REVERSE ENGINEERING OF A MILKTANK AND EVALUATION OF VOLUME METERING PROCEDURE

K. Papadopoulos[1], D. Tzetzis[1*], G. Oancea[2], P. Kyratsis[3]

ABSTRACT: Since liquid storage tanks have an increasingly number of industrial applications, their volumetric measuring is imperative both for cost control in transactions and for quality assurance. The current paper focuses on the volumetric measurement of a stainless steel milk tank. The main objective is to compare two different methods of tank calibration and evaluate their results, in order to deliver the most accurate measurement method. In particular, the paper evaluates the traditional procedure for volume measurement and uses different tools for reverse engineering, in order to evaluate their compatibility with the product characteristics and the accuracy of each one. Emphasis is given to 3D scanning as a new method which provides high accuracy and high density positional information about the tank. The analysis shows that 3D scanning presents results which are very close to the traditional method of measurement.

KEY WORDS: Reverse Engineering; 3D Scanning; Tank Volume Measurement; Computer Aided Design.

1. INTRODUCTION

The use of liquid storage tanks in industry is widespread for numerous liquid storage applications (water, milk, wastewater, oil, fuel and other chemical/industrial liquids). There is a wide range of storage tanks found throughout the industry for storing liquid products, such as fixed, cone roof tanks, floating roof tanks, sphere and bullet tanks, underground tanks etc. Tanks are generally chosen based on the flash point of liquid stored in the tank, while in the case of specific products (chemicals, diary etc.) additional requirements must be considered. Among the numerous specifications, a high degree of reliability and accuracy in measuring their volume capacity is of great importance. In fact, over the years, tank calibration, tank inspection and certification of storage tanks has been made mandatory in most countries worldwide [1]. Also, the value of the best gauging system, or accurate manual measurement is directly proportional to the accuracy of the volumes extracted from the calibration tables.

Tank volume calculations are based on tank geometries, assuming exact geometric solid shapes such as cylinders, circles and spheres. However, actual fuel tanks may not be perfect geometric shapes or might have other features, which make these calculations to only be considered as estimates.

Geometrical calibration of horizontal and vertical fuel tanks is most commonly performed using three methods. The first one is the tank strapping (manual) method, in which calibrated measuring tapes are used to measure the circumference of the tank at several elevations. More specifically, the tank is strapped at some height point using a strapping tape laid around the vertical walls of the tank, parallel to and at a measured distance from a particular ring. The strapping tape then must be calibrated using a master tape, accounting for imperfections in the shell of the tank. The second one is the optical reference line method, which is simply an alternative method for determining the diameter of the tank by using an optical device [2]. It can be applied internally or externally using an optical theodolite to establish a perpendicular ray in a vertical plane. The ray measures deviations in the tank diameters at various course heights with respect to a reference offset at the bottom course, which taken together with the reference circumference are translated into the appropriate tank diameters [3,4]. The third method is the optical triangulation measurement method in which tank profile can be defined by triangulation with two theodolites and a target point on the tank, or with one theodolite and two target points on the tank at a number of stations around the tank [5]. Besides the abovementioned methods, a very common and widely used methodology is the volumetric (liquid) calibration by metering a known quantity of liquid and gauging the tank at regular height intervals to develop a capacity

[1] International Hellenic University, 57001 Thermi, Greece
[2] Transilvania University of Brasov, Department of Manufacturing Engineering, Brasov, Romania
3 Western Macedonia University of Applied Sciences, Department of Mechanical Engineering and Industrial Design, GR50100, Kila Kozani, Greece

Fig. 1 a) Closed type milk cooling tank, b) Open type milk cooling tank

table. It can be used in the calibration of either the total or partial capacity of a tank, with a high accuracy –which exceeds other methods- when used in the calibration of small, especially horizontal, cylindrical tanks. This method is also mainly preferred in the case of uneven, inclined tank floors, spherical or conical bottoms etc. Wet calibration at intervals is required for deformed, inclined horizontal tanks or irregular bulging rectangular tanks. The calibration liquid may be either water or a suitable petroleum product having a low volatility and viscosity. However, water is preferred where wide temperature variations are expected during calibration, given that water has a low coefficient of cubical expansion [6].

