MĀPAN-Journal of Metrology Society of India
DOI 10.1007/s12647-017-0224-6

ORIGINAL PAPER

Generation of Calibration Charts for Horizontal Petroleum Storage Tanks Using Microsoft Excel

O. O. Agboola*, P. P. Ikubanni, R. A. Ibikunle, A. A. Adediran and B. T. Ogunsemi

Department of Mechanical Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria

Received: 23 August 2016 / Accepted: 10 July 2017

Abstract: Petroleum and petroleum products are expensive commodities due to their global demand as a major source of energy. As a result of its expensiveness, there is need for proper inventory to know what is going in and coming out of the storage tanks. Proper inventory is achieved by accurate measurement through the generation of a calibration chart for every storage tank. Calibration chart (tank table) gives the needed information about the level (height) and the corresponding volume of the petroleum product in the storage tank. Geometrical method (dry calibration) is the most widely used method of computing tank table using the field data such as circumference, shell or plate thickness, length of barrel and lap/butt strap while taking the necessary correction factors into consideration. 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 from Société Générale de Surveillance (SGS software) and the results were found to be within the statistical controlled limit.

Keywords: Calibration; Chart; Storage tanks; Tank table; Microsoft Excel

1. Introduction

In the petroleum industry, crude oil and its refined products exist generally in liquid or gaseous form. This bulk fluid of crude oil and its products require accurate measurement. Such accuracy eliminates disputes about the receipt of refined product or crude oil into terminal storage and on delivery, while promptly alerts operators to unnecessary product losses [1].

Storage tanks and barge tanks can generally be calibrated either by liquid calibration approach or geometric calibration [2]. Liquid method of calibration involves the determination of volume at the incremental heights of a tank by transferring a known quantity of liquid to a vessel or withdrawn from a vessel [3].

Geometrical method of tank calibration (popularly known as dry calibration) is applied to both horizontal and vertical storage tanks [4]. It is a process of gathering accurate measurements of the tank dimensions in order to use mathematical approach to determine its capacity [5]. Various approaches are being used in geometrical method of calibration. The most modernized and technically-based among them is 3D Laser scanning method as described by Knyva et al. [6]. Dou et al. [7] proposed a model for determining the tank's position in the generation of tank capacity table and the study focused more on vertical storage tanks.

Generally, horizontal storage tanks can be classified as surface horizontal tanks or underground horizontal tanks. This can further be sub-divided into flat-ended tank, elliptical-ended tank, conical, spherical and hemispherical tanks. According to Dan [8], the commonly encountered tank shapes are flat, elliptical, spherical and hemispherical. Mathematical equations have been developed for all these commonly encountered shapes through which the volume at various heights can be computed. Sun [9] asserted that determination of tank capacity is not as simple as it may appear because of some other factors which are different from the common correction factors such as temperature, shell thickness, heads/ends. In a bid to accurately determine the capacity of horizontal storage tanks, the volume of the straight cylindrical section is first determined before adding it to the volume of the ends. This is easily done for straight/perfectly horizontal tanks. However, it poses a

*Corresponding author, E-mail: omegawole@gmail.com

Published online: 04 August 2017

very difficult task for inclined or tilted tanks because there is need to take into consideration the effect of tilt [10]. Tilt is not always a desirable condition in the installation of horizontal tanks but it may be intentionally done in some rare conditions which include enhancing free flow from one section to the other. Correction for the effect of tilt and its optimization was given by Wei et al. [11] where a model of oil volume marking for a tilted oil tank was validated.

Calibration of a horizontal storage tank should be done once in every five (5) years [12]. Tank capacity table, which is the output of tank calibration process, is a set of data relating the filled volume of storage tank to the gauge height/level. MS-Excel has been used over the years for mathematical calculation instead of manual calculations [13]. When a correct program is written on a spreadsheet, the output would definitely be right. Sanjid and Chaudhary [14] designed a software for the calibration of angle block and validated it with the results obtained from MS-Excel calculation. Validation could be done by comparing already existing method(s) with the new proposed method. Chunhui and Johnson [15] researched into the bilateral comparison between NIM's and NIST's gas flow standards and found that all the data are in compliance with ISO 9300 empirical equation within its 0.3% expanded uncertainty limit.

