



EMPIRICAL MODEL AND SOFTWARE DEVELOPMENT FOR CRUDE OIL CARGO QUANTITY MEASUREMENT AND DISCREPANCIES DETERMINATION IN NIGERIA

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Abstract

The petroleum industry is faced with measurement problem. The reason for this could be as a result of low value of petroleum products derived at the time of installation. However, over the years, with increasing crude oil prices of associated petroleum products, there is a need to ensure that cargoes loaded and discharged are measured more accurately with minimum losses. Hence, this research is focused on developing an empirical model for oil cargo quantity shipment, discrepancies determinations in Nigerian oil and gas sector. To achieve the objectives of this research, collection of data of past shipping activities were carried out. MATLAB was used to analyze the collected data and model was developed as well as a discrepancy predictive software, using Visual Basis Software. The volume correction factor (VCF), a factor used in converting crude oil volume at tank temperature to volume at standard temperature 15°C was determined. The weight correction factor (WCF), a factor used in converting volume of crude oil in barrels to weight in long tons was generated through a model which can be used to get the corresponding weight correction factor at different temperatures. A comparison was done between the results generated from the developed software and the certificate of quantity COQ of crude oil obtained from the Department of Petroleum Resources in the Ministry of Petroleum Resources, Nigeria (July 2019). It was found that 80 metric ton valued at N12,000,000.00 of crude oil was lost due to the miscalculation of the transported crude oil. With the aid of this software, similar errors in crude oil shipment can be detected and minimized.

Keywords: Model, software development, crude oil, cargo quantity, measurement

Introduction

The Nigerian petroleum industry has brought exceptional changes to the country's economy, particularly in the last five decades when it replaced agriculture as the bedrock of her economy. The oil industry had risen to an unassailable loftiness, contributing the lion's share to gross domestic product GDP and this account for the bulk of Federal government income and foreign exchange earnings since early 1970 (Apata, 2010; Akinlo, 2012). It is reported to be the primary driver of speedy advancement in technology and economic growth experienced, which has brought civilization to humans over the century (Yakubu, 2017).

This sector of the economy has been adjudged to be the largest among all industries in the country and is a critical energy sector which provides over 50 percent of all energy consumption globally. It is a known fact that revenues accrued from crude oil in Nigeria are of great advantage as it is used in financing various expenditures on projects at various tiers of government. Thus, the economy depends heavily on the revenue

derived from petroleum products, providing about 70 percent of government revenue and 95 percent of foreign exchange earnings (Onwe, 2012). However, in spite of being the main source of government revenue, reports showed that in the year 2020, the oil sector trailed other sectors in terms of GDP's contribution. The contributions of oil and gas sector to the country's GDP is reported to be declining, from 13% in 2013 to about 7% in 2020. Interestingly, other sectors continue to increase (PWC, 2021).

The industry has been extensively described as the country's live wire and this account for outstanding literatures that abound on its significance on Nigerian economy. However, the extreme over-dependence on the crude oil earnings had led to unexpected structural difficulties for the economy, as crude oil revenues fluctuate along with market trends (Aigbedion and Iyayi, 2007).

Despite Nigeria's huge oil wealth and gains made, the economy has been plagued by sustained underdevelopment resulting to poor human

development, inequalities in income distribution, unemployment, militancy and oil theft in the Niger Delta (Nwezeaku, 2010). The oil boom of the last four decades led to economic shift which resulted to neglect of its viable agricultural and manufacturing bases in favour of over-reliance on crude oil (Gbadebo, 2007).

Kato (2019) posited that Nigerian crude oil is being stolen on an industrial scale and some of what is stolen is exported. This is believe to be orchestrated by militants, politicians, security operatives, personnel of oil industry and the host communities. The trade also encourages other transnational organized crime at the Gulf of Guinea (Christianah and Aaron, 2013). Most of the stolen crude oil in Nigeria is transported by the criminal gangs through the inland waterways, thereby requiring adequate laws and strict enforcement of the laws. For instance, Shell Petroleum Development Company (SPDC) in the year 2017 confirmed that it lost nearly 3, 204, 000 barrels of crude oil to thefts (Osakhare, 2018).

