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An Overview of Methods Applied To Quality Control Of Storage Tanks Volume

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***Abstract* – Fixed storage tanks at atmospheric pressure or under pressure are built for bulk liquid storage and may be used for the measurement of volume or mass of liquid contained. When used for that measurement, they shall comply with the requirements described in international legal norms, developed by the International Organization of Legal Metrology (IOLM). There are different approaches and methods used for the conformity assessment of tanks, covering all or part of the operations for initial verification as well as subsequent verification or recalibration in service of the tanks. In this paper, conclusions will be shown based on the understanding of the definition of storage tanks for petroleum products, the needs of the gauging process of tanks, selections, and comparations of officially recognized methods, as well as relevant researches with respect to improving and advancing of traditional methods. The main categorization implies the geometrical and volumetric operations, a combination of these two, or some other more appropriate method. The aim of this paper is to select, compare and analyze existing approaches, as well as give recommendations to improve general aspects of tank control using the new and advanced methods based on the capabilities of automated and sophisticated tools.**

***Keywords* – calibration, tanks, geometric, volumetric, laser scanning, remote sensing.**

I. INTRODUCTION

Large storage tanks are used in a wide range of industrial applications for different kinds of liquids, e.g., petroleum and petroleum products, mineral oil and its products, liquid food, colors, or chemical and pharmaceutical products. Such storage tanks are found in refineries, petrochemical industry, distribution terminals, pipeline terminals, fuel depots, air fueling storage at airports, chemical storage, etc. Petroleum product movement and operations depend on the reliable and readily available tank information. In the context of this paper, tank definition will be used as the measuring unit of petroleum volume for the measurement of volume or mass of liquid contained. The measurement of liquids in large storage tanks has the purpose of quantifying the volume and mass of the product in the tanks and presents the very important approach for monitoring of fluid quality, called the tank gauging.

A tank defined like a measuring unit is considered as a measuring equipment or measuring instrument, and belongs to the comprehensive management of the petroleum measurement systems and its quality. Three general principles apply in considering the quality assurance aspects of instruments, equipment or measures (IEM). The first is that the IEM should be capable of doing the job required of it. The second principle is that all IEMs should be kept in optimal condition for use as needed. This implies both preventive maintenance and control over the use of the equipment by personnel. The third principle is that IEM should be frequently monitored and evaluated, what implies calibration [1]. Calibration means the operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and the corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication [2]. Understanding and quantifying the uncertainty of measurements as well as measurement errors, are critical to maintaining the quality of equipment, instruments or measures.

According to the International document ISO 10012:2003, only an effective and efficient measuring management system can secure a quality result, competent to reduce appearing risk of performing any incorrect activities. Methods applied in management of measurements and its quality processes, cover a wide range of activities, from the verification to the statistical techniques. All these activities describe one set of interconnected elements required to achieve metrological validation and continuous management of measurement processes and its quality. For quality assurance, it is necessary to create a systematic approach that involves defining and providing many important factors: metrology, standardization, reliability, i.e., personnel, methods and techniques, technical equipment, information, etc. The main object of this paper is to illustrate tanks quality control through all these important factors. Further, in this paper, relevant technical and metrological requirements for quality control of tanks, available methods for metrological control of tanks including verification and calibration methods, as well as relevant previous researches related to tank quality control issues and conclusions for the further investigations will be shown.

II. TANKS QUALITY CONTROL: TECHNICAL, LEGAL, AND METROLOGICAL TANK CONDITIONS

Taking into account different needs and purposes of measuring tank information, there are different ways of measuring the liquid level and other properties of the liquid, depending on the type of tank, the type of liquid, and the way the tank is used. The main three important factors for measuring fluid inside of tanks are level, temperature, and pressure measurements. Before selecting and analyzing available methods of measuring, it is useful to make a brief retrospective of the criteria concerning tank classification. The main criteria are shape, position regarding the ground, means used for measuring levels or volumes (quantities) of liquid contained, and kind of liquid(s) to be contained and conditions of use.

Technical requirements

Safety is the primary condition that is set before the construction of any tank for the storage of petroleum products. Storage of dangerous goods in tanks must be executed in a safe way. In order to reduce the economic as well as the environmental risks, a thorough knowledge of the tank condition and, in particular, the tank bottom and shells, is of utmost importance. International norms and codes prescribe mandatory conditions for the production of tanks, in order to build tanks in accordance with sound engineering practice. In addition, the requirements for the tank are conditioned by the type and content of the liquid that will be stored inside. With reference to their construction, position, and conditions of use, the tanks shall comply with the legal requirements for storage of contained liquids, in relation to the characteristics of these liquids (potable, petroleum, chemical, etc.). Conformity assessment body that performs quality control of tanks must be familiar with technical, legal, and metrological tank requirements.

