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Comparative Analysis of Manual Strapping Method (MSM) and Electro-Optical Distance Ranging (EODR) Method of Tank Calibration

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Abstract-

Oil storage tanks are mandated for calibration before putting to use and to be re-calibrated as a statutory requirement at every five year interval. Oil tanks could be calibrated by geometrical methods such as Manual Strapping Method (MSM) and Electro-Optical Distance Ranging (EODR) method. This study compares 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.

Key words: Calibration, Comparative analysis, Oil storage tank, Custody transfer, Measurement

1. Introduction

Tanks are containers used in storing liquids or compressed gases. Though it can be in various shapes such as cubic/cuboidal shape and spherical shape or spheroid, but the acceptable shape in oil industry is cylindrical shape [1]. Upright cylindrical storage tanks used in oil industries are calibrated at an interval as directed by the regulatory agency of various countries. For instance, oil storage tanks are calibrated at five (5) years interval both in Lithuania and Nigeria [2], [3].

Basically, tank calibration can be classified as a wet or dry calibration. Wet calibration involves transfer of a known quantity of liquid into a tank or withdrawal of a known quantity of liquid from a tank [4]. Though, wet method of tank calibration is adjudged to be the most accurate method however it is only practicable in the calibration of small-sized tanks [4], [5]. Dry calibration is known as the geometrical method of tank calibration which involves the accurate measurement of tank dimensions so as to use mathematical formulae and relations to determine its capacity [6]. Dry/Geometrical method of tank calibration is sub-divided mainly into: Manual Strapping Method [7] and Electro-Optical Distance Ranging Method [8]

Manual strapping method (MSM) is the oldest geometrical method of determining tank volume [9]. When using this method, a strapping tape (steel tape) is wound firmly round the circumference of each course of the tank to obtain the actual value of the circumference. Other



measurements such as height of the tank, thickness of each course, temperature, specific gravity of the product to be stored, deadwoods in the tank and their locations; are also required to determine the tank capacity. MSM could be modified into: Optical Reference Line Method (ORLM) and Optical Triangulation Method (OTM). Agboola *et al.* [5] used Microsoft Excel in generating calibration chart for horizontal petroleum storage tanks. It was revealed that the results of comparison done between Microsoft Excel program and Société Générale de Surveillance (SGS software) was found to be in statistical controlled limit. In the study, only manual strapping method (MSM) was used to obtain the field data. Electro-optical Distance Ranging (EODR) involves the use of surveyor's total station to internally scan about eight (8) or more points round the circumference of each course of the tank. Unlike MSM, EODR eliminates the use of scaffold to obtain circumferential measurements and also saves time [2]. There are recent studies in advanced method of tank calibration such as 3D scanning of storage tanks using 3D scanner to determine its capacity as well as the automation of tank calibration process [2], [10], [11]. EODR which has been on ground for a while now is yet to gain total acceptance in Nigeria because of the fear of high cost, efficiency and technical know-how of the calibrators. It is on this note that this study was carried out in comparing MSM and EODR in terms of the efficiency of the generated calibration chart, cost of calibration and duration with safety requirement.

