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Conformity assessment applied to custody transfer in the oil and gas industry: A brief review

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ABSTRACT
In the oil and gas industry, measurements should be highly reliable to avoid unnecessary conflicts in business relationships that could bring to significant financial losses for the parties involved. This study highlights the importance of using the measurement uncertainty tool for conformity assessment purposes in the oil and gas industry. Some methodological approaches and considerations within the context of conformity assessment were presented, such as global and specific risks, producer and consumer risks, and the use of the guard band tool. Based on a literature review, it was observed that measurement uncertainty is widely applied in conformity assessment in various industries, such as pharmaceuticals, materials engineering, production, and quality engineering, as well as laboratory analysis. However, it was found that none of the reviewed studies proposed or used the measurement uncertainty tool to minimize the risk of false conformity assessments in the transfer of petroleum and its derivatives by producers and consumers. Therefore, it is considered that this tool can also be an excellent alternative to minimize the risks of inadequate compliance during custody transfer operations in the oil and gas industry. As a main contribution, we sought to highlight the relevance of the guard bands tool as a methodological resource in the treatment of data from oil and gas industry processes that require conformity assessment. Finally, it was concluded that the implementation of this approach can reduce risks and help in decision making related to compliance assessments, ultimately avoiding significant losses for the parties involved.

Section: RESEARCH PAPER

Keywords: guard bands; conformity assessment; measurement uncertainty; risk minimization; transfer of custody

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1. INTRODUCTION

The oil and gas industry represents a significant portion of the global economy, and its development is substantial. Therefore, a policy of control and regulation in this sector is essential. Accurate measurements of the volumes of oil, natural gas, and derivatives produced by companies are crucial for result reliability and decision making [1].

Oil and its derivatives can be transported under the control of another company at any point, from production to final consumption, through a process known as custody transfer [2]. The measurements carried out in this procedure are essential to assess the degree of compliance between producers and consumers, to avoid unnecessary conflicts in commercial relationships that could lead to significant financial losses for the parties involved [3].

For these reasons, the Brazilian Technical Measurement Regulation was developed to enable greater control of production companies operating in this sector, ensuring improved production, minimising losses, and providing more effective management and decision making. Through this document, the Brazilian Agency of Petroleum, Natural Gas, and Biofuels (ANP) and the Brazilian Institute of Metrology, Quality, and Technology (INMETRO) jointly standardised the procedures for monitoring the production of oil and natural gas, presenting the minimum requirements and monitoring conditions for custody transfers, aiming to ensure better result reliability [4].

Typically, in these operations, large volumes are transported, with average daily transfers reaching around US$ 6 million, generating an annual revenue of US$ 2.2 billion. Assuming a hypothesis that there might be an error of 0.25 % in the measurements conducted, both the producer and the consumer could experience a profit or loss of approximately US$ 15,000 per day or US$ 5.5 million per year [5]. For that reason, the economic impacts resulting from these small measurement errors prompt companies in the sector to focus on continuously improving their measurement systems, prioritising compliance with contractual requirements to meet the expectations of both parties involved [3], [6].

Consequently, if the measurement results are close to the tolerance limits imposed by specifications, the conflict can be high, with the risks of false acceptance or rejection reaching up to 50 %, leading to significant disputes. Hence, the results obtained by both parties should fall within certain ranges of acceptance to be statistically compatible [3], [7].

To ensure that the results can be accepted or rejected within an appropriate level of confidence, guard bands are employed for measurement uncertainty [7], [8]. These bands ensure that all relevant sources of uncertainty are considered in the evaluation of conformity, allowing the measurement results to be as reliable as possible. As a result, it becomes possible to make informed decisions based on the obtained results [9]-[11].

Accordingly, the guard bands tool, which uses measurement uncertainty for conformity assessment in proposing acceptance limits, proves to be an excellent methodology for evaluating the "risk of accepting a non-conforming item", directly affecting the consumer, and the "risk of rejecting a conforming item", when the producer incurs the loss [7], [10], [12].