A cargo shortage out-turn claim where the quantity discharged is reportedly less than the 'Bill of Lading' (B/L) loaded quantity, could arise either through a physical loss or paper loss. According to Focus (2016), a physical loss may ensue due to evaporation loss during the voyage, (occasioned by high heat generated by the cargo or faulty pressure vacuum valves), errors in measurement onboard and ashore, leakage into other tanks, pollution, poor pumping and discharge performances incorrect pipeline settings onboard and ashore and theft when loading into trucks or cargo diverted to ship's fuel tanks. On the other hand, a paper loss usually occurs as a result of errors in measuring the shore tanks, inflated figures of the quantity loaded, calculation and measurement errors in producing the B/L and understatement of the quantity received in shore tanks.

Various studies have been undertaken on crude oil losses in Nigeria. Bhatia (2004) worked on daily oil losses in shipping crude oil and reported that appalling crude oil spills excite media interest but operators usually manage greater losses from daily shipping operations. Anifowose (2008) researched on environmental challenge of transportation in Nigeria's oil and gas industry. The work identifies some noteworthy limitations in environmental impact assessment (EIA) protocols in Niger Delta areas and recommended a number of improvements to abate oil industry environmental impacts. Emeghara and Ndikom (2012) evaluated delay contributory factors in Nigerian ports industry with Apapa ports complex as focus. Jack *et al.*, (2016) analyzed contents of the current state of resource to explain the relationship between oil exploration and underdevelopment in the country. It further presents limitations for attaining sustainable oil exploration and development of Nigeria.

In spite of researches on petroleum exploration, much has not been done in the area of cargo quantity measurement with the view to identifying potential errors in measurement of crude oil and petroleum products which may result in discrepancies in loaded or discharged cargo quantities, and this is the motivation behind this work.

Methodology

In order to determine the discrepancies associated with loading and discharging of crude oil, data used for this research were sourced for from the Department of Petroleum Resources DPR, Port-Harcourt. The data were statistically analyzed using MATLAB and were used for model formulation and the development of software for determination of volumes of selected crude oil tank geometries

Model Used

The nomenclatures used for the model development are given as follows:

α_{60} is the coefficient of thermal expansion; Δt is the difference between the reference temperature and tank temperature; ρ_{60} is the density of the standard temperature 60°F ((KG/M³)²/°F); is the relative density at temperature t ; API_t is the American Petroleum Institute (API) gravity at temperature t ; K_0 and K_1 are the thermal expansion constants; V_f is the filled volume (Gauged Volume) of the crude oil; COQ is the certificate of Quantity; G_{ST} is the gross standard volume of the crude oil; G_{LT} is the gross long ton of the crude oil; G_{MT} is the gross metric ton of the crude oil; W_f is the Barrels of water in the crude oil; N_B is the Net Barrel; N_M is the Net Metric ton; N_L is the Net Long ton; t_{ref} is the tank temperature; D_V is the Displaced Volume of the crude oil.

Volume Correction Factor

The following models 1-6 were used for the determination of volume correction factor according to Tanker (2022).

$$VCF = EXP[-\alpha_{60}\Delta t(1+0.8\alpha_{60}\Delta t)] \quad (1)$$

$$\Delta t = t - t_{ref} \quad (2)$$

$$\alpha_{60} = \frac{K_0}{\rho_{60}^2} + \frac{K_1}{\rho_{60}} \quad (3)$$

$$\rho_t = \frac{141.5 \times 999.012}{131.5 + API_t} \quad (4)$$

$$\rho_t = \rho_{60} EXP[-\alpha_{60}\Delta t(1+0.8\alpha_{60}\Delta t)] \quad (5)$$

$$\rho_t = \rho_{60} \times VCF \quad (6)$$

Determination of Weight Correction Factor

Weight correction factor, WCF as presented in equation 7 is used in converting volume of the crude oil in barrels to weight in long tons.

$$WCF = \frac{C_1}{API_t + C_2} \quad (7)$$

C_1 and C_2 are constants gotten from the development of model which fits the referenced data of WCF

Determination of Gross Observed Volume

Gross observed volume, G_{OV} as shown in equation 8 is the volume of the crude oil measured at the tank temperature. It includes dissolved water, suspended water and sediments.

$$G_{OV} = F_V - D_V \quad (8)$$

Determination of Gross Standard Volume

Gross standard volume, is the volume of oil including dissolved water, suspended water and sediment, measured at standard conditions but excluding free water and bottom sediment. This can be gotten by multiplying the gross observed volume by the volume correction factor and it is presented in equation 9.