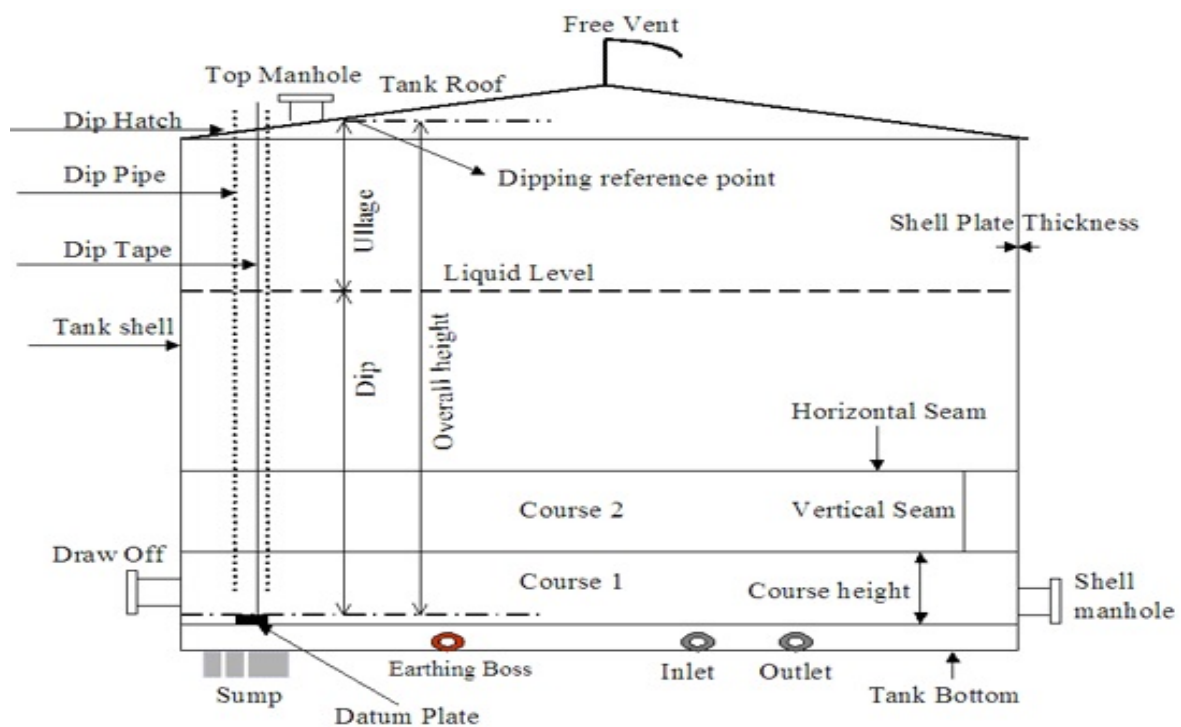


Figure 1: Oil Storage Tank

1.1 Terminologies associated with oil tanks

Some of terminologies associated with oil storage tanks are indicated in Figure 1

Datum Plate: A metal plate located along the vertical axis descending from the dipping reference point, providing a fixed contact surface from which liquid dip measurements are taken.

Dip Hatch: An opening on top of a tank through which dipping, ullaging or sampling operations are carried out.

Dip Pipe: A hollow metal pipe fitted below the dip hatch which projects downwards and ending near the bottom of the tank. It is directly above the datum point and acts as a guide for the dip weight, particularly, when obstructions have to be avoided. It is compulsory for a floating roof tank.

Shell Plate Thickness: This is the value of thicknesses for each course as obtained from the ultrasonic thickness measurement (UTM) machine

Dipping Reference Point: This is a clearly marked point on the dip hatch. It is normally located along the vertical axis ascending from the dipping datum point to indicate the upper reference position to which ullage is measured.

Overall Height: This is the vertical distance between the dipping reference point and the datum point which shall be marked on the tank at the dip hatch.

Dip: It is vertical distance between the datum point and the liquid level.

Ullage: The vertical distance between the liquid level and dipping reference point. It can also be called outage.

Course: One circumferential ring of plates in a tank.

Deadwood: This refers to any tank fitting in a tank. It is called ‘positive’ when the capacity of the fitting adds to the effective capacity of the tank, or ‘negative’ when the capacity of the fitting subtracts from the effective capacity.

2. Methodology

2.1 Equipment used

Table 1 gives the list of equipment used for this study. The study was conducted at Port-Harcourt, Rivers State, Nigeria.