In recent years there have been major technological advances in the field of 3D scanning with applications in various fields [7-9]. As 3D laser scanning technologies can capture a vast array of three-dimensional positions (X, Y, Z coordinates or points), they can capture accurate position information in order to identify shape, geometry, deformation and locations of interior structures. Among their benefits when applied for tank measurement is that they can provide high accuracy and high density positional information in a very short time and, therefore, complement other measurements used to evaluate the conditions of tanks [10].

By using a software application designed specifically for this task, multiple scans produced over time can identify the speed and extend of tilting or deformation over time due to use or internal pressures [11]. In contrast to traditional methods, equipment does not need to be in normal operating temperature (+5°C to +35°C) as calibration can work also at lowest temperature (-10°C) [12]. Finally, calibration with 3D scanner is water conservation efficient as it does not use water to fill the tank. In particular, 3D laser scanners typically incorporate a laser source and a mirror assembly which rotates at high speeds. The laser source creates light, which is reflected off the mirror in a programmed sequence. The light travels then until it encounters a targeted object and a portion of that is reflected back and picked up by the scanner. Then, sensors within the scanner are used to compare the emitted light with the reflected light, allowing the scanner to calculate the exact dimensions of the targeted object. Knyva et al. presented a new approach for calibration of horizontal and vertical fuel tanks using 3D point clouds [12, 13]. 3D laser scanning involves placing the scanner inside the tank in order to capture data for both the tank flour or sump and the filling volume. This method does not require estimation of tank thickness, as the internal cavity is directly measured. Based on this method, one has to do the following steps [12]. Firstly, volume calculation of the bottom of the tank must be performed; this includes a high level of uncertainty and therefore, one should calculate different 3D point clouds and then calculate their mean value. Secondly, volume calculation of the upper part of the tank should follow; for the calculation of the upper part of the tank, one should filter all unnecessary points inside the circle and calculate the volume of the tank by integrating data millimeter after millimeter until the top of the tank. Accuracy compared to other methods used is very good because the calculation is conducted for each millimeter of the tank and not for only few basic strapped levels.

The current paper focuses on measuring the quantity of a vertical milk tank using a traditional and reverse engineering method. An analysis of the current procedure for tank volume calculation is presented and it is used as a reference point for comparing to the alternative method which is using a 3D scanner for the volume measurement.

2. MILKTANK CHARACTERISTICS

A milk tank is a stainless steel tank in which milk is cooled quickly to 2-4°C and stored until collected by a bulk tank for transport to the milk plant. Milk is a delicate product that requires specific environmental conditions to maintain its quality. Milk tanks may be either open-top with a cover or closed-up with an access hole as shown in Figure 1. According to their specifications tanks must have level marks which should be clearly and permanently indicated. They should also be fitted with a linear measuring device, such as a dipstick or sight-gauge to determine the volume of liquid in the tank. A dipstick should have the producer's name and serial number on it, corresponding to the number of the tank, a stamping plug to imprint an inspector's mark or a servicing licensee's mark and a statement of the volume of liquid which corresponds to the interval between adjacent scale marks, near the top of the dipstick on its graduated face [14].