$$G_{SV} = VCF \times G_{OV}$$

Determination of Gross Long Tons

Converting crude oil from standard volume to long tons require weight correction factor. This factor which depends on the APT at tank temperature was determined using equation 10

$$G_{LT} = G_{SV} \times WCF \quad (10)$$

Determination of Gross Metric Tons

Metric tons can be derived by multiplying long ton with 1.01605 according to the Imperial system of measurements.

$$G_{MT} = G_{LT} \times 1.01605$$

Determination of water content

The water content can be calculated using the gross observed volume in barrels and the percentage water content observed.

$$W_P = G_{OV} \times W_C \quad (12)$$

2.1.9 Determination of Net barrels N_B , Net long ton N_{LT} and Net metric ton N_{MT}

The net barrels, net long ton and net metric ton are determined using equations 13, 14 and 15 respectively.

$$N_B = G_{SV} \times W_P \quad (13)$$

$$N_{LT} = G_{LT} - (0.15615 \times G_{OV} \times W_P) \quad (14)$$

$$N_{MT} = 1.01605 \times G_{LT} \times (0.15615 \times G_{OV} \times W_P) \quad (15)$$

Analysis on Weight Correction Factor (WCF)

The weight correction factor (WCF) is the factor used in converting volume of crude oil in barrels to weight in long tons. This value can be found in ASTM table 11 (Tanker, 2022). While reading table it is possible the exact corresponding value is not available which will require professional to interpolate or extrapolate the value, the result gotten from this procedure is not 100 percent valid because if the graph of the data is not linear, performing a linear interpolation can give a falsified result. So therefore, we will go ahead to generate a model which can be used to get the

corresponding weight correction factor at different temperature.

To achieve this, MATLAB was used to model an equation from a given set of data. 360 x and y data were gotten from ASTM table 11 where x and y are corresponding temperature and weight correction factor respectively. These data were inputted inside MATALAB and thereafter plotted inside a figure. The plot was fitted with different model and it was found out that the below rational model was the best fit as presented in equation 16.

$$f(x) = p_1 \left(\frac{1}{x+q_1} \right) \quad (16)$$

Where x is a known temperature in °F

p_1 and q_1 are constant which are 21.99 and 130.7 respectively. The constants have 95% confidence bounds.

The flowchart for the model development is presented in Figure 1.

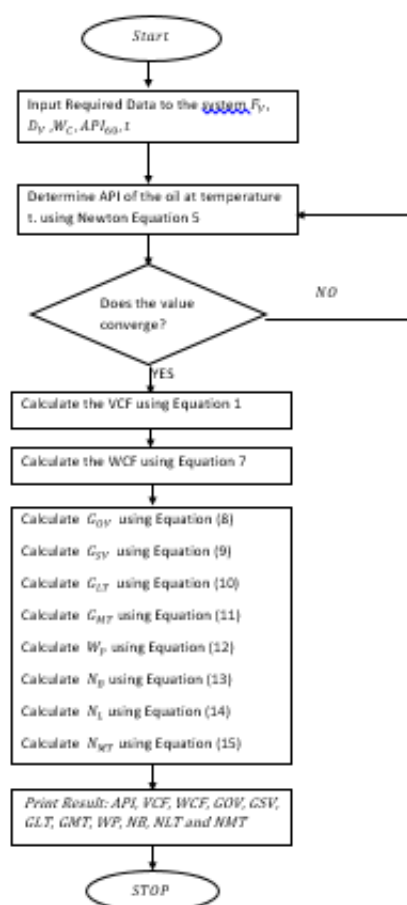


Figure 1: Flowchart for the software development

Results and Discussion

Various tests were performed using MATLAB to see how the model fits into the real data (Goodness of fit). The results of the test are tabulated and presented in Table 1.

Table 1: Test Results using MATLAB

Test	Result
Sum of square error	0.000004799
R-square test	0.9996
Adjusted R-square test	0.9996
Root mean square error	0.0001267

The tabulated results showed that the model has a very good fit to the known data. This model was used to develop the software and the screenshot of the user interface is shown in Figure 2.