S/N	Name of Equipment	Specification	Uses
1	Strapping tape	100m long steel tape, made by Komelon	To measure the circumference of the course shell of a tank
2	Dip	20m BMI steel tape	To determine the overall internal height of a tank
3	Pocket tape	5m steel tape, made by Crocodile	To measure the height of the course shell of a tank
5	Surveyor's leveling instrument	Pentax N 2.0" Display	To determine the profile of the tank floor

6	Surveyor's Total Station	Pentax W-1500N, 3.5" Display, WinCE 7.0 operating system.	To take the coordinate of various target points round the circumference of each course of a tank
7	Flowmeter	3" size manufactured by Cowell, 75-750L/min flow rate, 150 Psi, 0.07 Repeatability, Model: FMC-80 Smith Flowmeter	To accurately measure the quantity of liquid metered/flowed into the tank
8	Water paste	N/A	To indicate the water level during dipping in wet calibration
9	Strapping rod	N/A	To properly position the strapping tape for higher courses
10	Ultrasonic Thickness Measurement (UTM) Machine	AR850+ Manufactured by: Smart Sensor 1.2 - 225 mm, 10mm, 5MHz	To measure the plate thickness of each course

2.2 Method

Three categories of storage tanks were considered: i. Small size tanks ($\leq 1,000,000$ litres), ii. Medium size tank (1,000,001 – 10,000,000 litres), and iii. Large size tanks (10,000,001 – 20,000,000 litres). A representative tank was chosen for each of the afore-mentioned categories, of which the dimensions and volumes are presented in Table 2.

Table 2: Representative tanks considered in this study

S/N	Tank ID	Nominal Dimensions (m)	Nominal Volume (Litres)	Categories of Tank
1	Tank A	10D x 12.3H	966,000	Small size
2	Tank B	22.49D x 15.1H	5,999,000	Medium size
3	Tank C	29.96D x 20.99H	14,799,000	Large size

Note that 'D' is the nominal diameter and 'H' is the nominal height

Four calibration vendors were contacted to give their best quotations for the calibrations of Tanks A, B and C. Two separate quotations, one each for MSM and EODR were obtained from the four vendors and the average cost for each of the method was computed.

Tanks A, B and C were calibrated by both MSM and EODR while noting their durations and costs. The efficiency of each of the method was determined by comparing the calibrated volume with the volume obtained by wet method at different levels up to 2 m height. The efficiency

was calculated using Equation (1). Wet volume and the corresponding level was obtained by using FMC-80 Smith Flowmeter to meter in/flow in a known quantity of water or liquid [4]. After metering in a known quantity of water, a dip tape coated with water paste was inserted to indicate the level of water metered in.

$$\text{Efficiency} = 100 - \left(\frac{\text{Wet volume} - \text{Geometric volume}}{\text{Wet volume}} \times 100 \right) \quad (1)$$

2.2.1 Manual Strapping Method

The strapping tape was wound round the circumference of each course shell at 20% height and 80% height of the course to determine the average circumference for each course as shown in Figure 2. Pocket measuring tape was used to measure the height of each course while the bottom survey was conducted on the floor of the tank by surveyor's leveling instrument as shown in Figure 3. Bottom survey is conducted to determine the volume at the datum (deadstock/zero volume). Plate thickness of each course was also determined using UTM machine. Internal diameter 'd' was determined using Equation (2) after putting into consideration the effects of temperature, tape rise and plate thickness

$$\text{Internal diameter 'd'} = \frac{c}{\pi} - 2t \quad (2)$$

where c is the average circumference for each course shell and 't' is the plate thickness for each course.



Figure 3: Strapping of tank shell



Figure 4: Bottom survey with leveling instrument

Commonly encountered bottom profiles as described by Dan [12] are spherical, ellipsoidal and conic [12], [13] is as shown in Figure 5. After establishing the profile of the bottom, exact mathematical equations (Equations (3) – (8)) as given by Dan [12] was then adopted to compute the volume at any level/height.

