanced levels of integration and digitization, and 72% expected to reach that level by 2020 [29].

2.3. Oil and gas 4.0 Era

Lu et al. [30] mention that the core goal for Oil and Gas market is to use advanced digital technology to achieve higher value in the industry. However, the digitization process of most companies is slow and are currently in the "exploratory phase" of the digital process. According to Deloitte's 2015 report, the digitization of the oil and gas industry is 4.68 (0–10) [31]. Beckwith [32] points out that, "of the hundreds of thousands of apps now publicly available, only a few dozen is devoted to the oil & gas industry"'. Yergin [33] cites "Hydrocarbon molecules are the product of the industry, but data is a product too. There are companies that produce oil and gas and generate data, the two are wholly inter-dependent".

The main digital application in the oil and gas industry is the Asset Life Cycle Management that includes automated operations, remote operations, advanced analysis tools and modelling, predictive maintenance and connected worker [2]. Asset life cycle management transforms operational models and enhances strategic decisions by collecting data. This process considers specialized sensors to collect real-time information from physical assets, relies on cloud analysis tools to process the data, and understands how it affects other steps in the workflow based on the data to summarize lessons and apply them to the future [30].

Intelligentization is the ultimate step after digitization and it is not limited to control, but it includes the ability to create and adapt. Intelligentization can greatly increase efficiency while reducing labor costs. According to Yang et al. [34] intelligent oil fields may increase production by 2%–8% and recovery by 2%–6%, intelligent refineries will automatically collect more than 95% of production data and increase labor productivity by more than 10%, while intelligent pipelines will realize pipeline life cycle management. Only a few leading enterprises have reached a high level of digitization and are developing towards intelligentization.

As mentioned, the basis of digitization and intelligentization is data collection. And for this to be fully processed, it requires compatible field networks so that information may flow from the lowest devices in the systems architecture. In terms of industrial automation for process control (focus of this paper), networks have been used since the 1980s, although at the beginning the focus was only on collecting primary variables in a multidrop way. Networks have evolved over the past 20 years and nowadays, in addition to operating at high speed, it is able to collect numerous diagnostic information generated by the lower layer devices.

The collection of these diagnoses is fundamental for the correct interpretation of the systems integrity and there is still no single standardization among device manufacturers. For example, in the Fieldbus Foundation Protocol, 18 bytes have been defined for standardized alerts that each manufacturer can use for alerts such as sensor failure, electronic card failure, local temperature outside the limits of the instrument, maintenance required and eventually output with a high signal. Some manufacturers even define a group of alerts to facilitate the identification of the main problem, since the same fault linked several different alerts. And since this grouping is not standardized, it has different configurations: for example, Emerson uses three clusters: Failed, Maintenance and Advisory [35] and Namur sensors users have defined Failed Maintenance, Off Spec and Check Function [36]. Fig. 1 presents a typical screen of how these diagnoses are made available to users.

What is observed is that there is a large space for the implementation of new technologies in the oil and gas segment and the article presents exactly a solution for the measurement stations destined for fiscal measurement and custody transfer with exactly this focus.

3. Results and discussion

Uncertainty and a dwindling knowledge base canmay cost companies millions of dollars through: a) Unexpected downtime as systems fail and result in lost or deferred revenue; b) Increased system uncertainty resulting in increases in unaccounted for losses; c) Nonconformance that may result in fines and/or legal action and; d) Unnecessary travel to detect issues resulting in travel costs, wasted resources and safety exposure.

With this focus, this item analyzes the traditional architectures found in liquid and gaseous hydrocarbon measurement systems, discusses the importance of analyzing the diagnostics generated by instruments, meters and analyzers and concludes by proposing a new architecture that allows the incorporation of these diagnostics, introducing some data analysis and interpretation tools specific to these stations.

3.1. Typical Metering System Architecture

Due to the need for retention of measurement data for traceability purposes, it is common for metering stations to have its flow computers connected to supervisory systems. These supervisory systems collect the historical, events and alarms logs generated by the flow computers and store them in a protected violation database as shown in Fig. 2. Consolidated measurement data is used for reporting and sent to top management.

Typically, instruments and meters connect to flow computers via standard 4–20 mA signals, pulses or via RS485 serial links with Modbus protocol. What is sent to flow computers are the values of the primary process variables (uncorrected instantaneous flow, pressure, temperature, differential pressure, density or fluid composition).

3.2. Evolution of diagnostics and connectivity

The introduction of instrumentation, gauges and valves based on pneumatic analog transmission signals in the 1950s was a breakthrough in the automation of industrial plants [37]. In the 1960s, the commercial start of the analog electrical signals based on the 4–20 mA/1- 5Vdc standard allowed for the reduction of panel size and increase in the number of monitored plant variables [38]. At the same time, originated by early developments in mechanical flow measurement turbines, all flowmeters transmitted instantaneous flow values based on electrical pulse signals. Even in modern industrial facilities it is common to find these forms of signal transmission, and they are even almost a standard in oil and natural gas measuring stations. This form of connection has the sole purpose of informing the value of the variable and it is not possible to know if the value is correct or unaffected by external interferences. The only tool available for assessing signal quality is simply using oscilloscopes or multimeters.

The incorporation of microprocessor electronics in the 1980s has made great strides in the amount of information generated by instruments, gauges, and valves. With the development of digital communication, in addition to the primary variable, these devices began to provide diagnostics and alerts about their operation and even about the process conditions. This information is important for establishing preventive and proactive maintenance routines but still of little use in the industry.