Having searched extensively in Nigeria by meeting with the renowned calibration companies to know if there are commercialized softwares for Tank calibration, it was discovered that none ever existed up till date. However, most companies combine various standards such as API, IP and ISO together to do manual computations. In order to reduce this rigorous task, the use of API 2551 was adopted in this work in addition to the exact mathematical findings of Dan [8] to generate calibration charts using MS Excel programme. This research aims at generating calibration charts for horizontal cylindrical storage tanks using simple Microsoft Excel programme. The programme interface is user-friendly. This makes the task of generating calibration charts simple.

2. Materials and Methods

Geometrical calibration involves different linear measurements such as knowing the circumference, shell plate thickness, tilt/slope etc. Equipment such as strapping tape is used to obtain the circumference of the tank. Ultrasonic Thickness Gauging (UTG) model TG110L machine was used for determining the shell thickness while leveling instrument was used to determine the degree of tilt.

2.1. Field Measurement

The three (3) basic measurements made on site were the circumference, shell plate thickness, tilt/slope (if any), and shell temperature. Though, there are two possible methods of physical measurements which are external and internal measurement, however; the scope of this paper is limited to external measurement because most of the storage tanks abide by external measurement except the insulated tanks where internal measurements are adopted.

2.2. Circumferential Measurement

Horizontal tanks consist of two heads commonly called ends. Amid the two heads is a cylindrical section called barrel. It is important to note that for a flat-ended tank, there is only barrel but no head.

Circumferences were measured at 20, 50 and 80% of the barrel length by winding a strapping tape round the shell at these various sections. The strapping tape was firmly held under tension using "little John grip". The circumferences obtained for two different Tank A and Tank A1 are as shown in Tables 1 and 2.

2.3. Shell Plate Thickness

The thickness of every section of the barrel as well as the end thicknesses was taken using UTG for spot scanning. The scanning was simultaneously done on the tank barrel. The field data obtained was shown in the Tables 3 and 4, respectively for Tanks A and A1.

2.4. Slope Measurement

No slope was found in Tank A because the value obtained as both assumed shallow end and deep end were the same. However, for Tank A1, negligible tilt value was observed. The observed value obtained in shallow end was 765 mm while 759 mm was obtained at the deep end.

2.5. Temperature

Master tape was certified at 23 °C but the field measurement was carried out at about 29–33 °C for both Tanks A and A1.

2.6. End Measurement

By visual inspection, Tank A has a conical shaped end with average cone radius of 78 mm whereas Tank A1 was an elliptical ended tank with a dish radius of 52 mm.

Table 1 Circumferential measurement of Tanks A

	20%	50%	80%
Circumference (mm)	9464	9463	9464

Table 2 Circumferential measurement of Tanks A1

	20%	50%	80%
Circumference (mm)	9476	9477	9479

Table 3 Average thickness and Length of barrel for tank A

Average thickness (mm)	6.0
Length of barrel (mm)	6000

Table 4 Average thickness and Length of barrel for tank A1

Average thickness (mm)	8.0
Length of barrel (mm)	7500

2.7. Computation of Tank Capacity Table

Volumetric quantity as a function of height (level) can be calculated from the exact mathematical findings of Dan [8]. Both ends of the tank must be identical and assumed to have the same dimensions for the equations to be valid. If one end is elliptical, the other must be elliptical with the same dimensions. However, the equations can be combined to deal with volumetric calculations of horizontal tanks with ends of different shapes.

In this computation, the two ends were treated together as a single section while the cylindrical barrel was also treated separately. The two sections were combined together to give the required volume of horizontal cylindrical tanks.