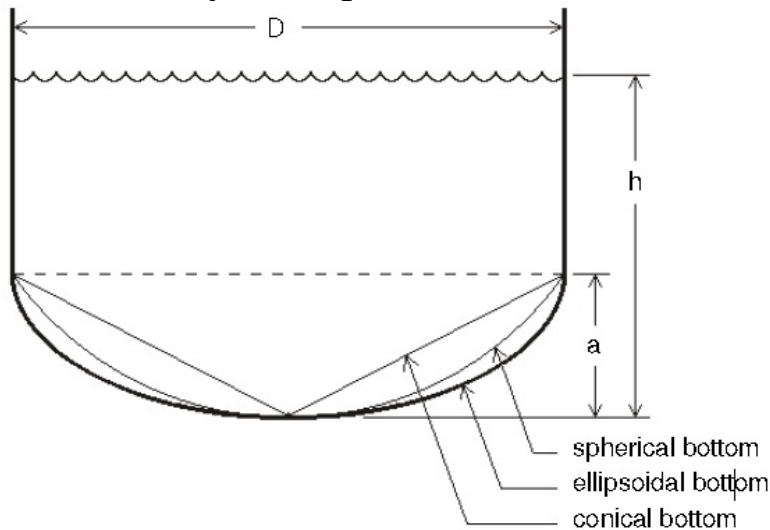


Figure 5: Commonly encountered bottom profile [12]

Conical bottom Profile

$$\text{Calibrated volume for conical bottom profile } V_c = \frac{\pi}{4} \left(\frac{Dh}{a} \right)^2 \left(\frac{h}{3} \right) \quad \text{when } h < a \quad (3)$$

$$\text{Calibrated volume for conical bottom profile } V_c = \frac{\pi D^2}{4} \left(h - \frac{2a}{3} \right) \quad \text{when } h \geq a \quad (4)$$

Ellipsoidal bottom Profile

$$\text{Calibrated volume for ellipsoidal bottom profile } V_e = \frac{\pi}{4} \left(\frac{Dh}{a} \right)^2 \left(a - \frac{h}{3} \right) \quad \text{when } h < a \quad (5)$$

$$\text{Calibrated volume for ellipsoidal bottom profile } V_e = \frac{\pi D^2}{4} \left(h - \frac{a}{3} \right) \quad \text{when } h \geq a \quad (6)$$

Spherical bottom Profile

$$\text{Calibrated volume for spherical bottom profile } V_s = \frac{\pi h^2}{4} \left(2a + \frac{D^2}{2a} - \frac{4h}{3} \right) \quad \text{when } h < a \quad (7)$$

$$\text{Calibrated volume for spherical bottom profile } V_s = \frac{\pi}{4} \left(\frac{2a^3}{3} - \frac{aD^2}{2} + hD^2 \right) \quad \text{when } h \geq a \quad (8)$$

where C is the average circumference of each course; t is the plate thickness of each course; a is the assistance between the datum point and the deepest point at the centre of the tank floor; h is the calibrated height/level; D is the internal diameter of the course shell; V_c is the calibrated volume for conical bottom profile; V_e is the calibrated volume for elliptical bottom profile; V_s is the calibrated volume for spherical bottom profile

2.2.2 Electro Optical Distance Ranging

Surveyor's total station and its ancillary equipment were set at the centre or near the centre at the tank floor. A series of target points (minimum of 8 points) were struck at 25% and 75% height of each course height. This was done from the first course through to the last course. The coordinates x, y, z generated round the internal circumference of all the courses were transferred

to AUTOCAD 2017 to generate the circular section so as to determine its cross-sectional area (Figure 6). The cross-sectional area generated from each course was multiplied by the corresponding height to obtain the calibrated volume at a particular level. Figure 7 shows the circular section for course shell generated from coordinates supplied into AUTOCAD 2017. The volume calibrated using EODR can be determined using Equation (9).

$$V_{EODR} = \text{Area obtained from AUTOCAD drawn section } A \times \text{Height considered } h \quad (9)$$