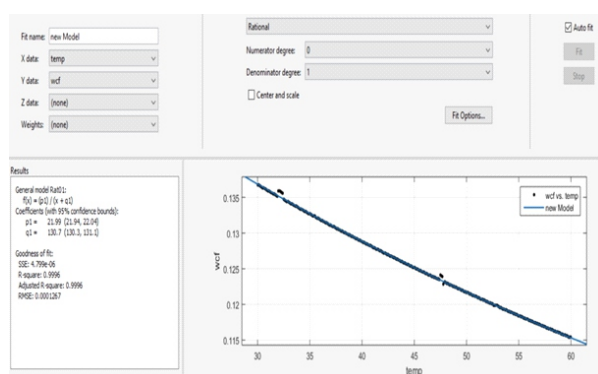


Figure 2: Model result interface

The developed software is divided into 3 sections namely; ASTM Tables calculator, Tank volume calculator, Quantity, calculator. This is shown in Interface of the software developed as presented in Figure 3.

Figure 3: Interface of the software developed

From the screenshot of the developed software as shown in Figure 3, once the API gravity and the corresponding temperature are inputted, the software will calculate the corresponding value and display the results. The ASTM values were calculated using Newton Rapson method and once the iteration converges, the resulting outputs are displayed on the model interface as presented in Figure 4. The software developed also include section to calculate tank volume of seven (7) different tank shapes which are, horizontal cylindrical tank, vertical cylindrical tank, rectangular tank, horizontal oval tank, vertical oval tank, horizontal capsule tank and vertical capsule tank.

The main window of the software is divided into 3 sections. The left side where the type of ASTM Table is listed, the middle where the input parameters are registered and the right side where the result are displayed. The volumes of the tank (output) are display in barrels while the sizes of the tanks (input parameter) are in feet as shown in Figure 4.

Calculated	Table	Value
API @ 60F		41.4179
VCF		0.9921
Den @ 60F		817.4985
WCF @ 60F		0.1278
GOV		282659
GSV		280425.99...
Gross LT		35838.442...
Gross MT		36413.649...
Wp		423.9885
Net Barrels		280002.00...
Net LT		35772.236...
Net MT		36346.380...

Figure 4:Interface of Volumes of the tank (output)

Table 2 shows the certificate of quantity of crude oil (COQ) gotten from the Department of petroleum resources in the ministry of petroleum resources Nigeria in July 2019. The certificate was obtained to compare the result with that of the software. "S" is the result generated from the software and "C" is the result gotten from the COQ. In the COQ, the total number of tanks available are ten (10). Input details such as tank temperature and water content are also available.

Table 2: Comparisons Analysis between the Proposed Software and Real Certificate of Quantity of Crude Oil COQ Data