This study aims to make a brief review, filling a gap in the literature, about the applicability of this approach in reducing risks and assisting in decision making related to conformity assessment in a quantitative way in the oil and gas industry custody transfers, avoiding significant losses among the parties involved.

2. METHODOLOGY

2.1. Specific global risks of false conformity/non-conformity assessment

In the study conducted by E. C. Oliveira and Lourenço [13], the conformity assessment and false conformity risks were estimated by means of the Monte Carlo method (MCM), using a spreadsheet in MS-Excel, with 50 thousand simulated values for each parameter through a pseudorandom number generator. Then, the producer (R_p) and consumer (R_c) specific risks were calculated with the help of the lower limit (LI) and upper limit (LS), as shown in equations (1) and (2), respectively:

$$R_\mathrm{c} = \frac{n^{\text{o}}\, y;\,]LI; LS[}{n^{\text{o}}\, total} \tag{1}$$

$$R_\mathrm{p} = \frac{n^{\text{o}}\, y;\, [LI; LS]}{n^{\text{o}}\, total} \,. \tag{2}$$

The study mentioned [13] also highlighted the importance of the overall consumer risk and the overall producer risk, when a measured value was within the acceptance range, but the value of Y was outside the tolerance range. The calculation of the overall risk consists of adding up all the specific risks at each possible value and multiplying them by their probability of occurrence. For continuous distributions, the probability of occurrence is replaced by the height of the curve describing the process distribution, and the sum becomes an integration over both process and measurement distributions, so the overall consumer risk can be calculated as:

$$R_\mathrm{c} = \int_{\tilde{C}} \int_{A} g_o(\eta)\; h(\eta_m|\eta)\; \mathrm{d}\eta_m\, \mathrm{d}\eta \,. \tag{3}$$

However, when a measurement outside the acceptance range occurs, but the value of Y is within the tolerance range, the overall risk of the producer can be computed as:

$$R_\mathrm{p} = \int_{C} \int_{\tilde{A}} g_o(\eta)\; h(\eta_m|\eta)\; \mathrm{d}\eta_m\, \mathrm{d}\eta \,. \tag{4}$$

An important difference between specific and global risks is that global risk strongly depends on the process distribution, while specific risk does not. In a further study [14], the Monte Carlo method was also employed to assess compliance in flow measurements in high-pressure gas systems, allowing a comparison between the legal tolerances and the acceptance criteria. The study assessed that it is possible to directly apply Monte Carlo methods (MCM) to carry out conformity assessment. This is because the Monte Carlo process generates a cumulative distribution, which can be directly compared with the (legal) tolerances. The major advantage of using MCM is that it is not necessary to know the distribution type.

2.2. Producer and consumer risk

Producer and consumer risk are terms used in studies [15], [16] in production process management and are applicable to many compliance situations. As shown in Figure 1, "producer risk" refers to the probability of rejecting acceptable products incorrectly, resulting in unnecessary costs to the producer. On the other hand, "consumer risk" is the probability of accepting non-conforming products incorrectly, increasing the chance of the consumer being harmed.

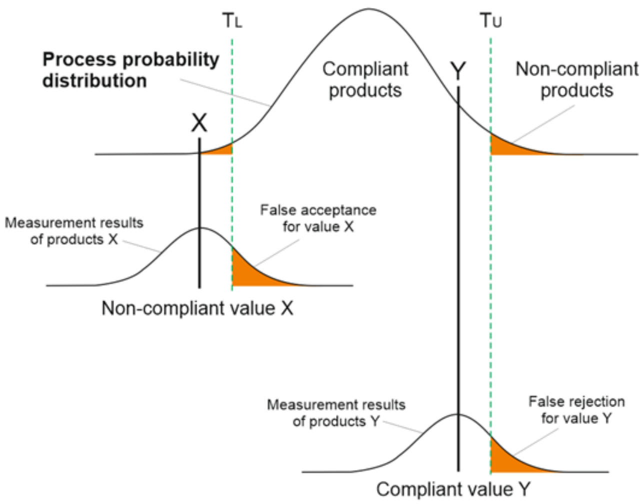

Figure 1. Producer and consumer risk of false conformity/non-conformity assessment [7].