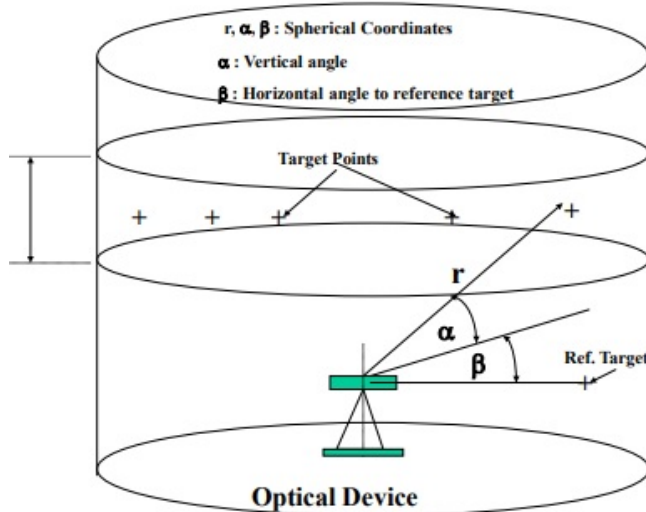


Figure 6: Use of EODR for tank calibration [14]

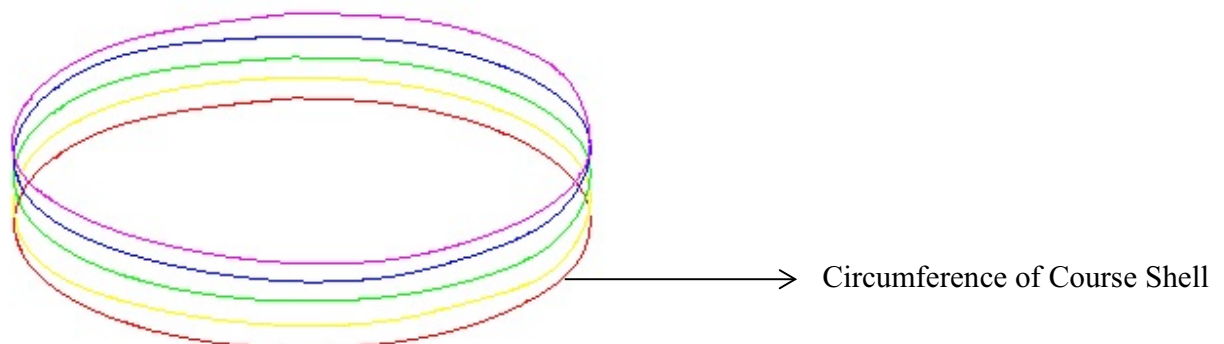


Figure 7: Circular section generated from each course shell

3. Results and Discussion

Table 3 shows the cost of calibration and the time taken to calibrate for both MSM and EODR. Tanks A, B and C illustrate the small, medium and large sample tanks based on their dimensions, respectively. The costs of calibration of the three categories of storage tanks as well as the time taken to perform the calibration using the two methods were reported as shown in Table 3. The costs of calibration for both methods range from #117,258.50 to #604,942.92. Calibration costs for both methods for small storage tank is below #200,000; for medium storage tank is below #300,000 and for large storage tank is below #610,000. An assumption that calibration personnels could only perform their duties for close to 8 hours was used in this study. Hence, the time to calibrate the small tank (Tank A) for the MSM and EODR are 7.6 h (1 day) and 4.1 h (1 day), respectively. Calibration time taken for Tank B and Tank C for MSM and EODR are

13.3 h (2 days) and 7.5 h (1 day), respectively; and 19.7 h (3 days) and 10.4 h (2 days), respectively.