Metrological requirements

Apart from technical requirements, there are metrological requirements for liquid volume inside of tanks. The root of metrological characteristics is the uncertainty of measurement (UM). The UM tells about its quality. It is the doubt that exists about the result of any measurement and thus in its broadest sense "uncertainty of measurement" means doubt about the validity of the result of a measurement. The official definition described in the Guide to the expression of uncertainty in measurement (GUM JCGM, 2008), defines UM as a parameter, associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand.

Legal metrology, with respect to the UM of volume inside of tanks, prescribes: The maximum permissible calibration uncertainty applies to the values between the lower limit of accurate capacity and the nominal capacity, shown in the calibration table. The maximum permissible uncertainty, calculated according to the GUM for a coverage factor of k = 2, positive or negative, shall be equal to:

- 0.2 % of the indicated volume for vertical cylindrical tanks;
- 0.3 % of the indicated volume for horizontal or tilted cylindrical tanks;
- 0.5 % of the indicated volume for other tanks.

The maximum permissible uncertainties indicated above do not include the uncertainty of the quantity below the datum plate, which is stated in the tank calibration table.

Tank control

The way to estimate UM, and perform conformity assessment of technical requirements, as well as to secure the granting of the "legal" status to a tank and the retention of that status, shall include initial verification and subsequent verification or recalibration of tanks in service. These operations are carried out by or under the control of the national authorities. In countries where the type approval is mandatory, the approval of design drawings partially replaces the type approval which is normally required for ordinary measuring instruments. This approval must be obtained by the manufacturer before he starts construction If a type approval is not required, a similar procedure shall be applied during the initial verification of the tank.

Initial verification implies two stages, in situ examination and calibration. During the "in situ" examination, the finished construction of the tank shall be checked for conformity to the "as-built" drawings. Conformity to all requirements shall be established and documented, the results being recorded in a document which shall be presented before calibration starts. The tank calibration shall be carried out in accordance with the applicable ISO Standards, or national standards as required. The choice of the method or of the procedure is imposed by the nominal capacity of the tank, the shape, the position, the conditions of use, etc. The calibration table shall be made according to applicable ISO Standards. If these Standards cannot be applied, the authority decides on the method which is acceptable.

Calibration tank methods

Calibration presents a set of operations carried out to establish, under specified conditions, the relationship between the liquid level in the tank and the volume of that liquid. The tank calibration shall be carried out by the applicable ISO Standards, or national standards as required, or if appropriate standard is not available, according to another relevant and competent method. The main categorization could be shown as geometric and volumetric methods. Further, geometric methods could be separated into manual-strapping method (MSM) for horizontal and vertical tanks, optical reference-line method and optical triangulation method for vertical tanks, as well as internal electro-optical distance-ranging (EODR) method for vertical and horizontal tanks and external EODR method for vertical tanks. Tanks with shape as sphere and spheroid, there are outlines of procedure, liquid calibration, calibration by meter, and calibration by tank procedures.

The geometric methods consist of direct or indirect measurement of external or internal dimensions of the tank, of the positive and negative deadwood and the floating roof or floating cover, if provided. The procedure of internal measurement using a tape with a tensioning device is generally not admitted for calibration of tanks containing liquids involved in international trade, except when no better method is applicable (for example, in the case of a thermally insulated tank). The geometric methods may be used on tanks with a nominal capacity of about 50 m3 and greater, which have a regular geometric shape and show no deformation.

The volumetric method consists in establishing directly the internal capacity, by measuring, utilizing a measurement standard, the partial volumes of a non-volatile liquid which are successively delivered into, or withdrawn from the tank. Water is a very suitable non-volatile liquid with the additional advantage of having a small coefficient of expansion. The volumetric method is generally used for the calibration of the following categories of tanks:

- underground tanks, of any type;
- tanks on the ground or above ground, with a nominal capacity up to 100 m3;
- tanks of a shape not suitable for a geometric method.

In addition, both the geometric and volumetric methods can be combined. The combination method consists in establishing, by means of the geometric method, the volumes corresponding to the shell of the tank and by means of the volumetric method, the volumes corresponding to the bottom of the tank. This method applies, under the same conditions as the geometric method, to tanks of which the lower part consists of a shape for which the volume cannot be determined with sufficient accuracy by means of the geometric method, for example, due to deadwood.

There are already officially recognized methods from the international application and harmonization aspect, and some of them are presented further in the Table 1, depending on the type and shape of the tanks.