However, its availability is only possible if the equipment is connected to another device through a digital link and that it has the capacity to collect these diagnostics. Today it is possible to find in the industrial market HART, Fieldbus Foundation and Profibus links that meet this condition [39].

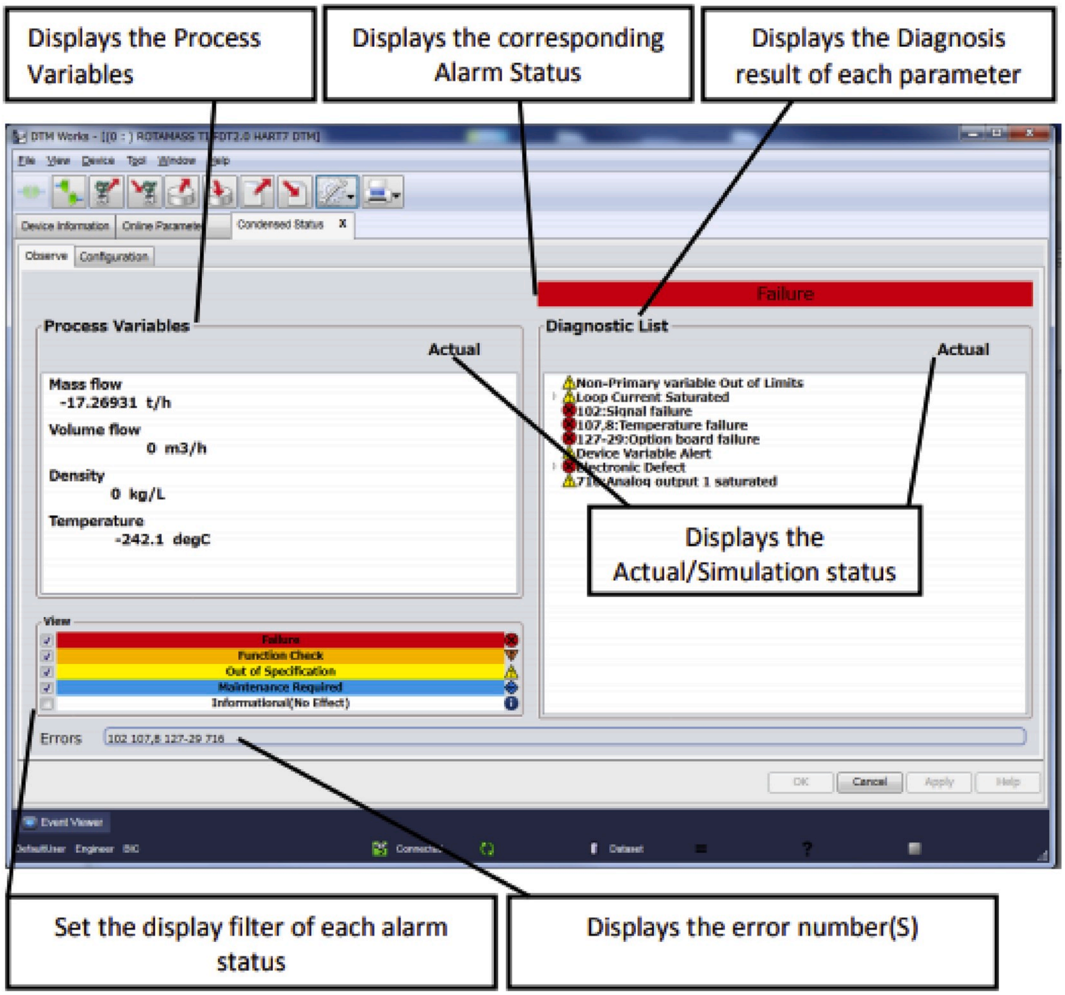

Fig. 1. Typical screen for presenting diagnostics of a flow meter. Source [36].

Devices using HART communication technology hit the market in the early 1980's and there are around 10 million HART devices in service throughout the world today. HART is well proven, has a large installed base and the technology is simple and well understood by technicians/engineers. HART Field Communications Protocol is superimposed on the 4–20 mA signal and provides two-way communications with smart field instruments without compromising the integrity of the measured data. HART communicates at 1200 bps and provides a host with two or more digital updates per second from a field device. Multi-drop HART networks are used in applications where fast update rates are not required (Douglas, 2003).

Devices using Foundation Fieldbus Technology became available in 1998 and there are over 700,000 Foundation Fieldbus Devices installed in over 10,000 systems. The technology is now proven and has a growing installed base. Foundation Fieldbus is a true multidrop system and has numerous advantages including automated data collection for asset management and communication performance (Douglas, 2003).

The Profibus, in its process version (Profibus PA), is very similar to Foundation Fieldbus with some advantages (mainly the number of nodes around the world, market leader, several versions, Profibus for CPU (Computer Process Unit) to CPU communication, master-slave communication, special profile for motion control application, and approved for safety application). Fieldbus Foundation has its benefits too, mainly the possibility for remote closed loop control, PID Loop in the instrument (Douglas, 2003).

Finally, it is worth mentioning about RTU and ASCII Modbus Protocol. It was launched in 1979 and was widely used as serial communication EIA-485 (Electronic Industries Alliance-485) in the 1980/90s and even today there are still many systems using it for communication from field devices to controllers. However, despite being multidrop, the possibility of collecting information from field devices is rather limited. An evolution of this protocol was the launching, in the late 1990s, of Modbus TCP/IP (also Modbus-TCP), which is simply the Modbus RTU protocol with a TCP interface running on Ethernet. Despite having some limitations in terms of data security, it has been an alternative to the communication between controllers and supervisory stations Douglas, 2003).