Generation of any tank capacity table starts from skeleton chart and consideration of different correction factors. Some of these correction factors are:

1. Effect of temperature.
2. Effect of Shell plate thickness.
3. Effect of tilt.
4. Effect of butt strap (usually applicable to vertical storage tanks).

2.8. Correction for the Effect of Temperature

The petroleum industry uses 60 °F (or 15 °C) as standard temperature for petroleum products. The master tape could be calibrated to this temperature using the equation:

$$\text{Correction factor} = 1 + [(T_s - T_c) \times C] \tag{1}$$

T_c is the calibration temperature of master tape, T_s is the reference temperature, C coefficient of expansion for mild steel 0.00000645 ft/ft/Degree Fahrenheit.

The average circumference of each course shell is then multiplied by the temperature correction factor to obtain the corrected circumference for each course.

2.9. Correction for the Effect of Shell Plate Thickness

$$\text{Required internal circumference } c = c_o - 2\pi t \tag{2}$$

where c_o is the corrected outer circumference, t average thickness of each shell plate.

2.10. Correction for the Effect of Tilt/Slope

Two corrections are usually made for the effects of tilt. These include:

$$T_1 = yD\left(L_R^2 - L_L^2\right) \times \frac{\sin\alpha}{2} \tag{3}$$

$$T_2 = y^2 \times \left(L_R^3 + L_L^2\right) \times \frac{\cot\alpha}{3} \tag{4}$$

L_R length of high end, L_L length of low end, D diameter of the cylinder, y slope

2.11. Correction for the Effect of Butt Strap

This correction is not normally applied to horizontal tanks except when the number of weld per ring exceeds 5. However, this is usually taken into consideration in the calibration of vertical storage tanks [10]

$$\text{Deduction} = \frac{2\text{NtW}}{d} + \frac{8\text{Nt}}{3}\sqrt{t/d} \tag{5}$$

where N is the number of butt straps or projections per ring, t is the amount of rise (thickness of straps or projections), W is the width of straps or projections, in inches, d is the nominal diameter of tank in inches

2.12. Overall Tank Capacity Table

2.12.1. Volume of Barrel

The barrel is cylindrical in shape, so its mathematical derivate is the same irrespective of the attached ends. Exact