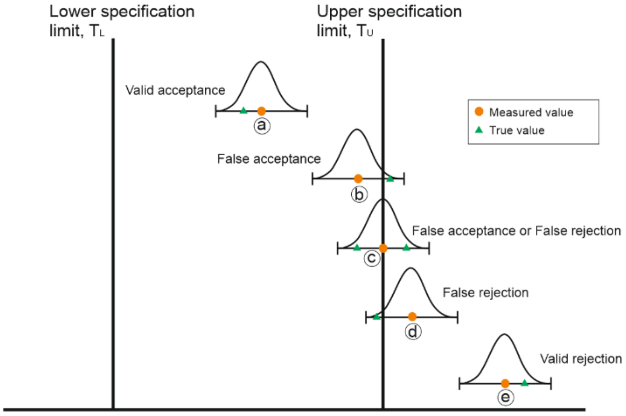

Figure 2. Conformity assessment using measurement uncertainty information [9], [17].

According to Figure 1, TL and Tu are the lower and upper allowable limits for a measured characteristic, respectively, where it is assumed that these limits are also set as acceptance limits, without any safety margin. A product between TL and Tu is conforming, while a product outside these limits is non-conforming. The value at X in the figure is nonconforming and at Y is conforming. The proportion (shaded) of these results that falls within the acceptance limits can be called the false acceptance rate for a product at X, while the part of Y that falls outside the acceptance limits represents the producer's risk, because the Y value is within the allowable limits, but there is a probability of results that fall outside the acceptance limits [7], [8].

More clearly and objectively, Figure 2 shows all the possibilities of false acceptance and false rejection risks, with a greater emphasis on hypothesis (c) where the risk of a false acceptance/rejection has a probability of 50 % for both cases [7], [9].

Broadly speaking, this methodology plays an important role in the management of production and quality processes, because it helps in the analysis of the trade-offs between the costs of rejecting acceptable products and the risks involved in accepting non-conforming products, resulting in significant losses between the parties [7], [15].

2.3. Guard bands

In general, the papers [15], [16], [18] employ the guard band methodology to mitigate the probability of making a wrong decision regarding compliance. Essentially, it is a safety element incorporated into the measurement decision process by adding a safety margin to the acceptance limit above the limit set by the specification/tolerance, as shown in Figure 3, ensuring less risk of a false conformity assessment to the producer [19].

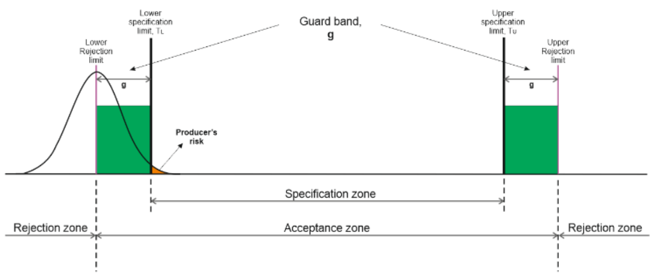

Figure 3. The use of guard bands minimizes the producer's risk, and high confidence in rejection [18], [20].

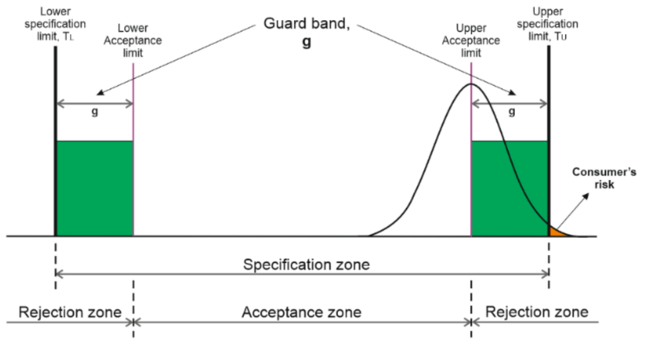

Figure 4. The use of guard bands to minimize consumer risk, and high confidence in acceptance [18], [20].