3.3. Integrated Metering System Architecture

One of the focuses of the fourth industrial revolution is digital transformation, but it is essential that actions maximize value through financial performance and add value to the user, the environment and society [2]. With this approach the study found three changes in the traditional architecture of an automation system: a) diagnostics collection generated by modern meters, transmitters and analyzers; b) the intensive use of collaborative centers and; c) the incorporation of a specific computational unit for analysis of the generated data. These three changes can be seen in Fig. 3.

Fig. 4 shows the schematic of information flow and activities with this new approach to the architecture of fiscal measurement systems.

In this architecture it is clearly possible to visualize data collection and treatment, the analysis and actions - a sequence in agreement with the good practices recommended for digital transformation.

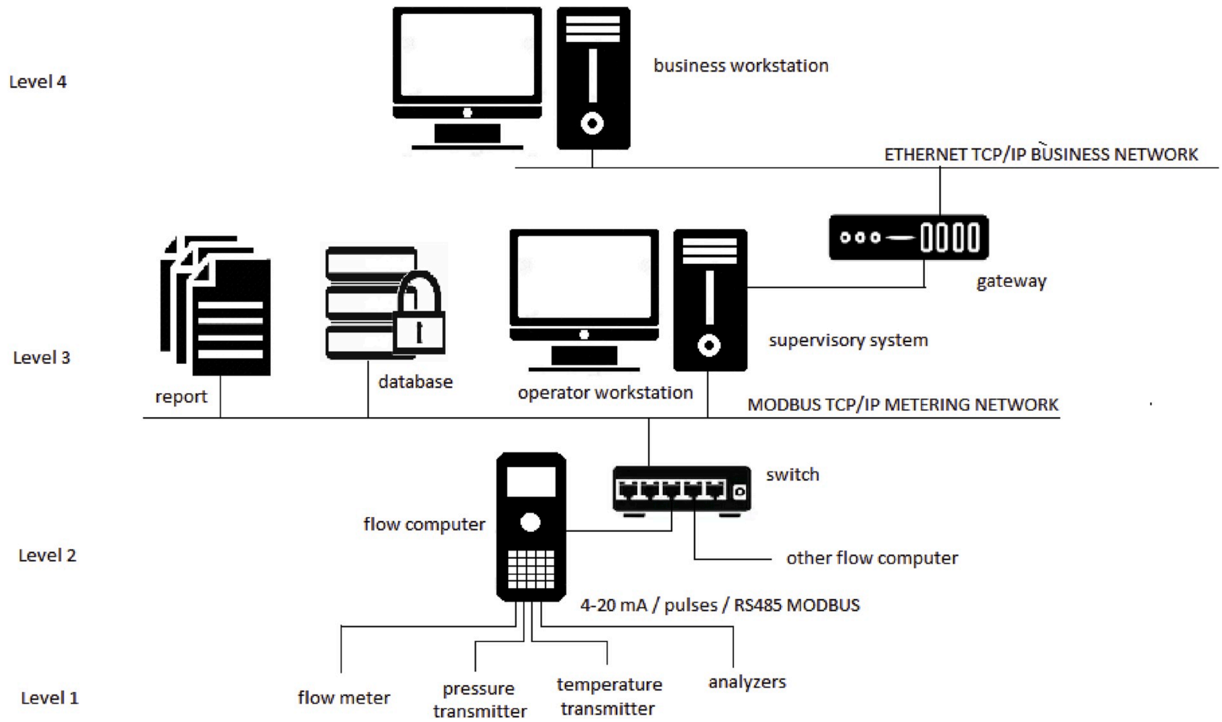

Fig. 2. Typical metering system architecture.