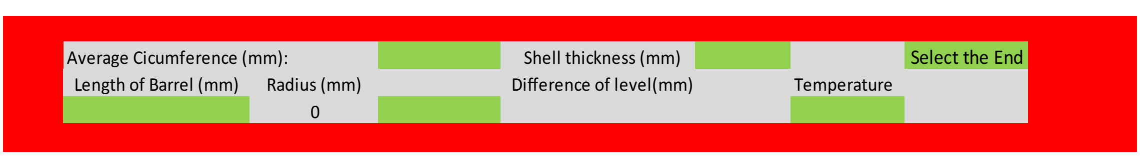

Fig. 1 Interface for MS-Excel programme for horizontal tank calibration

Table 5 Chart for Tank A

Level (mm)	Excel prog. Volume (L)	SGS software Volume (L)	% Deviation
0	0	0	0.00
10	14	14	0.00
20	39	39	0.01
30	72	72	0.01
40	110	110	0.01
50	154	154	0.01
60	203	203	0.01
70	255	255	0.01
80	311	311	0.01
90	371	371	0.01
100	434	434	0.02
110	500	500	0.02
120	570	570	0.02
130	642	642	0.02
140	716	716	0.02
150	794	794	0.02
160	873	874	0.02
170	956	956	0.02
180	1040	1040	0.02
190	1127	1127	0.02
200	1216	1216	0.02
210	1307	1307	0.02
220	1400	1400	0.02
230	1495	1495	0.02
240	1592	1592	0.02
250	1691	1691	0.02
260	1792	1792	0.02
270	1894	1894	0.02
280	1998	1999	0.02
290	2104	2105	0.02
300	2212	2212	0.02
310	2321	2321	0.02
320	2432	2432	0.02
330	2544	2544	0.02
340	2658	2658	0.02
350	2773	2774	0.02
2660	40,122	40,143	0.05
2670	40,236	40,257	0.05
2680	40,348	40,369	0.05
2690	40,459	40,480	0.05
2700	40,568	40,590	0.05
2710	40,675	40,697	0.05
2720	40,781	40,803	0.05
2730	40,886	40,908	0.05
2740	40,988	41,010	0.05
2750	41,089	41,111	0.06
2760	41,188	41,210	0.06
2770	41,285	41,308	0.06
2780	41,380	41,403	0.06
2790	41,473	41,496	0.06
2800	41,564	41,587	0.06
2810	41,653	41,677	0.06
2820	41,740	41,764	0.06
2830	41,824	41,848	0.06
2840	41,906	41,931	0.06
2850	41,986	42,011	0.06
2860	42,063	42,088	0.06
2870	42,138	42,163	0.06
2880	42,210	42,236	0.06
2890	42,279	42,305	0.06
2900	42,346	42,372	0.06
2910	42,409	42,435	0.06
2920	42,469	42,495	0.06
2930	42,525	42,552	0.06
2940	42,577	42,605	0.06
2950	42,626	42,653	0.06
2960	42,669	42,697	0.07
2970	42,708	42,736	0.07
2980	42,741	42,770	0.07
2990	42,766	42,795	0.07
3000	42,780	42,810	0.07

All values under volume for both Excel programme and SGS software are rounded off to the nearest whole number. However, the full values were used for the computation of % deviation $\left\{\left(\frac{\text{SGS volume}-\text{Excel prog volume}}{\text{SGS volume}}\right)\times 100\right\}$ before rounding up to 2 decimal places

mathematical equation of horizontal cylinder with respect to its height is given as

$$V_{cy} = \text{Cross - sectional area}, A \times \text{length}, L$$

$$V_{cy} = L \times \left[R^2\cos^{-1}\left(\frac{R-h}{R}\right) - \left((R-h)\sqrt{2Rh-h^2}\right)\right] + (T_1 + T_2) \tag{6}$$

where R radius of the cylindrical barrel (mm), h height (level) in mm measured from the dip point, L length of barrel in (mm), T_1 and T_2 are the corrections for the effect of tilt as shown in Eqs. 3 and 4.

Equations (3–6) above is converted to Litres (L) by multiplying with 10^{-6}.

2.12.2. *Volume of the Ends*

As earlier stated, the two heads were treated together as one. The three heads commonly encountered are discussed below.

Table 6 Chart for Tank A1

Level (mm)	Excel prog. Volume (L)	SGS software Volume (L)	% Deviation
0	0	0	0.00
10	17	17	−0.02
20	49	49	0.02
30	90	90	0.01
40	138	138	0.01
50	193	193	0.02
60	254	254	0.02
70	319	319	0.02
80	390	390	0.02
90	465	465	0.02
100	544	544	0.02
110	627	627	0.02
120	714	714	0.02
130	804	804	0.02
140	898	898	0.02
150	995	995	0.02
160	1095	1095	0.02
170	1198	1198	0.02
180	1304	1304	0.02
190	1413	1413	0.02
200	1524	1524	0.02
210	1638	1639	0.02
220	1755	1755	0.02
230	1874	1875	0.03
240	1996	1996	0.03
250	2120	2120	0.03
260	2246	2247	0.03
270	2374	2375	0.03
280	2505	2506	0.03
290	2638	2639	0.03
300	2773	2773	0.03
310	2910	2910	0.03
320	3048	3049	0.03
330	3189	3190	0.03
340	3332	3333	0.03
350	3477	3478	0.03
2660	50,169	50,214	0.09
2670	50,312	50,357	0.09
2680	50,453	50,498	0.09
2690	50,592	50,637	0.09
2700	50,728	50,775	0.09
2710	50,863	50,910	0.09
2720	50,996	51,043	0.09
2730	51,127	51,174	0.09
2740	51,255	51,303	0.09
2750	51,381	51,429	0.09
2760	51,505	51,554	0.09
2770	51,627	51,676	0.09
2780	51,746	51,795	0.10
2790	51,863	51,912	0.10
2800	51,977	52,027	0.10
2810	52,088	52,139	0.10
2820	52,197	52,248	0.10
2830	52,303	52,354	0.10
2840	52,406	52,458	0.10
2850	52,506	52,558	0.10
2860	52,603	52,656	0.10
2870	52,697	52,750	0.10
2880	52,787	52,841	0.10
2890	52,874	52,928	0.10
2900	52,957	53,011	0.10
2910	53,036	53,091	0.10
2920	53,110	53,166	0.10
2930	53,181	53,237	0.11
2940	53,247	53,303	0.11
2950	53,307	53,364	0.11
2960	53,362	53,420	0.11
2970	53,410	53,468	0.11
2980	53,451	53,510	0.11
2990	53,482	53,542	0.11
3000	53,500	53,561	0.11