Table 1. Published standards in relation to tank calibration methods

Tank	**Method category**		**Standard**
vertical cylindrical	geometrical	MSM	ISO 7507-1:2003
		ORL	ISO 7507-2:2005
		OT	ISO 7507-3:2006
		internal EODR	ISO 7507-4:2010
		external EODR	ISO 7507-5:2000
horizontal cylindrical	geometrical	manual	ISO 12917-1:2017
		internal EODR	ISO 12917-2:2002
	volumetric	liquid	ISO 4269:2001
Spheres/ Spheroids	volumetric	Liquid	API 2552
	geometrical	by meter	API 2552
	volumetric	by tank	API 2552
Paralelopipedic	/	/	No available

Non-standard shape	/	/	No available

III. RELEVANT RESEARCH WITH RESPECT TO TANK QUALITY ISSUE

The development of technology creates new approaches in practice, and this leads to new researches. Fields of research with respect to tank quality control could be directed to the aspects of new calibration methods, comparisons between methods, uncertainty of measurement, software, or conformity assessment, as Table 2 presents.

Table 2. Directions in the field of tank quality control research

Direction of research	**Reference**
New calibration methods	Knyva et al. (2017), Milinkovic et al. (2016a), Knyva et al. (2012), Khaisongkram and Banjerdpongchai (2004)
Comparisons between methods	Milinkovic et al. (2018), Milinkovic et al. (2018), Milinkovic et al. (2017), Agboola et al. (2019)
Uncertainty of measurement	Knyva et al. (2020), Milinkovic et al. (2019), Sivaraman et al. (2010)
Software	Milinkovic et al. (2016b), Nosach and Belyaev (2001), Agboola et al. (2017)
Conformity assessment	Milinkovic et al. (2017)

The previous research in this field conducted by the corresponding author of this paper was focused on 3D lasers scanning as new laboratory method for quality control of tanks. Many factors determine the correctness and reliability of the tests and/or calibrations performed by a laboratory. These factors include contributions from human factors, accommodation and environmental conditions, test and calibration methods and validation method, equipment measurement traceability, sampling, the handling of test and calibration items, etc. Milinkovic et al. (2019) presented all sources of errors that can occur during tank calibration using laser scanning with? both internal and external scan methods. Concerning the estimation of UM, Knyva et al. (2020) focused to the preprocessing method of the 3D point cloud data, defined and applied for calibration of the horizontal fuel tanks. The uncertainty analysis and estimation of the horizontal fuel tank calibration is performed implementing 3D point cloud FIR filtering and regression preprocessing techniques. Sivaraman et al. (2010) presented the methodology of horizontal fuel tank calibration uncertainty estimation using tank filling with liquid.

There are few directions to comparisons of different methods for tank calibrations. Milinkovic et al. (2018) performed a comparative analysis of the harmonic volume horizontal cylinder reservoir determined by volumetric method, electro-optical method, combined volume-geometric method, manual method, and 3D laser scanning method. The main goal was to verify the validity of the 3D laser scanners in the process of verification of the volume of horizontal cylinder reservoirs. Also, Milinkovic et al. (2018), following international standards and methods in the scope of legal metrology and calibrated laboratories, presented an analysis of two methods for tank control. There were shown tank conformity assessment results collected by Leica MS60 scan station and Leica BLK360 imaging scanner stations. There is also a third work with the similar focus, Milinkovic et al. (2017), aimed to present a comparative analysis of the application of two different methods for calibration of the volume of horizontal cylindrical tank, namely the volumetric method using the calibration system MES2000, and laser scanning by the two sensors, laser scanner Leica P20 and multi station Leica MS60. Measuring represented in this work is realized in an underground horizontal cylindrical tank. Other authors were also interested in comparison issues of methods, so Agboola et al. (2019) compared both MSM and EODR in terms of cost incurred, duration of calibration, and efficiency. Both methods were found to be efficient as they satisfied 95% minimum efficiency as stated by API MPMS 2.2 standard when compared with the wet method of tank calibration; though the cost of EODR was slightly higher than MSM but this was compensated with higher efficiency and reduced duration/time of calibration.

Knyva et al. (2012) presented a new method for calibration of horizontal fuel tanks using 3D laser scanning techniques and data processing algorithms and estimated the fuel tank volume measurement expanded absolute standard uncertainty. Main advantages of the 3D method – time and water savings were analyzed. Khaisongkram and Banjerdpongchai (2004) proposed a novel calibration method called combined geometric-volumetric calibration. The method is based on the data fitting of a level-volume (LV) characteristic curve where LV data are acquired through partially volumetric calibration.

From the new methods research aspect, it could be chosen the following researches. The Internet-of-Things (IoT) and Cloud technologies today provide new options for remote measurement data collection, storage, and processing. Fuel tank calibration process automation by adapting IoT infrastructure model is explored in Knyva et al. (2017). The impact of geometric and volumetric fuel tank calibration methods upon hardware and communication channels requirements in IoT infrastructure are considered in this work. In Milinkovic et al. (2016a), it is focused on demands concerning calibration method as one of the general criteria for practice that laboratories must accomplish, in terms of implementation SRPS ISO/IEC 17025:2006 standards. The subject of this paper is the method that modifies the standard electro – optical method of measurement internal distances in favor of 3D laser scanners that are used for making capacity tables.