3. THE TRADITIONAL PROCEDURE FOR TANK VOLUME ESTIMATION

For calculating the volume of the milk tank a flowmeter is used, which is installed on the exit valve of the tank (Figure 2a). Also, the exact diameter of the inner tank is measured in order to use it as a correction parameter of the indicated litres. The first step is to level the milktank. To achieve that a leveller is placed on the top of the tank to calibrate the side parts. Two dipsticks are placed on both front and back side of the tank which is filled with water until it covers both dipsticks. The heights of the legs are adjusted so that both dipsticks to have the same measurement. After calibration, the volume metering procedure is initiated. First the tank is filled with water as much as the nominal capacity (500 litres for the tank of the report). At that point the levelling of the tank is monitored by checking the indication of both dipsticks which have to be the same. As mentioned, adjustment of the legs is required to succeed that. The indication on both dipsticks is recorded and the flow meter is set to zero point. Then the valve is opened to empty the tank. When the flow meter indicates 1/10 of the nominal capacity of the tank (50 litres) the valve is closed. After some period when the level of the water is stable the measures of the dipsticks are recorded as well as the amount of water indicated on flow meter. The same procedure is repeated until the zero point of the dipsticks is reached as shown Figure 2(b). During this phase the indication of the two dipsticks has to be equal (± 1mm) otherwise all the steps are repeated from the beginning so to succeed a better levelling of the tank. After reaching the zero point of the dipsticks the tank is emptied completely and the indicated amount of the litres is recorded. This procedure is repeated twice. The measurements are processed in a spread sheet for calculation of the volume of the tank. For the calculation it is assumed that the tank is a cylinder with constant diameter for every horizontal slice. However, this is not exactly correct because there is certain deformation of the tank due to the manufacturing process, which cannot be measured precisely. The data processing is divided in two sections. The first one consists of the measurements of the body of the tank. Using the first and the last (at zero point) measurement the LPM factor (litres per millimetre) is calculated by dividing the total litres by the millimetres of the first measurement. The rest of the measurements are used to confirm that there is no large deviation between them. This LPM factor is compared with the nominal factor A, which is calculated using the equation $A=\pi D^2/4$, where D is the diameter of the tank, and results in a correction factor. The second section is the calculation of "zero point" volume, which is the subtraction of the litres on "zero point" from the total litres of the procedure. Using the correction factor, which was calculated in first phase, the calculated amount is corrected. The correction factor is needed to modify the indications of the flow meter calculated by a number which has to be changed according the conditions of every procedure. With the above mentioned procedure the corrected volume of "zero point" is calculated as well as the LPM factor. With these, the volume metering table can be created for every mm, by adding to the "zero point" amount the (LPM)x(mm) litres. The final chart is produced by the average values of both measurements.

4. 3D SCANNING METHODOLOGY

The 3D models of the milktank were generated using a portable optical photometric Artec™ 3D scanner (Eva Artec™, Artec Group LLC, Luxembourg) where structured illumination is the principle of the scanning process. The scanner is similar to a video camera which captures objects up to 16 frames per second in three dimensions. These frames are aligned automatically in real-time, which make scanning easy and fast.

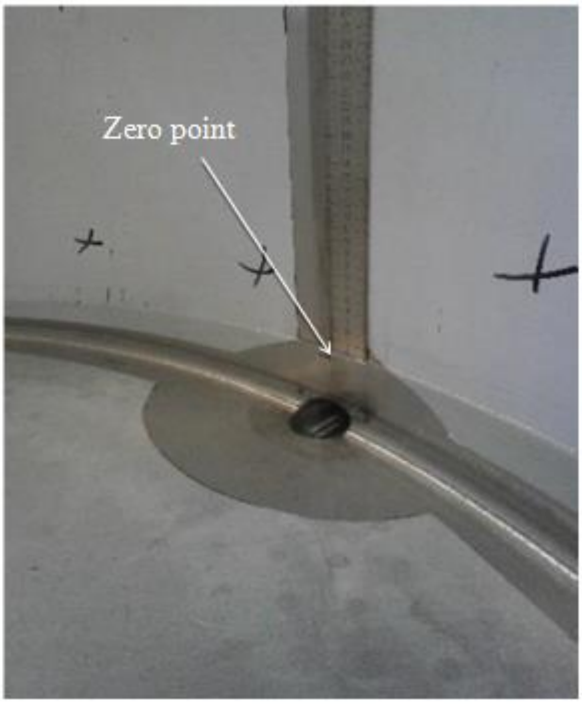


Fig. 2 a) Flowmeter on the exit valve of a milk tank, b) Zero point level

The scanner allows digitization of a single frame of a sufficiently large surface area of a scanned object. Upon usage the Artec™ 3D scanner provides information regarding the shape of an object within a matter of seconds up to several minutes. This specific scanner has the ability to capture the image of the milktank by combining the calculated volume with the scale that is found on the dipsticks.

Following the scanning process, data processing is performed by using the Geomagic Studio™ software to smooth the polygon mesh and flatten any single-point spike to prepare the model for transfer it to the parametric modelling software Solidworks™. To complete the transformation two different methods of surface creation were used. The first one was "Parametric surfaces" method to create the CAD model. With this procedure the current procedure for volume metering is simulated. As mentioned before, in the current procedure the body of the milk tank is assumed to be a cylinder (parametric feature). The second one was the "Exact surfaces" method for creating the model. With this method it is feasible to have the absolute mapping of the surfaces as captured from the scanner.