All values under volume for both Excel programme and SGS software are rounded off to the nearest whole number. However, the full values were used for the computation of % deviation $\left\{\left(\frac{\text{SGS volume}-\text{Excel prog volume}}{\text{SGS volume}}\right)\times 100\right\}$ before rounding up to 2 decimal places

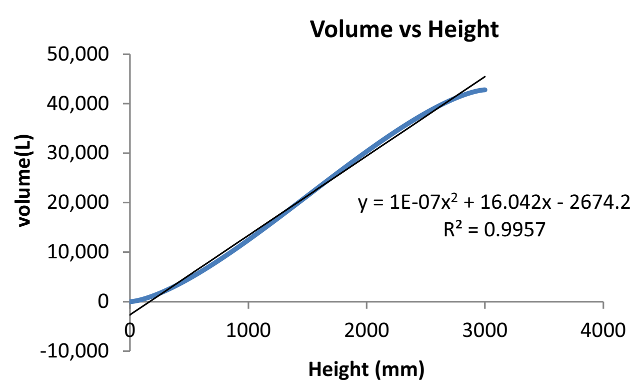

Fig. 2 Volume against height for Tank A using Excel programme

2.12.3. Conical Ends

A conical-ended tank has a cone rise c_r measured from the centre of the cylindrical section to where the cone ends. Conical end is sub-divided into three distinct sections:

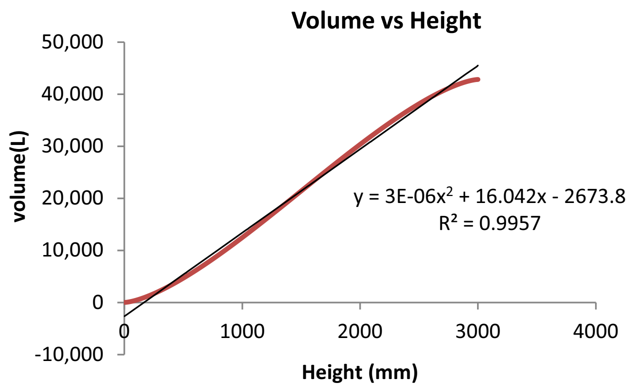

Fig. 3 Volume against height for Tank A using SGS

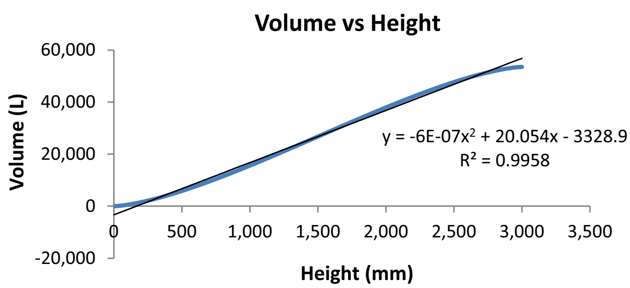

Fig. 4 Volume against height for Tank A1 using Excel programme

1. When the measured height h is less greater than zero but less than the radius of the cylindrical barrel R (i.e. $0 \leq h < R$).
2. When measured height h is equal to the radius of the cylindrical barrel R (i.e. $h = R$).
3. When radius of the cylindrical barrel R is less than the measured height h but h too less than or equal to 2R (i.e. $R < h \leq 2R$).

The volumes of the conical end at these three sections are given in mathematical form as:

For $0 \leq h < R$,

$$\text{Conical end volume } V_{cn} = \frac{2c_r R^2 K}{3} \tag{7}$$

For $h = R$,

$$\text{Conical end volume, } V_{cn} = \frac{2c_r R^2}{3} \times \frac{\pi}{2} \tag{8}$$

For $R < h \leq 2R$,

$$\text{Conical end volume, } V_{cn} = \frac{2c_r R^2}{3} \times (\pi - K) \tag{9}$$

But

$$K = \cos^{-1} M + M^3 \cosh^{-1} \frac{1}{M} - 2M\sqrt{1 - M^2} \tag{10}$$

$$M = \left| \frac{R - h}{R} \right| \tag{11}$$

c_r cone rise (mm), R radius of the cylindrical section, h measured height/level (mm) and V_{cn} conical ended volume [8].

2.12.4. *Elliptical Ends*

For elliptical ended tanks, ellipsoidal radius e_r is measured from the centre of the cylindrical barrel

$$\text{Elliptical volume, } V_e = \pi e_r h^2 \left(1 - \frac{h}{3R}\right) \tag{12}$$

where V_e elliptical volume, e_r elliptical radius (mm), h measured height/level (mm).

2.12.5. *Hemispherical Ends*

When two hemispherical ends combine, they give a complete sphere. Hence, the volume of hemispherical ends V_h is given as:

$$V_h = \frac{\pi h^2}{3}(3R - h) \tag{13}$$

where V_h hemispherical heads volume, R radius of the cylindrical section (mm), h measured height/level (mm)

2.13. MS Excel Programme Interface

The interface where the inputs are supplied is shown in Fig. 1.

3. Results

Information from Tanks A and A1 were fed into both the MS-Excel programme and SGS software and the chart generated for each of the tanks are displayed in Tables 5 and 6 respectively.

4. Discussion

From the Tables 5 and 6, the maximum deviation and average deviation for Tank A are 0.07 and 0.03 respectively while the maximum deviation and average deviation for tank A1 are 0.11 and 0.06 respectively. The above deviations are consistent with the provision of 0.3% variation of the indicated volume [12]. Adetokunbo [16] reported on the effectiveness of geometrical method of tank calibration where it was observed that the maximum deviation noted for chat obtained from SGS and chart from

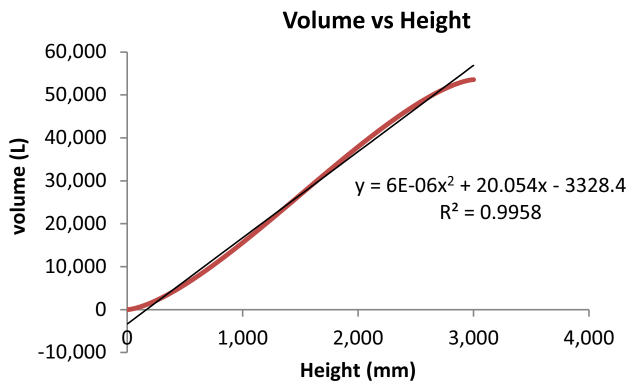

Fig. 5 Volume against Height for Tank A1 using SGS software

Wet calibration of 45,000 L amounts to 0.006. The trend obtained from SGS chart was corroborated with the use of MS Excel package. As a result, there was consistency of results from both charts.