Generally, the guard band parameter (g) is expressed as a multiple of the standard uncertainty (u). In the case where the distribution of the values of the measurand assumes an approximately normal form, a factor of $1.64 \cdot u$ is related to a probability α of 5 %, while a factor of $2.33 \cdot u$ is associated with an α of 1 % [7].

However, it is possible to exercise control over these probabilities and reduce them through the use of acceptance intervals that differ from tolerance intervals [8]. By establishing the acceptance interval within the tolerance interval (Figure 4), the probability of incorrect acceptance is reduced, which in turn minimises the risk imposed on the consumer [7].

Consequently, the reduction in these probabilities is directly linked to the width of the guard band g. However, it is worth noting that by reducing the risk to the producer, there is an increase in the risk to the consumer and vice versa. Therefore, when establishing decision rules, considering the risks associated with wrong decisions is essential [7], [9].

3. A BRIEF LITERATURE REVIEW

3.1. Custody transfer in the oil and gas industry

Generally speaking, as far as oil, gas, and oil products are concerned, four different types of measurement are usually defined: fiscal measurement, appropriation measurement, operational measurement, and custody transfer measurement [4].

The Brazilian joint resolution ANP / INMETRO n° 01 [4], concerning measurement of custody transfer, establishes that the measurement of the point at which the ownership of oil or gas is transferred from the seller to the buyer, in accordance with the obligations agreed upon in the contract, shall primarily follow the tax requirements. Thus, payment is based on the amount of fluids transferred, and therefore, it is an operation in which accuracy is fundamental, since a minimum error in the measurement, as these are transfers with large volumes, can quickly lead to harmful financial exposure in the transactions [3], [4].

At this purpose, selecting the transfer method with high reliability is considered paramount to avoid economic losses. It is also worth noting, that custody transfer measurement provides quantitative and qualitative information that is passed to the physical and fiscal documentation of an oil and gas ownership change [21]. Therefore, it can be inferred that accurate and reliable measurement of oil and gas transfer in custody is a key factor for economic development, consumer protection, and fair trade [2].

In general, custody transfer in the oil and gas area can be exemplified in different ways. This transfer usually occurs between different companies involved in the supply chain, such as refineries, distribution terminals, and carriers, among others [22]. Hence, custody transfer has been considered one of the most important processes in the oil and gas industry, as it allows different companies involved in the supply chain to transfer the physical and legal ownership of oil, natural gas, or derivative products, ensuring the safety and reliability of transactions [2], [4], [5].

3.2. Conformity assessment

From a metrological point of view, the measurement results must be as reliable as possible, since producers and consumers need to assess the conformity of these operations to minimise disputes and misunderstandings, considering that the values involved are very significant [2], [5].

For these measurement systems, there are some accuracy classes according to products and fields of application that are based on the international recommendation of the International Organisation of Legal Metrology (OIML); for example, the maximum allowable measurement uncertainty for operations involving custody transfer in line measurement systems is 0.3 % [23]. On the other hand, there is no fixed uncertainty in static measurement systems, and these values depend directly on the tank tonnage tables, the transferred volume, the fluid density, and the temperature at the time of the measurements [6].

Thus, at each stage, volume or mass measurements are taken by producers and consumers, and the respective uncertainties are calculated according to the measurement systems used. As mentioned before, conflicts arising from transfers between producer and consumer can be significant when the measurement result is close to the specified limit, leading to false assumptions or risks of false acceptance and rejection [13], [24].

For this reason, the results statistically should fall within a certain acceptance range to be compatible [3], [25]. Therefore, the reliability of measurement results is essential for producers and consumers to assess the conformity of operations. As a result, determining measurement uncertainty and establishing appropriate acceptance intervals are critical to minimise the risks of false assumptions and ensure mutual trust [3], [7].

3.3. Measurement uncertainty in conformity assessment

In general, measurement uncertainty is an important factor in different sectors of society that should be considered when assessing the conformity of a product or service. This is because measurement uncertainty represents a confidence interval associated with measurements taken to determine whether a product or service conforms to established specifications. If measurement uncertainty is not taken into account, there can be a mistaken assessment of conformity, leading to the false conclusion that a product or service meets requirements when in fact it does not. Therefore, proper consideration of measurement uncertainty is critical to ensure that conformity assessments are accurate and reliable [8], [9].