		G. O.V.	Tan k Temp	API Gravity	V.C.F	W.C.F	G.S.V.	Gross LT	W. C	H2OCO N.	Net barrel	Net LT	Net. MT
Tank No.1	S	53646	85.2	37.8761	0.9876	0.1304	52980.79	6908.695	0.08	42.9168	52837.88	6901.994	7012.771
	C	53646	85.2	40	0.9874	0.12881	52970	6823	0.08	42	52928	6816	6925
	S	4068	83.9	37.5008	0.9883	0.1307	4020.404	525.4669	0.23	9.3564	4011.04	524.0059	532.4161
	C	4068	83.9	39.5	0.988	0.12918	4019	519	0.23	6	4013	516	526
Tank No. 2	S	90893	85.9	37.8183	0.9873	0.1305	89738.66	11710.89	0.08	72.7144	89665.95	11699.54	11887.32
	C	90893	85.9	40	0.9869	0.12881	89702	11555	0.08	72	89630	11544	11729
	S	5624	84.6	37.4434	0.998	0.1308	5556.512	726.7918	0.23	12.9352	5543.58	724.7719	736.4045
	C	5624	84.6	39.5	0.9877	0.12918	5555	716	0.23	13	5542	716	721
Tank No. 3	S	57987	87.6	37.6784	0.9865	0.1306	57204.18	7470.865	0.08	46.3896	57157.79	7436.622	7583.413
	C	57987	87.6	40	0.986	0.12881	57181	7365	0.08	46	57135	7358	7476
	S	11266	85.8	37.3427	0.9874	0.1309	11143.8	1458.723	0.23	25.9578	11117.84	1454.67	1478.017
	C	11266	85.8	39.5	0.987	0.12918	11139	1439	0.23	25	11114	1455	1458
Tank No. 4	S	127347	91.7	37.3427	0.9845	0.1309	125373.1	16411.34	0.08	101.8776	125271.2	16395.43	16658.58
	C	127347	91.7	40	0.9841	0.12881	125322	16143	0.08	100	125222	16127	16386
	S	27440	88.2	37.1495	0.9863	0.131	27064.07	3545.393	0.23	63.112	27000.96	3535.538	3592.284
	C	27440	88.2	39.5	0.986	0.12918	27056	3445	0.23	62	26994	3480	3541
Tank No. 5	S	122695	90.6	37.4325	0.985	0.1305	120852.6	15807.52	0.08	98.1544	120754.5	15792.19	16045.66
	C	122695	90.6	40	0.9846	0.12881	120804	15561	0.08	97	120707	15546	15796
	S	20316	69.4	38.7041	0.9953	0.1298	18417.03	2390.531	0.23	42.5592	18374.47	2383.885	2422.146
	C	20316	69.4	39.5	0.9952	0.12918	20015	2586	0.23	46	19969	2576	2620
Tank No. 6	S	81757	84.7	37.9173	0.9879	0.1304	80767.74	10532.11	0.08	65.4056	80702.33	10521.9	10690.78
	C	81757	84.7	40	0.9877	0.12881	80751	10402	0.08	65	80686	10392	10559
	S	13530	84.5	37.4516	0.988	0.1308	13367.74	1748.487	0.23	31.119	13336.52	1743.628	1771.613
	C	13530	84.5	39.5	0.9877	0.12918	13364	1726	0.23	30	13334	1721	1749
Tank No. 7	S	110526	83.5	38.0163	0.9884	0.1303	109243.9	14234.48	0.08	88.4208	109155.5	14220.67	14448.91
	C	110526	83.5	40	0.9882	0.12881	109222	14069	0.08	87	109135	14055	14281
	S	20104	64.5	39.117	0.9978	0.9215	20059.77	2597.74	0.23	46.2392	20013.53	2590.52	2632.098
	C	20104	64.5	39.5	0.9871	0.12918	19857	1926	0.23	46	19811	2558	2598
Tank No. 8	S	85752	85.8	37.8266	0.9873	0.1305	84662.95	11048.51	0.08	68.6016	84594.35	11037.8	11214.96
	C	85752	85.8	40	0.9869	0.12881	84629	10901	0.08	68	84561	10890	11065
	S	10645	85.4	37.378	0.9876	0.1308	10513	1375.101	0.23	24.4835	10488.53	1371.278	1393.287
	C	10645	85.4	39.5	0.9872	0.12918	10509	1358	0.23	30	10479	1350	1376
Tank No. 9	S	56939	83.2	38.0413	0.9886	0.1303	56289.9	7334.573	0.08	45.5512	56244.34	7327.461	7445.066
	C	56939	83.2	40	0.9884	0.12881	56279	7249	0.08	45	56234	7242	7358
	S	10973	83.8	37.509	0.9884	0.1307	10845.71	1417.535	0.23	25.2379	10820.48	1413.594	1436.282
	C	10973	83.8	39.5	0.9882	0.12918	10844	1409	0.23	25	10819	1308	1418
Tank No. 10	S	57945	84.2	37.9586	0.9881	0.1304	57255.45	7466.111	0.08	46.356	57209.1	7458.873	7578.588
	C	57945	84.2	40	0.9879	0.12881	57244	7374	0.08	46	57198	7367	7485
	S	9475	83.5	37.5336	0.9885	0.1307	9366.038	1224.141	0.23	21.7925	9344.24	1220.738	1240.331
	C	9475	83.5	39.5	0.9882	0.12918	9363	1210	0.23	22	9341	1201	1236

Result of the Discrepancies Discovered

A Comparison was done with the result generated from the designed software and the certificate of quantity of crude oil obtained from the Department of Petroleum Resources (DPR) in the Ministry of Petroleum Resources, Nigeria (July 2019). With reference to Table 4.5, it was found out that 80 MT (N12,000,000.00) of crude oil was lost due to the miscalculation of the transported crude oil.

The source of this error or loss of crude oil can be traced to the calculations of the ASTM Standards. The ASTM standards are correct but during interpolation or extrapolation while reading the tables, some data were lost, thereby giving rise to loss of crude oil. The model used in the software was developed to correct the error. With the aid of this software similar error in crude oil transport can be solved.

Figure 5 shows the weight correction factor for the software developed software and COQ of Nigeria crude oil.