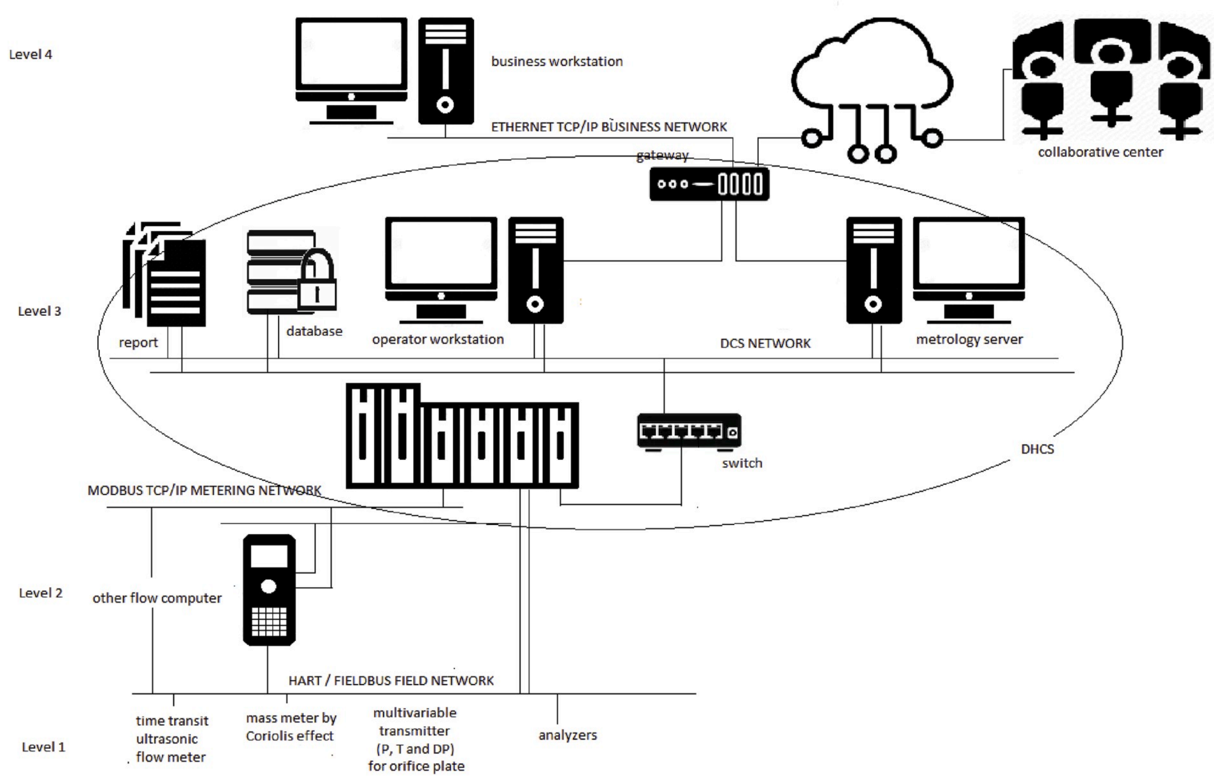

Fig. 3. Integrated metering system architecture.

3.3.1. Diagnostic collection

It should be noted that flow computers are tightly regulated with specific model approval and that good practices in fiscal measurement recommend that process control activities should not be performed on the same equipment which generates corrected flow calculations. Considering this very specific focus, flow computers are not prepared for the extensive collection of diagnostics generated by instruments, flow meters and analyzers, but only limited to some already provided by the API [10].

Thus, the proposed solution considers the incorporation of a specific

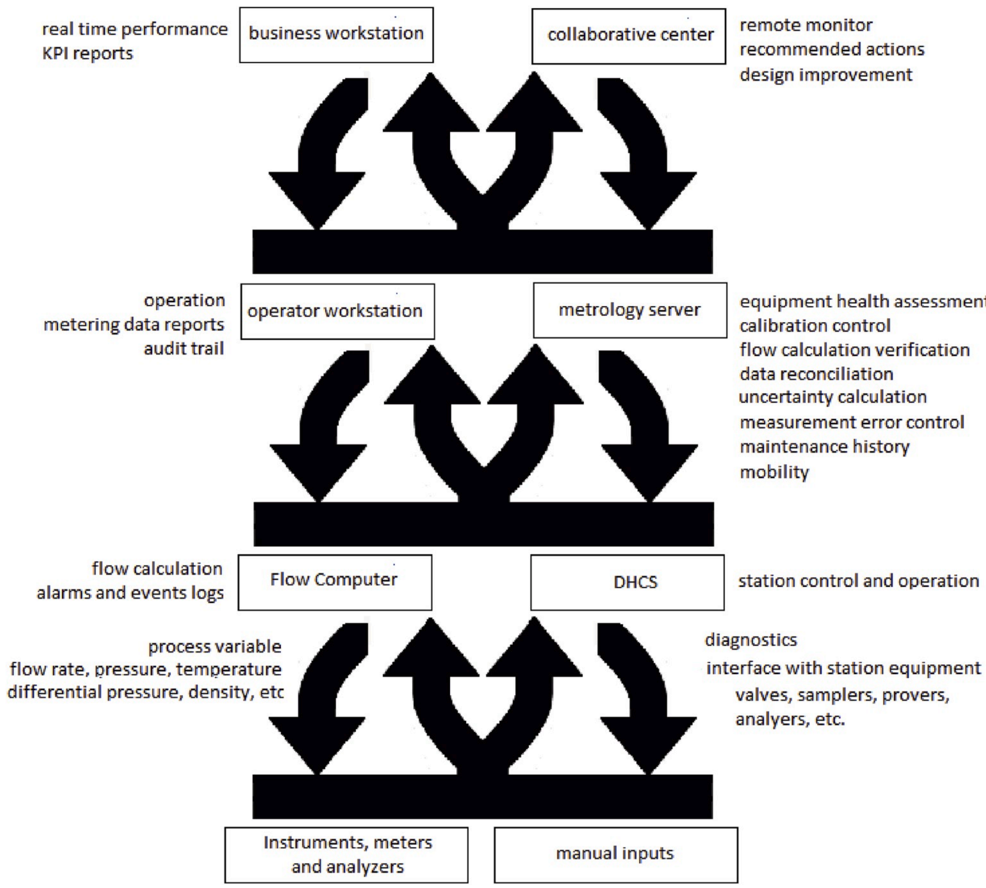

Fig. 4. Information flow chart of new metering system architecture.

system that collects the diagnostics generated by the field equipment, while the main variables necessary for the corrected flow calculations are sent to the flow computers. A modern distributed hybrid control system (DCS) was chosen, with the necessary modularity for this application and with the correct field equipment interface connectivity. This system is also responsible for the complementary operations to the metering station, such as valve actuation and sampling, analyzers, master meter routines and other control activities.