Apart from the fact that the two charts generated from MS-Excel fell within the acceptable limit of ±0.25 as stipulated in the manual of petroleum measurement standards (MPMS), the average time of computation using excel programme is between 180 and 240 s when compared with SGS software which took about an average of 540–660 s.

Also Figs. 2 and 3 which are the graph of volume versus height for Tank A for both Excel programme and SGS software have the same coefficient of determination $R^2 = 0.9957$. The same thing applies for Figs. 4 and 5 for Tank A1 which have coefficient of determination $R^2 = 0.9958$. Though, the model equations for Figs. 2 and 3 may not exactly be the same but have the same coefficient of determination $R^2 = 0.9957$ which confirms the authenticity and correctness of the developed excel programme.

5. Conclusion

Going by the results obtained above, it can be concluded that MS-Excel programme is a better alternative to the customized tank calibration software. Excel is a common software, readily available and easy to learn. Once the algorithm is understood, computation is easily done. Calibrator and Calibration Companies are therefore encouraged to take the better advantage that MS Excel offers.

References

[1] E. A. Agboola, Petroleum product measurement and quality assurance, presentation at the National Seminar on Petroleum Measurement, Department of Petroleum Resources, Lagos, Nigeria (2009).

[2] V. Knyva, M. Knyva and J. Rainys, New approach to calibration of vertical fuel tank, J. Elektron. Elektrotech. **19**(8) (2013).

[3] API 2555, Method for liquid calibration of tank, Measurement Coordination Department, Washington, DC (1998).

[4] J. Guan and H. Zhao, Practical methods of oil volume calibration of horizontal storage tank. Metrol. Meas. Tech. **31**(3) (2004) 21–36.

[5] API MPMS 2.2F, Measurement and calibration of vertical cylindrical tank. Measurement Coordination Department, Washington, DC (2000).

[6] M. Knyva, V. Knyva, Z. Nakutis, V. Dumbrava and M. Saunoris, A concept of fuel tank calibration process automation within IoT infrastructure. MAPAN-J. Metrol. Soc. India **32**(1) (2017) 7–15.

[7] J. Dou, Y. Mei, Z. Chen and L. Wang, Model of the identification of oil tank's position and the calibration of tank capacity table. Pure Appl. Math. **27**(6) (2011) 829–840.

[8] J. Dan, Calculating tank volume. http://www.webcalc.com.br/blog/Tank_Volume.PDF (May, 2015).

[9] F. J. Sun, A Discussion on some difficulties in calibration calculation of horizontal oil tank volume. J. Petrol. Prod. Appl. Res. **18**(5) (2000) 20–24.

[10] T. J. Tian, Volume calculation of straight cylindrical part of tilted horizontal tanks. J. Mod. Meas. Test **5** (1999) 32–36.

[11] X. Wei, W. Xiaojing, C. Huizhe, C. Jun, Optimization model of oil-volume marking with tilted oil tank. Open J. Optim. **1** (2012) 20–24.

[12] OIML R 71 Fixed storage tanks-general requirements. OIML (2008).

[13] X. Weiwei and W. Guodong, Design and implication of a system of measuring oil volume of underground tank. J. Linyi Norm. Univ. **29**(3) (2007) 31–33.

[14] M. A. Sanjid and K. P. Chaudhary, Validation of software used for calibration of angle block at CSIR-NPL India. MAPAN-J. Metrol. Soc. India **31**(1), (2016) 31–41.

[15] L. Chunhui and A. Johnson, Bilateral comparison between NIM's and NIST's gas flow standards. MAPAN-J. Metrol. Soc. India **26**(3) (2011) 211–224.

[16] O. Adetokunbo, Calibration of oil storage tanks, presentation at the Department of Petroleum Resources, Portharcourt branch office, Nigeria (2012).