Thus, this concept is fundamental to several areas of study, ensuring the reliability of the results obtained in measurement and testing processes. Its application is broad, covering sectors such as industry, research laboratories, chemical analysis, and others. In particular, as for the field of metrology, Williams [26] presented a review of the EURACHEM/CITAC guide, and discussed the key principles and concepts presented in the guide. Examples and practical cases were presented to illustrate the application of the principles in conformity assessment. Additionally, one could highlight a similar work [27] that also presented a review (of the literature) and demonstrated practical examples of the application of measurement uncertainty in conformity assessment in legal metrology and trade, proving that conformity assessment was a critical process to ensure the quality and reliability of marketed products and services.

For the laboratory analysis industry, Weitzel and Johnson [25] highlighted the importance of measurement uncertainty as a measure of suitability for measurement. They addressed how measurement uncertainty could be used to determine the suitability of a measurement result for a specific purpose, considering the tolerance requirements of the process. In addition, the paper discussed how measurement uncertainty could be used to set acceptance limits for measurement results in critical situations, ensuring the reliability and adequacy of measurement results. In another study [28], the concept of measurement uncertainty was used to assess risk in the analysis of water from a Brazilian river, using non-parametric tests and guard bands to attest to the compliance of some water properties with Brazilian environmental regulations.

Besides, in the field of earth and environmental sciences, another research [29] discussed the importance of uncertainty estimation in the field of conformity assessment. The authors explain the concept of measurement uncertainty and its calculation, as well as the role of uncertainty in conformity assessment; in addition to highlight the importance of uncertainty estimation in ensuring reliable and consistent results in conformity assessment.

Additionally, the measurement uncertainty approach for conformity assessment is also widespread in the pharmaceutical industry, as products must meet quality requirements to ensure efficacy and safety. Various applied studies in this field have been identified in the literature, such as a study on the evaluation of measurement uncertainty in microbial enumeration tests used in microbiological quality assessment of non-sterile pharmaceutical products [30], and another one on the use of multivariate guard bands as a simple way to ensure false compliance decisions with the reduction of specific and total risks, which was of great interest to regulatory agencies and drug manufacturers [31]. Within the same context, researchers used univariate and multivariate safety margins to define more restrictive specification values, reducing the risks of false compliance decisions, and contributing to improving product quality and safety and decision support [32]. Still within this scope, Separovic and Lourenço [33] found a method to evaluate the risks of false decisions in compliance testing, based on the measurement uncertainty of liquid chromatography analytical procedures, aiming to estimate consumer and producer-specific risks to assess performance in compliance evaluation. Separovic and Lourenço [34] have also evaluated the performance of liquid chromatography analytical procedures based on measurement uncertainty and thereby estimates the risk of false compliance decisions. Simabukuro et al. [35] highlighted that the use of measurement uncertainty can be important concerning the evaluation of compliance or non-compliance of pharmaceutical products. Another relevant contribution to the state of the art [36] evaluated the measurement uncertainty of an analytical procedure for the determination of terbinafine hydrochloride in creams by HPLC, and optimised the process using the Analytical Quality by Design (AQbD) methodology, showing that the evaluation of the measurement uncertainty was important to ensure the reliability and precision of the results obtained by an analytical procedure. Finally, Burgess [37] discussed the requirements for generating a scientifically sound reportable value, exploring the use of the guard band technique to determine a risk-based specification for chemicals, as well as methods for calculating the associated measurement uncertainty.