3.3.2. Collaborative centers

The second major change is the establishment of a shared collaborative center to centralize monitoring, assisting operators in their decision making with the help of third-party expertise. Remote monitoring capabilities and web-based access allow the right information to get into the right hands at each level of the organization. Customers have steadily seen operational improvement over the years by deploying smart automation technologies that provide them with more data and visibility [40]. But data alone is not enough. The real opportunity is to imagine new organizational workflows, such as the formation of cross functional collaboration centers which bring together decentralized expertise to enable better, faster decision-making.

Collaborative centers concentrate expertise, even if geographically dispersed, and provide coverage over a greater area. Such expertise may reside in process plant, suppliers, or third-party service providers. Collaboration occurs physically or virtually, depending on where the experts reside. Workflows and processes should align for agility to facilitate faster decisions to take advantage of opportunities and provide quicker, coordinated responses to events.

These collaborative centers include operations, maintenance, collaboration workflows, production planning and business operations. Operations include remote process monitoring, remote process control and managing the operations key performance indicators (KPIs). Maintenance includes the existing centralized maintenance and field operator maintainer practices and adds remote asset monitoring and maintenance KPIs.

Collaboration involves multi-discipline expertise - both within the company and externally with suppliers and third parties. Suppliers may provide remote expertise services on installed technologies and applications. Collaboration also includes training, certification and compliance with health, safety, security and environment (HSSE).

3.3.3. Computational unit for analysis

The third major change in traditional architecture is the incorporation of a metrology server, which really makes it possible to take advantage of fourth industrial revolution technologies. Obtaining the data without their correct treatment is ineffective and does not help in obtaining any advantage with the digital transformation [41]. Its features will allow the reduction of unexpected downtime, improvement of system uncertainty, reduction of non-conformance unnecessary travel to detect issues by means of the use of advanced neural network, capable of proactively identifying potential issues in the measurement system.

The introduction of a metrology server is the most important improvement of this new architecture, due to the power of the information generated for decision making and its blocks need to be deepened so as to understand the advantages of this new approach. This unit includes the following modules:

- Equipment Health Assessment
- Calibration Control
- Flow Calculation Verification
- Data Validation
- Uncertainty Calculation

- Measurement Error Control
- Maintenance History
- Mobility

3.3.3.1. Equipment Health Assessment. The asset management is a real-time system which helps plants operators avoid unplanned shutdowns and inefficient practices that eat away at profits. Based on real-time condition data from intelligent field devices, plant staff may respond fast and make informed decisions on whether to maintain or replace field devices. Each measurement technology has its own inherent diagnostics but there is no standardization by the manufacturers. The research allowed us to obtain some of the most important available, as detailed below.

a) Pressure and Differential Transmitters Diagnostics: Impulse lines may fill with solid material or freeze in cold environment due to heat trace failures. This condition is detected by plugged impulse line diagnostics inside modern pressure transmitters. Historically, transmitters have provided diagnostics focused mainly on detecting internal device problems. A new micro processed pressure transmitter has statistical process monitoring (SPM) providing new process insight for abnormal situation prevention (ASP). Process problems detected include pulsation indicative of pump or compressor damage; entrained air causing flow measurement errors; leaks in impulse lines and manifolds; liquid carryover in gas stream [42].
b) Temperature Transmitters Diagnostics: A new temperature transmitter has SPM for ASP. SPM can detect abnormal process behavior before operation constraints are reached, providing an early warning. It may be used to detect hydrate formation in natural gas lines, scaling formation, thermowell coating, etc. It detects if sensor wiring is open or shorted or if a sensor breaks and fails completely, but a new transmitter has predictive thermocouple degradation diagnostics that alert before the thermocouple fails. Such failure prediction helps reduce process downtime and decrease energy costs. Thermocouple degradation diagnostics may help detect a failing thermocouple and allow preventive maintenance to be scheduled before failure. For temperature transmitters mounted integrally to the sensor, heat from the process is conducted to the transmitter housing. The transmitter has min/max temperature tracking diagnostics, monitoring if the temperature of the transmitter itself has exceeded the operating limit. Another application for the min/max tracking feature is capturing transient events, calibration error, process temperature or cold-junction temperature reading degradation, electronics or memory failure, configuration error, and hardware/firmware incompatibility [42].
c) Coriolis Effect Mass Flow Meter: in this type of equipment, the diagnostics results of comparing the values of physical quantities of the main components against the same parameters measured at the factory - this process is called equipment signature [43]. Table 1 gives a summary of the main available diagnoses for this meter.

3.3.3.2. Calibration Control. Continuous comparison between factory parameters and equipment operation allows for another important functionality: controlling the need for meter recalibration. The current situation vs benchmark analysis deviation increases operator confidence in the flow meter performance. Financial exposure by using faulty equipment may be minimized by calibration, but costly implementation is also required. The use of specific algorithms to establish this optimization function as proposed by Pashnina [46] and with comprehensive diagnostics reduces potential problems when performing risk-based maintenance.

Local regulations certainly define the obligation to calibrate at a certain frequency and this is a very difficult point to change even with the advances of new technologies. However, it is still quite useful as it

Table 1
Typical diagnostics performed on Coriolis Flow Meters.

d) Time Transit Ultrasonic Flow Meter: Ultrasonic flow meters do have a large variety of diagnostic parameters. The latest generation of meters is even equipped with ultrasonic sensors that are not used for flow measurement at all, being solely used to generate diagnostic information ensuring measurement reliability. These diagnostics are important because this technology is greatly affected by process conditions such as fouling, severe flow profile distortions and high level of ultrasonic noise in an early stage and corrective actions may be taken long before significant measurement errors occur [44,45]. Table 2 presents a summary of the main available diagnoses for this meter.