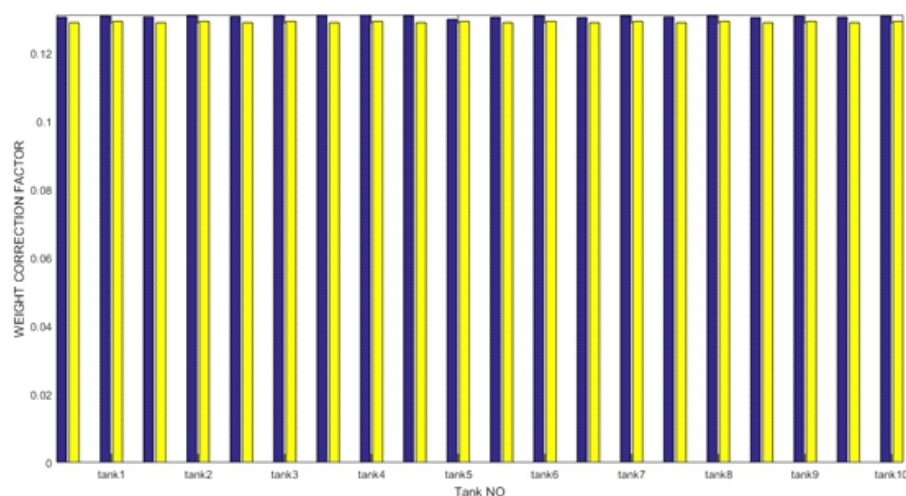


Figure 5: Weight correction factor WCF for the software and COQ of Nigeria crude oil

From Figure 5, the weight correction factor is used in converting of the crude oil in barrels to weight in long ton. The WCF model has been validated with various statistical test with high confidence result up to 0.996 for sum of square error. Comparing the results generated from the software with the COQ, it was noted that the factor generated from the software are

more valid compare to that in the COQ. The factor gotten from the software is more accurate because it gives more valid quantity when compared with the one used in the COQ.

The summary of the WCF statistical data of the 10 tanks are presented in Table 3

Table 3: Summary of the WCF statistical data of the 10 Tanks

	Mean	Standard Variation	Variance	Skews	kurtosis
Software	0.1306	0.00028	0	-1.0732	4.1870
COQ	0.1290	0.00020	0	0	1.0000

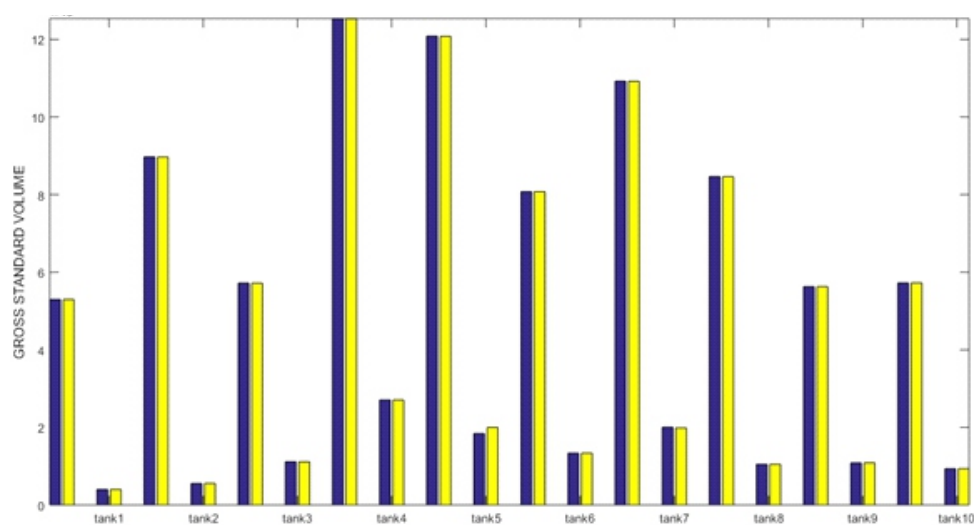


Figure 6: Gross standard volume GSV and COQ Nigeria Crude Oil

From Figure 6, the GSV is the volume of the crude oil including dissolved water, suspended water and

sediment measured at standard condition (60°F and 14.7 psia). Looking at the bar chart, it is observed that

the software result is a little bit higher than that of the COQ except the tank 5 data which may have cause the average value higher than the software. This is not a

conclusion because the GSV contain water and other sediment matter. The summary of the GSV statistical data of the 10 tanks are presented in Table 4.