Table 3: Cost of calibration and time taken for calibration

S/N	Tank ID	Nominal Dimensions (m)	Cost of calibration (#)		Time taken (hour/Day)	
			MSM	EODR	MSM	EODR
1	Tank A	10D x 12.3H	117,258.50	198,685.99	7.6h/1 day	4.1h/1 day
2	Tank B	22.49D x 15.1H	228,470.37	285,885.41	13.3h/2 days	7.5 h/1 day
3	Tank C	29.96D x 20.99H	589,627.66	604,942.92	19.7 h/3days	10.4h/2 days

Assumption is that the calibration personnel could only work for a maximum of eight hours (8 h) in a day. A day is ≤ 8 h

From Table 3, it was observed that the cost incurred while adopting EODR was slightly higher than that of MSM when compared for each tank under study. However, the duration of calibration was reduced in EODR when compared with MSM for each tank under study. Therefore, it can be said that EODR is faster and slightly expensive than MSM for usage for each tank level.

MSM and EODR calibrated volume at different level/height up to two metres (2 m) for the three tanks are shown in Table 4. The bottom profile for the tanks A, B and C are flat, cone and cone, respectively. For both methods, calibrated volume increases as the level or height increases. Moreover, calibrated volume in EODR was higher than MSM at every level considered for all the three tanks. This indicates that EODR can be said to be more accurate in volume calibration of storage tanks **than MSM as supported by Knyva et al. [2]**

Table 4: Calibrated volume at various levels

Tank ID	Bottom profile	MSM (Calibrated volume at different level/height in Litres)				EODR Calibrated volume at different level/height in Litres)			
		0 m	1 m	1.5 m	2 m	0 m	1 m	1.5 m	2 m
Tank A	Flat	341	78,891	118,166	157,441	350	79,930	119,735	160,120
Tank B	Cone	797	405,288	603,943	802,598	7990	406,090	605,440	804,990
Tank C	Cone	200	725,062	1,077,592	1,430,121	2001	725,095	1,782,715	3,192,875

Table 5: Efficiency at the datum level and at the highest calibrated level

Tank ID	Wet calibration		MSM		EODR		MSM Efficiency		EODR Efficiency	
	0 m	2 m	0 m	2 m	0 m	2 m	0 m	2 m	0 m	2 m
Tank A	358	164,910	341	157,441	350	160,120	95.3	95.5	97.1	97.1
Tank B	8,305	824,720	7,978	802,598	7,990	804,990	96.1	97.3	96.2	97.3
Tank C	20,806	1,472,183	20,002	1,430,122	20,015	1,430,175	96.1	97.1	96.2	97.1

Table 5 gives a further analysis of Table 4, where the efficiency of both MSM and EODR was determined. The wet calibration values and dry calibration values based on MSM and EODR for datum and highest calibrated levels were as shown in Table 5. The efficiencies for MSM and EODR were obtained based on Equation (1) for each of the tank. The efficiencies obtained show the accuracy of the methods.

Tank A which has the smallest nominal capacity had its MSM efficiency lower than Tanks B and C. It was observed that for Tank A that the EODR efficiency maintained same value of 97.1 m at datum and highest calibrated level. This might be due to uniform cross-sectional area between the datum and the highest calibrated level for this study. Furthermore, it could be opined that there are no local deformations such as bulges and dents. More so, the efficiency at 2 m was slightly higher than the MSM and EODR efficiencies at the datum (zero level) for all the tanks. From the foregoing, it could be inferred that the efficiencies increase with an increasing level. Higher efficiency with shorter duration observed when using EODR corroborated the work of Knyva *et al.* [2]. It could also be said that the results of calibration of both methods are efficient because they satisfied the minimum requirement of 95% efficiency when compared to wet calibration [3], [13].

4. Conclusion

The comparative analysis of Manual Strapping Method and Electro-Optical Distance Ranging method of tank calibration has been carried out. The results confirmed that both methods were efficient. The cost of utilizing EODR for calibration is a bit higher than MSM but compensated with higher efficiency and a shorter duration when compared with MSM which shows longer duration with lower cost. Due to the shorter duration involved in EODR, the study suggests that the method can viably be used in Nigeria for storage tanks calibration. More so, based on the analyzes done for both methods, the study has offered the decision makers opportunity to make choice of calibration method they preferred to use; considering the cost, efficiency and duration.

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