Meter Verification	Diagnostics
measurement of the coil circuit resistance	coil circuit performance
measurement of magnetic field strength	magnetic behavior of the sensor
measurement of electrode circuit resistance	electrode circuit performance
measurement of tube temperature	vibration tube performance
measurement of amplification gain levels	basic electronics performance
measurement of erosion and corrosion	verification of tube stiffness

Table 2
Typical diagnostics performed on Time Transit Ultrasonic Flow Meter.

e) Orifice plate: this is a measurement based on a mechanical principle - the pressure drop after the flow is reduced in the sectional area. Typically, diagnostics that may be implemented are those addressed for pressure and temperature transmitters.
f) Turbines/positive displacement: these are purely mechanical equipment with an electric pickup. Virtually impracticable the possibility of incorporating sophisticated diagnostics and basically limited to observe the raw signal output from a turbine meter amplifier and detect faults by comparing to a baseline waveform. For this reason, these technologies are difficult to incorporate with gains in the proposed architecture.

Meter Verification	Diagnostics
measurement of signal-to-noise ratio per sensor path	sensor performance
measurement of gain per sensor path	sensor performance
pulse acceptance of each individual path	sensor performance
speed of sound of each individual path	process condition check
velocity of each individual path	process condition check

allows the calibration decision to be made ahead of schedule when the meter deviates too much from factory conditions.

3.3.3.3. Flow Calculation Verification. This functionality allows flow computer calculations to be verified in real-time to ensure allows for another that no additional uncertainty is introduced to the system. It uses industry-standard algorithms to calculate and verify the flow of hydrocarbon gases or liquids using the electronic flow measurement (EFM) configuration adjusted, and primary and secondary inputs. The application reduces the uncertainty by alerting the operator before issues cause mismeasurement (Daniel, 2016).

3.3.3.4. Data Validation. Data errors may cause big problems in any metering station system. Process measurements may be corrupted by power supply fluctuations, network transmission and signal conversion noise, analog input filtering, changes in ambient conditions, malfunctioning instruments and meters, miscalibration, and the wear and corrosion of sensors, among other factors. This functionality helps detect, analyze, solve, and avoid the data acquisition problems that may rob the metering station performance by error detection techniques.

3.3.3.5. Uncertainty calculation. Live system uncertainty gives real-time visibility to the system performance, based on operating conditions and diagnostics. Uncertainty is calculated according to ISO/IEC GUIDE 98–3:2008 (ISO, 2008) and combines the live operating conditions alongside any bias detected by the condition-based monitoring and verification components. It allows the metrology experts to prioritize issues across multiple sites, driving efficiency to the team. The pursuit of flow metering device and secondary instruments uncertainty and its influence on the measured quantities are fundamental to the risk management of measuring stations and having this control live is a major improvement in station performance [47].

3.3.3.6. Measurement Error Control. Control, logging and simulations of impact of measurement station errors are part of the functionality required for traceability and auditing purposes. The regulations and standards accept the measurement correction based on predicted values when abnormal data is detected but for this it is necessary a robust system to track the causes and changes considered.

3.3.3.7. Maintenance History. The recording of all interventions performed on instruments, meters and analyzers is essential to ensure operation traceability of measuring stations. History of calibrations, corrective, preventive and proactive maintenance routines, tests and procedures are key sources of information for data reconciliation and error control.

As mentioned by Skålvik [48]; the mean time between failures, the mean time to repair and the metering station uncertainties are important parameters that must be quantified to control the total risk of operations. Thus, it is essential to have a history of interventions to apply risk reduction algorithms.

3.3.3.8. Mobility. Mobility is part of Fourth Industrial Revolution initiative to introduce a suite of apps that, along with new cloud functionalities, will help existing solutions to deliver better business efficiencies. Historically, industrial operators learned how to do things by gaining knowledge about process and machine operations from mentors and supervisors through years of on-the-job training. But, as industry has advanced with far more levels of hardware and software technologies, today's operator has become a multi-faceted, data-empowered, critical facet of the production process who is able to leverage data from many sources, make objective decisions based on complex, real-time information, and understand the system to solve problems.

As a result of this change, the next step involves mobilizing the data that drives the next generation of operator. Equipping this operator with a mobile device takes operations to the next level. Mobile technology can send real-time data to an operator based on their role that is also pinpointed to their location based on geo-technology. Operators responding to an alarm no longer must make independent decisions based solely on training - they may review electronic standard operating procedures on their smartphones. Mobility changes all of that. Mobile software can parse the information from your automation system and present it by dashboards highlighting just the key performance indicators that apply to them [49].

Mobile technology allows the operator to take advantage of his smartphone and delivers real-time data from devices within his vicinity. This points out that this kind of situational awareness technology combines criticality of situation with location and proximity to ensure that the user has the information they need, saving time and cost [50].

4. Conclusion

When it comes to achieving operational excellence, information is power, but only if it is the right information in the right hands. Thanks to the Industrial Internet of Things (I2oT) basis of the Fourth Industrial Revolution, modern-day metering stations can generate more information than ever before but often lack the analytics and expertise needed to transform such information into truly actionable data – data that operators may use to dramatically improve the safety, reliability and efficiency of assets, people and processes.

The current version of industry evolution extends the power of automation beyond process control to the entire enterprise to enable the best performance. For this it is important to fulfill the critical needs of the company: real-time operating data across the business, secure transport of that data where it is needed, robust and scalable software applications to convert that data into actionable insights, and the domain expertise to make decisions and drive outcomes.