Table 4: Summary of the GSV statistical data of the 10 Tanks

	Mean	Standard Variation	Variance	Skews	kurtosis
Software	48236.16	41124	1.69×10^9	0.5781	1.9626
COQ	48291.25	41057	1.69×10^9	0.5777	1.9656

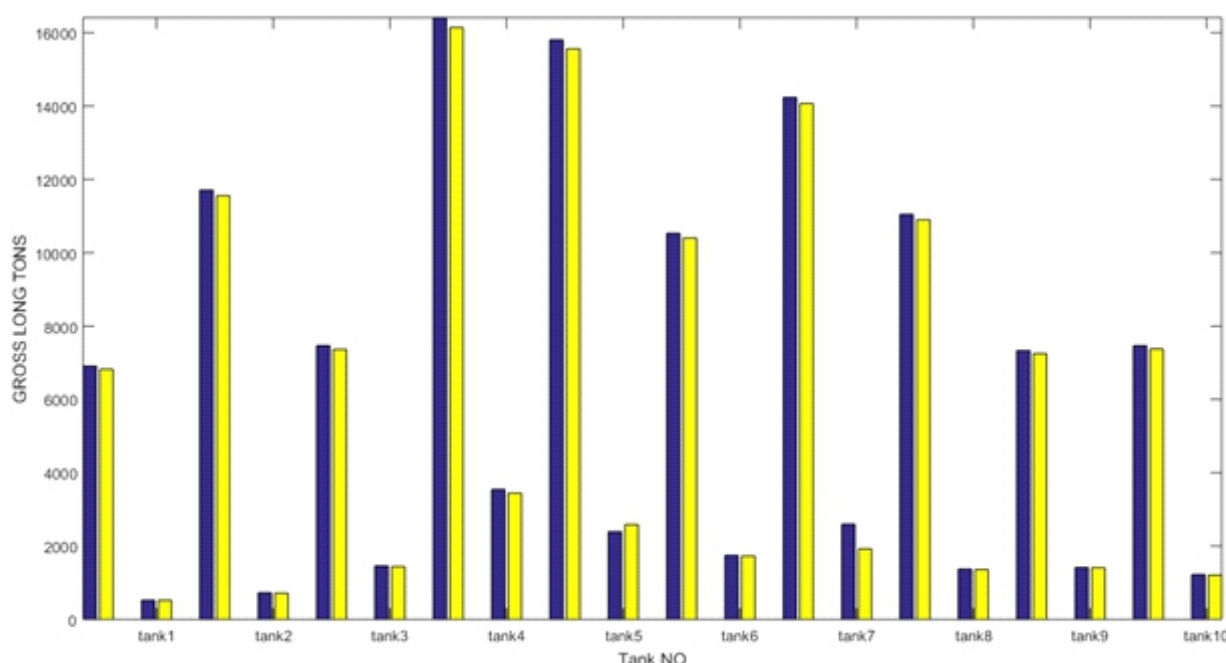


Figure 7: Gross long tons GLT and COQ GLT of Nigeria Crude Oil

Figure 7 shows gross long tons GLT and COQ GLT of Nigeria crude oil. The barrel gotten from the GSV can be converted to long ton by multiplying the GSV with the WCF. From the bar chart, the weight gotten from

the software is more than that of the COQ. The reason for this is because the WCF is higher and more accurate than the COQ. The difference in the software WCF and the COQ weight correction factor was not that much (

Table 5: Summary of the GLT statistical data of the 10 Tanks

	Mean	Standard Variation	Variance	Skews	Kurtosis
Software	6296.7	5372.9	2.89×10^7	0.5822	1.9714
COQ	6188.8	5312.9	2.82×10^7	0.5780	1.9542

Conclusion

An empirical model for oil cargo quantity shipment discrepancies, determination and remedies in Nigerian has been carried out. To achieve this, collection of data of past shipping activities was carried out. The data collected were statistically analyzed and a model developed using Visual Basic Software to predict the level of discrepancies in cargo crude measurements. This model was used to program the software. Comparison was done with the result generated from the designed software and the certificate of quantity COQ of crude oil obtained from

the relevant Government agency. It was found out that 80 MT (N12,000,000.00) of crude oil was lost due to the miscalculation of the transported crude oil.

The source of this error or loss of crude oil could be traced to the calculations of the ASTM Standards. The ASTM standards are correct but during interpolation or extrapolation while reading the tables, some data were lost, thus giving rise to loss of crude oil. The model used in the software was developed to correct the error. With the aid of this software, similar error in crude oil transport can be solved.

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