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Use of data reconciliation: A strategy for improving the accuracy in gas flow measurements

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ABSTRACT

The economic impact that results from the reliability of measurements associated with natural gas (flow rate and fluid properties) and caveats related to custody transfer contracts demands vigilant control of the net balance in the delivery systems. The methodology for data reconciliation has proved to be an effective tool to reduce uncertainties associated with measurements used in the calculations of the net balance in distribution networks such as gas pipelines. The intrinsic nature of the calculation algorithm, founded on the redundancy of measurements, qualifies the technique for increasing confidence in the measurement, thus reducing the individual uncertainty associated with each physical magnitude capable of affecting the measurement.

This Brazilian gas pipeline study discusses the adequacy of the data reconciliation technique. The proposed technique proves to be very effective as it generates lower uncertainties than those obtained by traditional techniques: the level of 1% associated with the accountability of the unaccounted for gas was reduced to less than 0.3% when the data reconciliation methodology was used.

1. Introduction

Although oil had been avoided by ancient civilizations— *a heavy waste that exhibits strong and viscous odor*—, early records confirm that natural gas was discovered in Iran between 6000 and 2000 BC and that the Persians had already used it to record the "eternal fire" symbolizing the adoration of their profound religious convictions. Since 900 BC, natural gas has been extracted in China with the help of bamboo poles introduced into wells 1000 m deep. However, it was only in the year 211 BC that the raw material was used to accelerate the drying of salt stones.

Motivating multimillionaire contracts for their commercialization, international technical cooperation and even wars between nations that dispute their exploitation, oil and natural gas are perceived by society in general as strategic energy inputs. Their commercialization, whether for lubrication or energy fuels, requires rigorous quality controls that impose challenges to ensure transport with safety and environmental care. Distinct in their composition, their transport and use require special care, specific operating and handling techniques, imposing challenges on their exploratory phases (Amui, 2010).

More specifically, as far as natural gas is concerned, diverse factors contribute to elect it as an attractive alternative less polluting energy: the growth in demand for energy; opportunities created by the competitive international energy market, and the high costs associated with the production and transport of oil. Its use has also been disregarded by the consciousness that oil consumption to generate electricity uncontestably constitutes a relevant portion of the consumer's ecological footprint.

Experience has shown that the control of measurements —sensitive to different measuring techniques— is not a simple task. The use of inadequate measuring methods, either for non-compliance with critical length established in measurement norms, incorrect installation and lack of calibration of the equipment are among factors that severely may compromise the quality of measurement. The reliability of measurement results depends on strict requirements related to the installation of the measurement system and characteristics of the flow to be measured (level of turbulence, velocity profiles upstream of the meter, variations in fluid properties). Inaccuracies associated with measurements certainly compromise the confidence in the audit processes associated with the transfer of custody, particularly in

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the case of volume flow measurement in gas pipelines. From the economic point of view, inaccuracies in measurements can reach intolerable amounts as easily estimated when one considers that enormous volumes of gas are transported (about 100 million cubic meters of natural gas are transported daily in Brazilian pipelines). The accuracy of measurement is dependent on the measuring technique, the capacity of the person responsible for the supervision, the calibration of the meter and the frequency of the measuring process. When operated correctly, ultrasonic and orifice plate meters are able to provide acceptable levels of accuracy.

The growing trend for the use of cleaner fossil fuels is the result of the global consciousness that any alternative utilized in the generation of electricity, one way or another, has a detrimental impact on the environment. From this perspective, natural gas should replace other fossil fuels in the energy matrix as its combustion generates lower levels of pollutant gas emissions and residues. However, the rational use of natural gas depends on an efficient process to make its safe and economic distribution viable. Despite the advances in gas pipelines (increasingly complex and operated in compliance with modern legislation founded on the concepts of transport logistics and appropriate regulation), the adequate bookkeeping for the so-called unaccounted for gas requires precise measurements whose accuracy and control of associated uncertainties still remain as metrological challenges to be overcome (Arpino, 2014). Orifice plate, turbine or ultrasound technology flowmeters continue to be the techniques most employed for measurements of gas flow, accepted by regulators as an appropriate alternative for custody transfer. The inherent properties of natural gas (e.g. low density and high volatility of its components) facilitate leaks and losses of volume that could result in serious economic impacts (on the order of billions of dollars) for the investors. This is the reason why the control of gas transported (conservation of mass) is so critical. Oliveira and Aguiar (2009) and Bagajewicz (2003) showed that the utilization of the technique called *Data Reconciliation* (DR) —the use of measurement redundancy to reduce the uncertainty associated with measurements— made an important contribution to the metrological control of unaccounted for gas in gas pipelines. Here, redundancy is the replication of critical components of a system with the intention of increasing its reliability.