This paper summarizes the key technologies that are already available in the industry and may be applied to a fiscal measurement system through changes in traditional architectures. Despite being an extremely regulated application due to the high added value of the transferred products, reliability is a critical success factor in this market and reduction of measurement risks is necessary to it. The tools made available by the fourth industrial revolution bring fiscal measurement to a new performance level.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] O. Sylthe, T. Brewer, The Impact of Digitalization on Offshore Operations, Offshore Technology Conference, Houston, 2018, https://doi.org/10.4043/28689-MS. Texas, USA.
[2] World Economic Forum/Accenture, Digital Transformation Initiative - Oil and Gas Industry, 2017. Available: http://reports.weforum.org/digital-transformation. (Accessed 11 November 2019).
[3] D. Kolberg, D. Zuhlke, Lean automation enabled by industry 4.0 technologies, IFAC PapersOnLine 48 (3) (2015) 1870–1875, https://doi.org/10.1016/j.ifacol.2015.06.359.
[4] D. Rudroff, Custody transfer: the value of good measurement and the search for the truth, Pipeline Gas J. 236 (7) (2009).
[5] Emerson Process, Fiscal Measurement – Natural Gas, White Paper, FSG-WP-0012, 2014.
[6] ANP (Agência Nacional de Petróleo), Portaria Conjunta ANP/INMETRO Nº 001, 2013.
[7] M. Damasceno, J. Medeiros, N. Penha Silva Junior, R. Felipe, R. Santos Felipe, G. Medeiros, Influence of the temperature, pressure and viscosity on the oil measurement with turbine type measurers, Braz. Arch. Biol. Technol. 49 (2006), https://doi.org/10.1590/S1516-89132006000200011.
[8] API (American Petroleum Institute), STD 2540 Standard Petoleum Measurement Tables, 1956.
[9] ISO (International Standards Organization), ISO 4267-2:1988 Petroleum and Liquid Petroleum Products — Calculation of Oil Quantities — Part 2, Dynamic Measurement, 1988.
[10] API (American Petroleum Institute), API MPMS 21 : Manual of Petroleum Measurement Standards Chapter 21, 2000.
[11] ISO (International Standards Organization), 17089-2:2012 (en) Measurement of Fluid Flow in Closed Conduits – Ultrasonic Meters for Gas — Part 2: Meters for Industrial Applications, 2012.
[12] ISO (International Standards Organization), ISO 10790:2015 Measurement of Fluid Flow in Closed Conduits — Guidance to the Selection, Installation and Use of Coriolis Flowmeters (Mass Flow, Density and Volume Flow Measurements), 2015.
[13] ISO (International Standards Organization), ISO 9951:1993 Measurement of Gas Flow in Closed Conduits — Turbine Meters, 1993.
[14] ISO (International Standards Organization), ISO 5167-6:2019(en) Measurement of Fluid Flow by Means of Pressure Differential Devices Inserted in Circular Cross-Section Conduits Running Full — Part 6: Wedge Meters, 2019.
[15] AGA (American Gas Association), AGA Report No. 9 - Measurement of Gas by Multipath Ultrasonic Meters, 2016.
[16] AGA (American Gas Association), AGA Report No. 3, Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids - Concentric, Square-Edged Orifice Meters, Specifications and Installation Requirements, Includes Errata, 2017.
[17] AGA (American Gas Association), AGA Report No. 11, Measurement of Natural Gas by Coriolis Meter, 2011.
[18] AGA (American Gas Association), AGA Report No. 7, Measurement of Natural Gas by Turbine Meter, 2006.
[19] ABNT (Associação Braileira de Normas Técnicas), NBR 14978:2003 Electronic Gas Measurement - Flow Computers, 2003.
[20] Emerson Process, Guide Proving & Calibration for Liquid Hydrocarbons, FSG BRO0014, rev A, 2015.