Both models were imported in the parametric modelling software Solidworks™ in order to create the volume which is contained in the calculated surfaces and is measured in different planes for the creation of a gauging chart. Also, the gauging chart was calculated through the current procedure with the use of the flow meter.

5. SCANNING PROCESS AND RESULTS

The scanning procedure was difficult because of the surface of the object. Stainless steel is a shiny material with a grey color which is not easy to capture with a 3D scanner. However, the milktank's inside surface when manufactured is covered with a protective plastic film (white plastic). This surface is also difficult to capture because there were no large differences on the texture and the scanner couldn't align the scanned parts. After some unsuccessful trials some marks were drawn on the plastic film with a black marker. These were drawn as random crosses on the side surface as well as at the bottom of the tank. Also, some powder was placed on the dipstick (not covered with a plastic film), which it was made from stainless steel too, because it was not visible by the scanner.

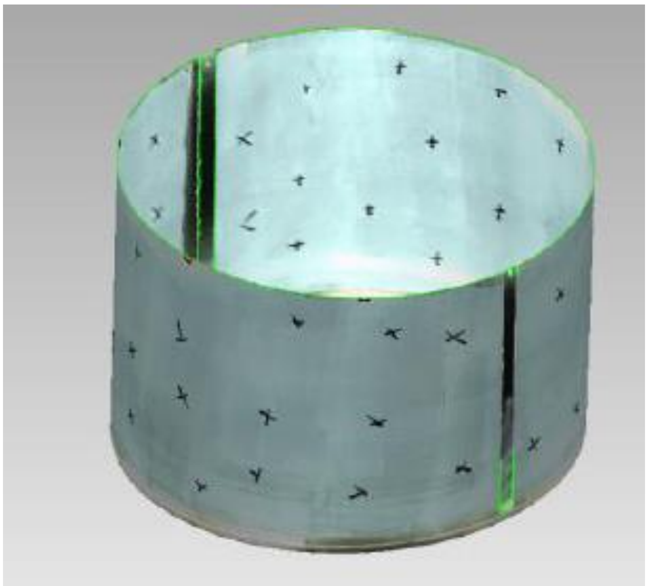


Fig. 3 Three dimensional model of the milktank with texture

Both marks and powder seemed to work reasonably well. Various scannings of the object were achieved, which were merged on the scanner's software (Artec Studio™) to get the complete scanned image of the milktank.

The data were exported from the Artec Studio™ software in .wrl format including the texture, which is necessary for the leveling of the tank. The file was inserted into the Geomagic Studio™ software where the starting image of the milktank was in the form shown in Figure 3. The first step was to align the model (virtual tank). To achieve that, a 3 point plane was created, parallel to the brim of the tank. It should be stressed that the brim of the tank has being used as a reference point for alignment of the real tank. Afterwards, an offset plane was created so that it crosses the dipsticks at zero level as shown in Figure 4. Given that the zero point was not visible from any of the two dipsticks due to missing point cloud, its shifting up to the point of 10mm was calculated and then the difference was added. The plane that has been created had a distance of 607mm from the original one. This plane was aligned to the xy plane of the coordinate system. With this step it was possible to relate the object's z value of all points to the indications of the dipstick in the tank.

In order to verify the accuracy of the process, two parallel to xy planes were created with a distance of 200mm and 600mm. These planes crossed the dipstick's scale at the 200mm and 600mm points, which meant that the alignment of the object has been achieved successfully.

In order to be able to transfer the object to the CAD software SolidWorks™, aiming to evaluate the geometrical characteristics of the milk tank, it was necessary to correct/fix the imperfections that were created during the 3D scanning procedure. Such imperfections may refer for example to self-intersections, spikes and holes that were created during the process of the 3D scanning, spotted around the dipsticks and behind them as well as inaccurate data information receiving in the case of areas with unreachable surface such as the internal part of the drain valve, which has a very small diameter. The fact that milk tanks had a smooth surface meant that there was a possibility to close the holes by using the tangent option. Finally, in order to create a unified object, the object's polygon mesh was repaired by removing the dipsticks and recreating the tank's surface.