Whenever the laws of conservation are violated, random or systematic errors are introduced to compromise the process of measurement (Narasimhan and Jordache, 2000; Özyurt and Pike, 2004). In this context, the technique of data reconciliation —an approach based on the statistical tool that considers the restrictions imposed on the process— does in fact improve confidence when measurements are analyzed on a global basis. Data reconciliation incorporates redundant information to compensate and eliminate random errors, thereby reducing uncertainties associated with measurement. Considering the heteroscedastic behavior associated with measurements to be reconciled, this approach deals with multivariate nonparametric locally weighted least squares regression (Alhaj-Dibo et al., 2008; Menéndez et al., 1998). The data reconciliation technique enables several redundant measurements to reconcile experimental data in one single value, yielding the so-called reconciled data. Oliveira and Aguiar (2009) have shown in previous work that controlled redundancy leads to lower levels of uncertainty when compared to what it would have been obtained in the absence of redundant data. Data reconciliation is based on the conjecture that if a gross error resulting from an apparent measurement bias is present in some measurement or if a noteworthy process leak was not accounted for in the model constraints; reconciled data may be very inaccurate.

Implementation of the data reconciliation technique requires that:

- The reference model be defined based on the mathematical premise that it is perfect, with no systematic errors. In other words, random errors are usually distributed and independent (Mansour and Ellis, 2008). An "objective function F_{ob}" is utilized to evaluate the resulting difference between the data produced by the model and the experimental data;
- The formulated "objective function F_{ob}" be optimized by making use of a multivariate distribution that models this routine, whose results are expressed based on weightings attributed to the experimental measurements of dispersion. In this work, the use of uncertainties associated with the measurements to support the results is proposed. In this stage it is necessary to minimize or maximize the probability of meeting experimental measures;
- The parameters be evaluated. Ramamurthi et al. (1993) suggested the evaluation by using the maximum likelihood estimation (MLE).

The data reconciliation approach is then applied to calculate the reconciled values and their associated uncertainty bands, therefore allowing detection and exclusion of the related gross errors. Whenever the uncertainty band falls within an unacceptable range, the experimental data will no longer be considered as the final results but rather used to calculate the reconciliated values, ensuring that there will be no partial overlap of their uncertainty bands.

The objective of this work is to apply the approach of data reconciliation to approve the analysis of the net balance in gas pipelines. Brazilian gas pipelines utilize the tolerance criteria of 1% as the social indicator to evaluate the quantity of unaccounted for gas. On making use of the data reconciliation approach, it is expected that with this indicator incorporated the index could achieve the international standard of 0.3%.

2. Methodology

Measuring loops and inherent inaccuracies associated with computer data processing and its storage usually contribute to the relatively high uncertainties and unacceptable tolerances associated with measurement control in pipelines. Because all product transactions associated with gas-pipeline network depend on flow-rate measurements, control of the associated uncertainties is absolutely critical. Assessment of the overall performance of a pipeline system requires control and monitoring of the energy and mass balances and a rigorous evaluation of potential leakages. Besides the economic impact associated with leaks, their control prevents possible environmental damage and increases the availability and maintainability of the pipeline network. Generally speaking, the operation of a gas-pipeline network is evaluated and controlled on the basis of the operating data (e.g. volume flow rate; internal pressure and gas temperature) allowing that pressure drop inside the pipeline and compressibility of the natural gas be calculated.

2.1. Data reconciliation: the concept

Data reconciliation and gross error detection is thoroughly discussed by Narasimhan and Jordache (2000). According to the authors, both are achieved by exploiting the redundancy property of measurements. The technique improves the accuracy of process data by adjusting the measured values to satisfy process constraints while the amount of adjustment made to the measurements is minimized whenever the random errors in the measurements are