[21] ISO (International Standards Organization), ISO 10012:2003 Measurement Management Systems — Requirements for Measurement Processes and Measuring Equipment, 2003.
[22] H. Kagermann, W. Lukas, W. Wahlster, Industrie 4.0: mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution, VDI Nachr. 13 (2011).
[23] GTAI (Germany Trade and InvestSmart), Industrie 4.0 Smart Manufacturing for the Future, GTAI, 2014.
[24] C. Roser, Faster, Better, Cheaper in the History of Manufacturing: from the Stone Age, 2016.
[25] H. Lasi, H. Fettke, T. Feld Kemper, M. Hoffmann, Industrie 4.0: bedarfssog und Technologiedruck als Treiber der vierten industriellen Revolution, Wirtschaftsinformatik 56 (4) (2014) 261–264, https://doi.org/10.1007/s11576-014-0424-4.2014.
[26] R. Geissbauer, J. Vedso, S. Schrauf, Global Industry 4.0 Survey - Industry 4.0, Building the Digital, 2016, 2016.
[27] M. Mamad, Challenges and benefits of industry 4.0: an overview, Int. J. Supply Oper. Manag. 5 (3) (2018) 256–265.
[28] L. Thames, D. Schaefer, Industry 4.0: an overview of key benefits, technologies, and challenges, in: Book: Cybersecurity for Industry 4.0: Analysis for Design and Manufacturing, Springer Publishing, 2017, https://doi.org/10.1007/978-3-319-50660-9_1.
[29] PWC (PricewaterhouseCoopers), 2016 Global Industry 4.0 Survey - Industry 4.0: Building the Digital Enterprise, PWC, London, 2016.
[30] H. Lu, L. Guob, M. Azimia, K. Huangc, Oil and Gas 4.0 era: a systematic review and outlook, Comput. Ind. 111 (2019) 68–90, doi.org/10.1016/j.compind.2019.06.007.
[31] G. Kane, D. Palmer, A.N. Phillips, D. Kiron, N. Buckley, Strategy, Not Technology, Drives Digital Transformation, MIT Sloan Management Review and Deloitte University Press, 2015.
[32] R. Beckwith, Apps and the digital oil field, J. Petrol. Technol. 64 (7) (2012) 40–46, https://doi.org/10.2118/0712-0040-JPT.
[33] D. Yergin, The Quest and the Prize: the Epic Quest for Oil, Money and Power, Simon & Schuster, 2011, ISBN 9780671502485.
[34] J.H. Yang, M.X. Qiu, H.N. Hao, X. Zhao, X.X. Guo, Intelligence–Oil and gas industrial development trend, Oil Forum 35 (6) (2016) 36–42, https://doi.org/10.3969/j.issn.1002-302x.2016.06.008.
[35] Emerson Process, AMS Device Manager Product Data Sheet, 2018.
[36] N.E. Yokogawa, 107 Field Diagnostics User's Manual, IM 01R01A15-01EN, 2016.
[37] S. Bennet, A Brief History of Automatic Control. Control Systems Magazine, Institute Of Electrical And Electronics Engineers (IEEE), 1996.
[38] C. Barateiro, L. Campagnac, J. Farias Filho, Um Breve Histórico da Automação no Controle de Process Industriais, Contr. Instrum. 153 (2009) 62–68. ISSN: 0101.0794.
[39] T. Blevins, K. Jensen, Communication Technologies Throttling Valve Control, 2016. Available: https://www.emerson.com/documents/automation/article-choosing-right-communication-protocol-fisher-en-178770.pdf. (Accessed 11 November 2019).
[40] M. Migliore, Integrated Operations for Production Efficiency, Flow Control, 2014.
[41] C. Matt, T. Hess, A. Benlian, Digital transformation strategies, Bus Inf Syst Eng 57 (5) (2015) 339–343, https://doi.org/10.1007/s12599-015-0401-5.
[42] J. Berge, Intelligent Process and Device Diagnostics, A&D India, 2011.
[43] Rosemount Inc, Smart Meter Verification, Rosemount, Boulder, 2013.
[44] M. Vermeulen, J. Drenthen, H. Hollander, Understanding Diagnostic and Expert Sysems in Ultrasonic Flow Meters, Krohne Oil & Gas, 2016.
[45] W. Kang, S. Lee, S. Leeb, Y. Hab, S. Jung, Effect of ultrasonic noise generated by pressure control valves on ultrasonic gas flowmeters, Flow Meas. Instrum. 60 (2018) 95–104, https://doi.org/10.1016/j.flowmeasinst.2018.02.023.
[46] N. Pashnina, Determination of optimal calibration intervals by balancing financial exposure against measurement costs, Flow Meas. Instrum. 60 (2018) 115–123, https://doi.org/10.1016/j.flowmeasinst.2018.02.001.
[47] A. Bekraouia, A. Hadjadjc, A. Benmounaha, M. Oulhadjd, Uncertainty study of fiscal orifice meter used in a gas Algerian field, Flow Meas. Instrum. 66 (2019) 200–208, https://doi.org/10.1016/j.flowmeasinst.2019.01.020.
[48] A. Skålvik, R. Bjørk, K. Frøysa, C. Camilla Sætre, Risk-cost-benefit analysis of custody oil metering stations, Flow Meas. Instrum. 59 (2018) 201–210, https://doi.org/10.1016/j.flowmeasinst.2018.01.001.
[49] J. Dymond, Integrated Operations Command Centers. 2016 Offshore Technology Conference, 2016.
[50] D. Greenfield, Reasons to Prepare for Industrial Mobility, Automation Word, Chicago, 2014.

Carlos Barateiro holds a BS in Mechanical Engineering at University of Campinas (1985), an MS in Civil Engineering at Fluminense Federal University (2011) and doctorate in Production Engineering also at Fluminense Federal University (2014). Technical Consultant with experience in the areas of process control, measurement, instrumentation, automation and EPC projects and adjunct Professor and Coordinator of Civil, Mechanical and Chemical Engineering Courses at Estácio de Sá University, Macaé.

Claudio Makarovsky holds an MBA degree in Corporate Finance by FGV/Babson College and is an MS student on Management Systems at the Fluminense Federal University, with a BS chemical engineering at Oswaldo Cruz Chemical College. Claudio is Director of Manufacturing Industries at Microsoft with experience in digitalization, process control and industrial instrumentation.

José Rodrigues De Farias Filho holds a BS in Civil Engineering at University of Fortaleza (1988), Specialist degree in Occupational Safety Engineering at Fluminense Federal University (1998), MS in Civil Engineering at Fluminense Federal University (1992) and doctorate in Production Engineering also at Fluminense Federal University (1996). Farias is currently Associate Professor IV at Fluminense Federal University with experience in Production Engineering, with emphasis on Work Processes, acting mainly on the following areas: Industrial Competitiveness, Project Management; Complex Enterprises, Total Quality, Production Administration, Strategy and Organizations and Organizational Changes.