As a next step two different methods were used for transferring the object into the CAD software. Table 1 shows the values from the deviation analysis chart for both methods.

a. Initially the tools of "Parametric surfaces" tab were utilised. During this process it was considered that the tank's body is a cylinder (such as during the process of volumetric measurement) the bottom of the tank is part of a sphere. Both these surfaces were parametrically unified with a constant radius surface, as happens with the tank construction. After the creation of the surfaces a deviation analysis was performed in order to estimate their deviation from the original model. Figure 5(a) shows the graphic representation of the deviation. The maximum positive and negative distance was 4,018mm and -4,272mm and the average distance was 0,758mm and -0,042mm correspondingly. The standard deviation was 1,003mm. It is clear from the image that the body of the tank is not a cylinder but it transforms to an ellipse moving upwards from the bottom of the tank.
b. The second method is the creation of the model's surfaces with the tools of "Exact surface" tab. The created model consisted of small surfaces which had the minimum, as possible, deviation from the original object

After the creation of the surfaces a deviation analysis was performed in order to estimate their deviation from the original model. The maximum positive and negative distance was 1,8060mm and -1,7854mm and the average distance was 0,096mm and -0,100mm correspondingly.

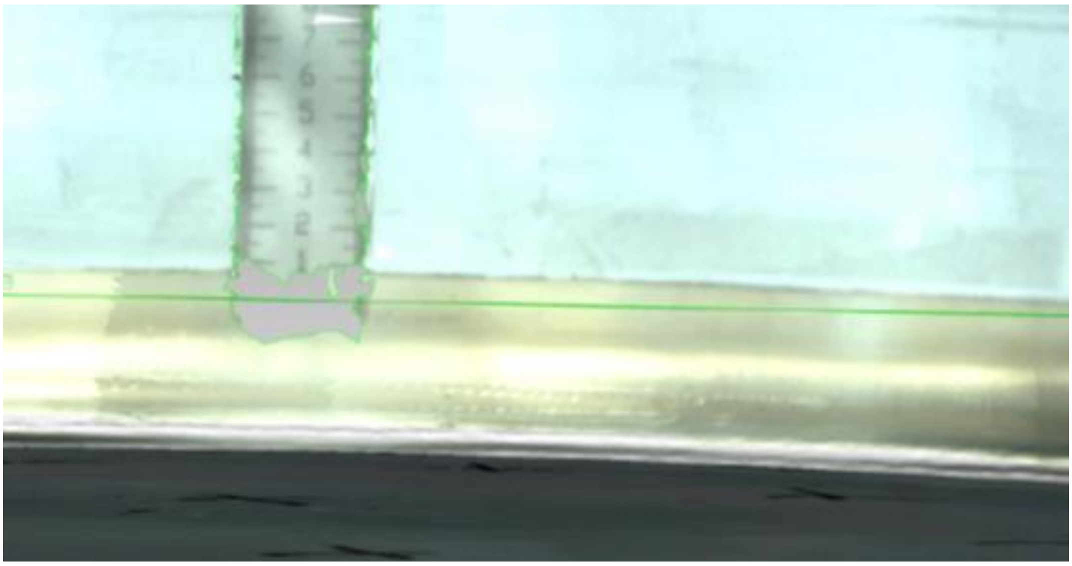
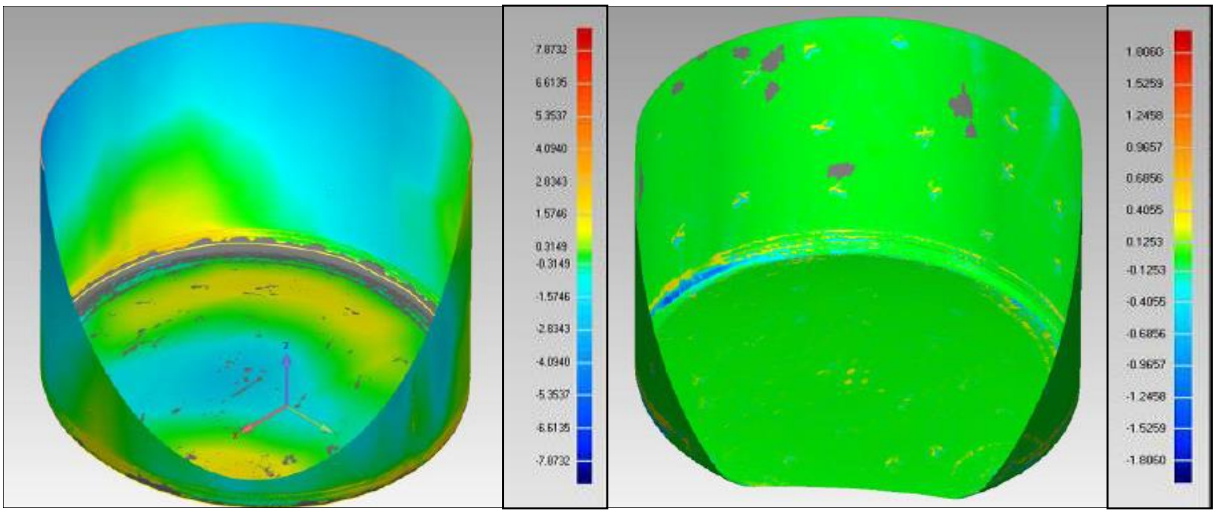