In the context of production and quality engineering, a study [11] was identified that presented a method to design cost-effective inspection procedures using guard bands when measurement errors were present. The proposed method was based on an optimisation model that considered the cost of inspection and the cost of making a wrong decision. Another study [38] evaluated the economic risk used to determine an optimal acceptance criterion, which can be applied to indicate processes that had a high potential return on investment by implementing improvements in production, an acceptance sampling plan, and the measurement of inspected items. Still within the same theme, Koucha et al. [39] determined whether a product met specifications based on its shape error using a probabilistic model, employing a Bayesian approach to assign a distribution to the shape error parameter and a methodology for conformity assessment and risk of incorrect decisions. Another identified approach [40], explored a methodology for optimising the acceptance range in conformity assessments, considering the balance between the costs associated with rejecting good products and accepting bad products. In a new study [41], these same authors subsequently proposed the optimisation of the acceptance interval in conformity assessment, using the expression presented in the first part of their previously published work. Finally, Pou and Leblond introduced an application in the area of risk management in production processes, especially in the evaluation of risks associated with suppliers and customers in supply chains, using guard bands as an approach to manage supplier and customer risks in measurement processes, considering measurement uncertainty [42].

However, in the field of materials engineering, a study [43] highlighted the need to establish clear rules for decision making in situations of uncertainty and risk, and presented examples of risk analysis tools, such as failure tree analysis and failure mode and effect analysis, as well as discussing the importance of considering uncertainty and variability in decision making. There is also a work [44] that presented the process of conformity assessment of the thickness of epoxy coating applied in water pipes made of gray cast iron, according to the specifications provided for this type of coating, showing how risk assessment can be used to identify the main sources of uncertainty and variation in the measurement process. Finally, it is also worth emphasising the work of Kuselman et al. [24], which analysed the total risk of a false decision on the conformity of a metallic alloy, considering the measurement uncertainty and the correlation of the test results, performing Monte Carlo simulations to evaluate the total risk of a false decision on the conformity of a metallic alloy.

Within the analytical chemistry segment, there is a relevant review that addresses the main techniques of measurement uncertainty and conformity assessment, including statistical methods and Monte Carlo simulation models. Furthermore, the article discusses the main international standards and regulations governing conformity assessment in chemical analysis [20]. In another article [45], the authors presented an overview of the process of conformity assessment of a substance or material, which was fundamental to ensuring the safety and quality of chemicals and materials used in various industries. Besides the aforementioned works, there is also a study of equal relevance in the literature that evaluates the specific risks of false decisions in the conformity assessment of potassium iodate with a mass balance constraint, considering that the conformity assessment of a substance or material was important to ensure the safety and quality of products [46].

The application of the methodology of using measurement uncertainty in decision making and compliance evaluation can be applied to several areas, such as food analysis and pollutant measurement [47]. Thus, aiming to evaluate the impact of the quality of measurement results in product conformity assessment for the effectiveness of quality control processes, the study by Runje et al. [48] used application examples in different areas, such as the food industry and the pharmaceutical industry.

In calibration laboratories, this methodological approach is also widely used, being noted in several scientific studies [9], [10]. According to Czaske [49], the investigation of the use of measurement uncertainty by accredited calibration laboratories, when declaring conformity, has become important to ensure the reliability of measurements and compliance with specifications. Dobbert emphasised the importance of a risk management strategy for false acceptance in measurement systems, based on guard bands which helped users to make more reliable decisions, thereby avoiding potential disruptions [47]. Within the same line of study [50], Runje et al. evaluated the consumer and producer risks in conformity assessment decisions, aimed at improving the quality and safety of products on the market, using data from different sources, such as laboratory test reports, manufacturer information, and others. Similarly, another related study [9] remarked the importance of measurement uncertainty in the evaluation of measurement data and the assessment of conformity to measurement standards. Thus, it presented a review of the literature on the importance of measurement uncertainty in the evaluation of measurement data and the evaluation of compliance with measurement standards. Finally, to close this batch of outstanding works regarding calibration laboratories, Ellison and Williams [10] presented a literature review with criticism on the use of acceptance and rejection zones in quality control processes in laboratories, the lack of statistical basis in the use of these zones, pointing out possible errors in the interpretation of results obtained through them, besides discussing possible limitations.