Concerning software aspects, there are also few researches to mention. Milinkovic et al. (2016b) present a software tool and its validation mode, which is used for calibration purposes of horizontal, vertical, and spherical storage tanks, applying method of 3D laser scanning. Especially when it comes to the software used in the methods of calibration and testing, when these methods meet the criteria of international demands that ensure the act by accreditation bodies, the software must be tested, and depending on the origin, validated or verified. Nosach and Belyaev (2001) include a brief description of the main approaches to constructing algorithms and programs for analyzing data obtained in different types of tests of horizontal, inclined, and vertical steel storage tanks. Also, Agboola et al. (2017) focused on generation of calibration charts for horizontal petroleum storage tanks using Microsoft Excel. Microsoft Excel is a powerful tool in Microsoft (MS) office package used for computation and programming through the use of visual basic for application. In this study, MS Excel was used to generate two different charts which were compared with the charts generated from customized specialized calibration software.

Since recognizing and officially development and applying of any methods needs respected quality control systems, with competent and relevant conformity assessment bodies, Milinkovic et al. (2017) demonstrated the role of an accredited calibration laboratory in the process of verification and calibration, and further applying a certificate with the accompanying capacity in metrological control process of tank. There have been presented example of a real tank inspection typical for economy and national petroleum industrial systems by accredited conformity assessment body.

IV. CONCLUSIONS

Wherever liquids are stored in large tanks, there are needs to perform that measuring procedures. The information delivered from a tank gauging processes and procedures has many different purposes, but with the one aim, to give the right data with high level quality information necessary to make good decision in real time, ad hoc, or for long term planning. Precise and accurately information delivered from tank gauging process is also very required but from aspects of inventory control and custody transfers. Tank gauging data have the purpose as the very important input for establishing correct invoicing and taxation for any kind of petroleum liquid trade. Certified tank gauging can provide more accurate transfer assessments compared with metering when performing large transfers such as from a tanker ship to a shore tank. For legal or fiscal custody transfer, the tank gauging system must be certified by international authorities, mainly IOLM.

This paper aims to make a brief retrospective of petroleum storage tank quality control range. For any good model of quality control, it is very important to understand the nature of tanks, their definitions, conditions, and purpose. Being familiar to technical and metrological requirements of tanks is crucial for tank gauging process, all necessary steps for quality control need to be covered, as well as relevant laws and institutions for the issue.

Tanks could be grouped in few groups, depending of shape, ground positions, purposes, and measuring systems installed on them. Different types need different gauging approaches, so future research will contribute for developing of one competent and validated method able to cover as more as possible tank type calibration. For that, the first step is analyzing technical, metrological, and quality control conditions of tanks, beginning from the most important documents officially recognized to state requests. There are IOLM Recommendations, interpreted with ISO and API, and other national and international norms and standards. In the paper it is presented a list with short description of relevant standards and norms for this issue. They had their own evolution, from manual strapping methods to the electro-optical measuring. Today, we have new technology revolution, so there are needs to use and develop officially norms followed with technical solutions from 3D laser scanning methods. Many private companies have technical resources to use this technology in storage tank conditions, but there is a lack of norms that can support it. Also, there are works and researches regarding to recognizing 3D laser scanning technology as useful tool. As final conclusions, we could make the following relevant statements for future investigations:

Laser scanning technology has advantages for verifying of tanks volume over other traditional applied methods, but there is a lack of standardization and validation of the method; Still, the influence of geometry on uncertainty measurement is not enough investigated, being one open question the impact of tank shell deformation on the volume. For external methods, the open question is how to make an estimation of deadwood still inside of tank, and its impact to the volume presented in the capacity table. Mostly available researches cover horizontal shape of tanks, so there is a lack of methods to analyzing for vertical, sphere, and non-standard shape of tanks. Also, it should be taken into account the measuring traceability of the measuring system to the national and international standards, so one aspect of research should be devoted to the metrology traceability chain. There are researches which show benefit of geometric-volumetric method combination, but 3D laser scanning method has the ability to overcome the needs for combination solutions. 3D laser scanning method should be used as good tool to make relevant solution with both components, hardware and software, which take into account all technical and metrological aspects, including: correction for hydrostatic head effect, in accordance with ISO 7507-1:2003, Annex A; correction to the certified tank shell temperature, in accordance with ISO 7507-1:2003, 16.1; correction for deadwood, in accordance with ISO 7507-1:2003, 17.1; correction for tilt, in accordance with ISO 7507-1:2003, 16.2.

One important part of future research should be dedicated to analyze the influence of temperature and pressure on the volume distribution of storage conditions and its impact on all gauging management.

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