Fig. 4 Virtual tank's zero point level



Fig, 5 a) Parametric surfaces deviation analysis, b) Exact surfaces deviation analysi

Table 1. Distance deviation analysis

	Exact Surfaces	Parametric Surfaces
Maximum Distance		
Positive	1,8060mm	4,018mm
Negative	-1,7854mm	-4,272mm
Average Distance		
Positive	0,096mm	0,758mm
Negative	0,100mm	-0,042mm
Standard Deviation	0,1667mm	1,003mm

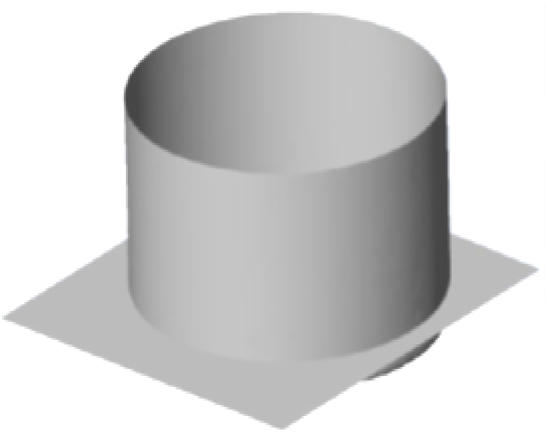


Fig. 6 Surface modelling in Solidworks™ to create the body and the bottom of the tank