With specific regard to the products' quality in the oil and gas industry, some other studies [13]-[16], [18] presented the application of measurement uncertainty in conformity assessment. According to Oliveira and Lourenço [13], the evaluation of the quality of automotive fuels required a multi-parametric conformity evaluation, where multivariate acceptance limits guarantee a total reduction of the risk of false conformity. In another work [15], the same authors highlighted the presence of discrepancies in measurement results in the conformity assessment of diesel and gasoline fuels, which could generate commercial conflicts between producers and consumers. In that study, the authors suggested that data reconciliation is a useful tool to improve the accuracy and reliability of the evaluation results. As another relevant contribution, Theodorou and Zannikos [18] evaluated the quality of automotive fuels by means of a multi-parametric conformity assessment, noting that the evaluation of measurement and data uncertainty can improve the reliability of the results of the conformity assessment of automotive fuel products. In another approach [14], the Monte

Carlo method was directly used to carry out the compliance assessment of a high-pressure gas meter calibration, without needing to know the type of distribution of the process. In this way, the difference between tolerances and acceptance criteria is slightly smaller compared to analytical methods. Recently, Matos and Oliveira [16] suggested a new methodology, based on data reconciliation connected to the concept of guard bands, to establish upper acceptance limits for producers, offering a comfortable margin to consumers, evaluating the risk associated with the presence of sulphur in fuels, and optimising the concentration of this element in marketed products.

This review shows that none of the aforementioned works has proposed or used the measurement uncertainty tool for conformity assessment to minimise the risks of false conformity assessment in oil and oil product transfer quantities in the oil and gas industry; that is, it is a gap in the literature.

With this precondition, this work aimed to highlight the importance of this approach in reducing risks and assisting in decision making related to conformity assessment applied to custody transfer in the oil and gas industry, avoiding significant losses among the parties involved.

4. CONCLUSIONS

This study aimed to comprehensively examine the current knowledge in the field of conformity assessment in the oil and gas industry, through a review of the literature. This work, using measurement uncertainty for conformity assessment with a special emphasis on the use of guard band tools, aimed to minimise the risks associated with false decisions in conformity assessment, both for producers and consumers.

The majority of the studies evaluated have the purpose of determining whether or not the result conforms to the limits established by regulations or specifications. One could conclude that, when the result approaches the limit, the decision is not so simple, requiring the use of specific rules. These rules, which should be accepted by all parties involved, are based on the acceptable level of probability of making an incorrect decision.

In addition, this work highlights that the implementation of tools such as guard bands offers greater predictability and security in the interpretation of measurements, reducing the impact of variations and uncertainties on critical decisions. The proposed approach can be especially valuable in high-risk commercial scenarios, where compliance errors not only harm the involved parties financially, but can also affect the reliability of operations in the sector as a whole.

While the gap identified in the application of this methodology to the custody transfer context indicates the need for further research, it also represents an opportunity for the development of standardised guidelines. These guidelines could benefit not only the oil and gas industry but also serve as reference for other sectors facing similar challenges in assessing compliance.

In short, the use of the guard band tool is a highly effective approach to assist in decision making related to conformity assessment, based on the methodology investigated. However, it was concluded that none of the reviewed studies proposed or utilised the measurement uncertainty tool for conformity assessment to minimise the risks associated with false conformity assessments in custody transfers of oil and petroleum products in the oil and gas industry. This highlights the existence of a knowledge gap in this area and, therefore, the need for additional research, and it suggests the consideration of the use of the measurement uncertainty tool, as an integral part of the conformity assessment processes in these transactions, for future work.

AUTHORS' CONTRIBUTION

Guilherme L. Orsay: conceptualization; methodology; validation; formal analysis; investigation; resources; data curation; writing—original draft; writing—review & editing; visualization; supervision; project administration; funding acquisition.

Khrissy A. R. Medeiros: conceptualization; methodology; validation; formal analysis; investigation; resources; data curation; writing—original draft; writing—review & editing; visualization; supervision; project administration; funding acquisition.

Elcio C. de Oliveira: conceptualization; methodology; validation; formal analysis; investigation; resources; data curation; writing—original draft; writing—review & editing; visualization; supervision; project administration; funding acquisition.

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