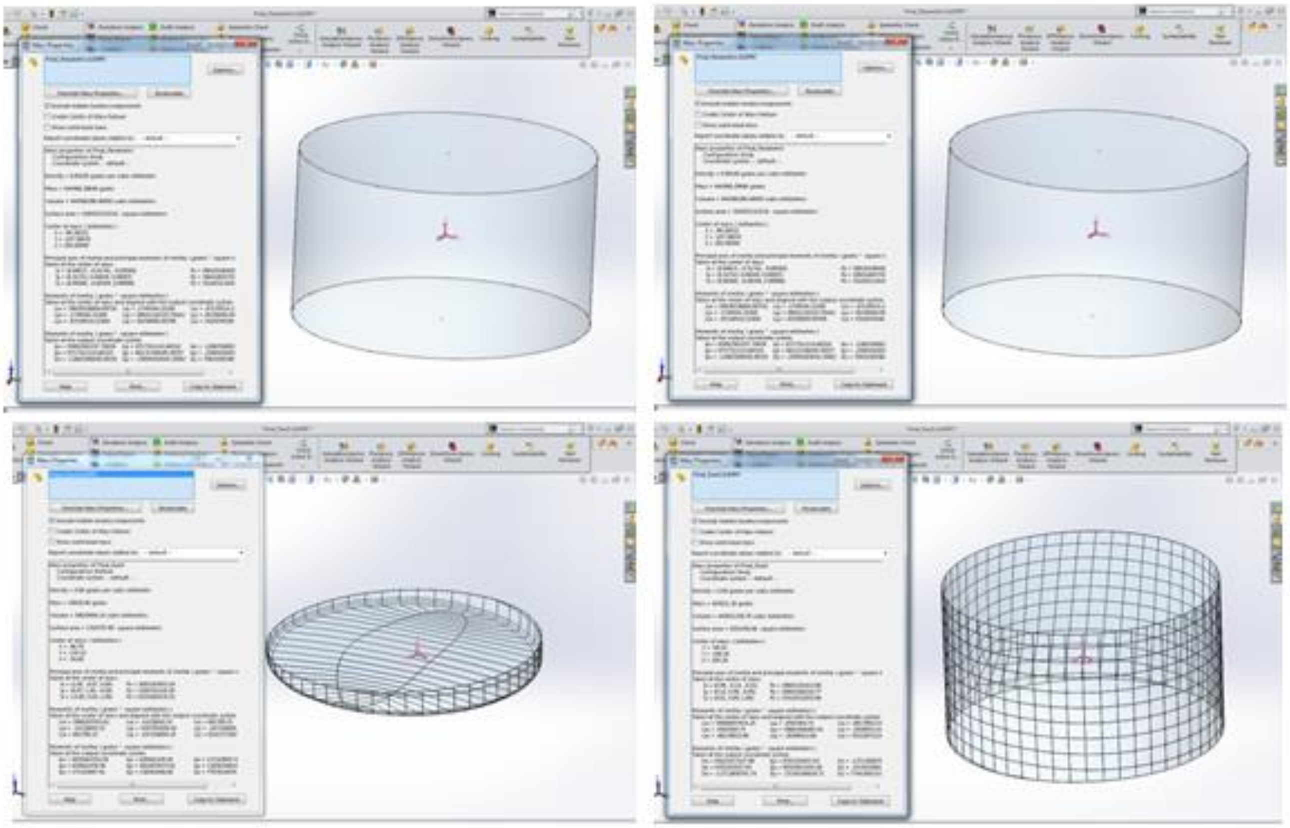


Fig. 7 Calculation of the mass properties of solids

Table 2. Volume Deviation Analysis

Tank Height (mm)	Exact Surfaces	Parametric Surfaces	Difference (%)	Flowmeter Procedure	Difference (%)
0	50,630lt	50,710lt	0,160	50,570lt	-0,120
100	78,047lt	77,994lt	-0,068	77,991lt	-0,072
200	156,161lt	155,988lt	-0,111	155,982lt	-0,115
300	234,359lt	233,982lt	-0,161	233,973lt	-0,165
400	312,656lt	311,976lt	-0,217	311,964lt	-0,221
500	391,022lt	389,97lt	-0,269	389,955lt	-0,273

The standard deviation was 0,1667mm. As shown in Figure 5(b) the deviation of the distance between the new surface and the scanned data is much lower than with the first method.

Finally, both models were imported to CAD software Solidworks™ in order to create the solid that is contained inside the surfaces of the model. With the use of surface modeling tools a plane on the zero level of the milktank was created. The object was then trimmed and separate it in 2 different parts a) the body and b) the bottom of the tank as shown in Fig. 6. Afterwards the surfaces were merged with the knit tool and the solid model was created with thicken tool. Since the solid model is available the mass properties can be evaluated for every part as shown in Fig. 7. Also, using the extrude cut tool the volumes of tank's small portions (100 mm height) were evaluated. Table 2 summarizes the values for both models and also the values of the flow meter procedure. The measurement values are almost identical. It is obvious that the 3D scanning procedure can be used for the measurement of a milktank's volume as long as the object is suitable prepared for scanning.

6. CONCLUSION

The recent proliferation of commercial 3D digital scanning devices can made 3D scanning, and virtual and physical replication, a practical reality in the field of volume metering. 3D scanning produces a high precision digital reference document that records condition, provides a virtual model for replication, and makes possible easy mass distribution of digital data. In the current work it was shown that the 3D scanning procedure can capture accurately the true internal shape and geometry of a milktank. The new digital approach to calibration provides time saving, water waste problems and ease of operation.

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