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***Abstract*—The purpose of this paper is to design a 10 million litre capacity petroleum storage tank for use in the oil industry in Nigeria with a view to overcoming the challenges associated with the loss of product due to evaporation. The tank having diameter and height of 27.4m and 17.5m respectively was designed to have two relief valves; a primary valve which would ensure that the product vapour pressure within high-level (h2) in meters of the storage tank does not exceed the minimum acceptable pressure. The second relief valve is designed to relief due to a sudden increase in pressure as a result of a possible fire in the tank. To this end, the design made reference to the American Petroleum Institute Manual 650 (12th Edition) as a guide. Some fundamental considerations include tank shape, height, diameter and materials used. A corrosion allowance of 3mm was also considered.**

***Index Terms*—Storage Tank; Shell Plate; Shell Course; Relief Valve; Tank Capacity.**

I. INTRODUCTION

Tanks are generally used for storage and find wide range of applications in different fields both domestically and industrially. These tanks are mostly made from steel and are located within the proximity of product sources which are mostly estuarine/offshore environment. Additionally, the problems of premium motor spirit (PMS) evaporation due to temperature rise (45°C) persist within the industry in addition to other challenges. A visit to a multiple tank farms in Ogara in Delta State was the first approach taken to solving the challenges of PMS loss due to vaporization in petroleum storage tanks. It was discovered that all of the tanks installed has a singular relief pressure valve which was design to relief at a pressure well above the evaporation pressure and temperature of PMS. This is loss both economically and environmentally due to the release of greenhouse gases into the environment. Storage tanks are essential part of the oil and gas industry. They are used for storing crude oil as well as the refined product of crude oil. The state of refined products of crude oil is highly unstable and poses a risk of fire and explosion because of its high volatility and flammability, and is more toxic than crude oil [2]. With the high demand for products of crude oil, it is therefore important to ensure a safe process for refining, transporting as well as its storage [4]. Tank farms have been set up to store the products of refined crude oil. The tanks are subject to the harsh weather conditions as well as chemical interactions with the products [7]. The tanks must therefore be designed to accommodate these conditions and function safely. Tank design and construction is a capital intensive project and several innovations have been introduced to reduce cost and maximize profit. The basic design parameters which must be considered in the design of the petroleum storage tank include the type of tank, the capacity of the tank, diameter of the tank, height of the tank, the average wind speed of the environment, working pressure, average temperature of the environment, the product to be stored, the physical and chemical properties of the product to be stored, safety and maintenance. The most important consideration in the design of the storage tank for the Nigerian environment is the product to be stored [8]. Most refined product of crude oil is volatile, the most being PMS because it vaporizes at temperatures at and above room temperature [9]. With losses in monetary and environmental values due to the evaporation of refined petroleum products from storage tanks into the environment being a major and prevalent challenge in the design of storage tank, it is important therefore to consider all relevant factors in the design and development of petroleum storage tanks [3],[6]. To this end, minimal use of modern materials/technology and incorporation of modern safety measures have been suggested by some tank designers. In this design, two relief valves performing different functions were introduced in an attempt to minimise the loss of petroleum product as a result of evaporation.

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II. METHODOLOGY

A cone-roof petroleum product storage tank of 10 million litre capacity is designed. With regards to the problem of product loss from evaporation, two relief valves were also designed to reduce the amount of product loss. Material usage was also optimized for cost. The API 650, IS 803, Department of Petroleum Resources' guidelines and other relevant documents were used as reference documents in the design.

III. DESIGN PARAMETER CALCULATION

To determine the storage capacity, product pressure, and materials required for the design of the storage tank, the following calculations were carried out as follows;

A. Tank Capacity

The capacity of the tank to be designed is the volume of product which is to be stored [5]. The API International Standard formula for determining the capacity of a petroleum storage tank is given in equation (1).

$$C = 0.785D^2H \quad (1)$$

Where

C = capacity (volume) of tank= 10,000,000 litre = 10,000 cm^3
D = diameter of tank in meter(s)
H = height of tank in meter(s)

Materials used in the fabrication of the volume of the tank are called a shell plates. Shell plates come in various sizes and dimensions. For a cone-roof petroleum storage tank, acceptable standard size of shell plate to be used is of size 2.5m by 10m.

Volume of tank = Area of tank * height of tank.

$$\text{i.e. } V = A*H$$

Assume for shell plate that the side with length of 2.5m used as the height,

Therefore, V = A * (height of shell plate * number of shell course)

NB: a shell course is the section of rolled shell plates butt welded together to form a complete shell.

Let number of shell course = 7;
Height of tank (H) = 2.5m * 7 = 17.5m

Therefore, from (1),

$$\text{diameter of tank (D)} = (C/0.758H)^{1/2} = 27.4\text{m} \quad (2)$$

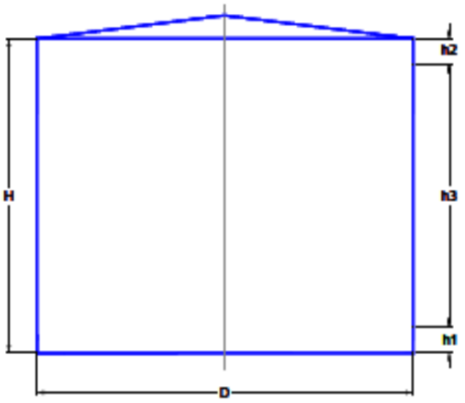

Fig. 1. Sketch of tank showing design parameters.

Where

H = total height of tank from ground to base of cone roof in meters
h1 = ground to low level height in meters
h2 = distance from base of cone roof to maximum storage length in meters
h3 = distance from low level to maximum storage length in meters.

B. *Primary Relief Valve*

The primary relief valve is designed to ensure that the pressure within the tank is insufficient to actuate the secondary relief valve. It achieves this by closing a circuit that automatically opens the flow of hydrant water meant for cooling and reducing the pressure within the tank. It is also designed to transport petroleum product vapour to a vapour recovery system, if any. To determine the pressure of PMS vapour within h2, the following calculations were considered. However, to know the proper and adequate calibration to be set for the primary relief valve, it is necessary to know the minimum pressure the petroleum vapour pressure will exert on the walls of the shell plates and roof shell plates at maximum storage capacity.

Assume PMS is the product to be stored.

Pressure of PMS vapour above storage height:

$$(P_{vapour}) = \rho_{pms}*g*h2$$

Density of PMS (ρ_{pms}) = 737.22kgm^3

Take h2 = 1.8m; g = acc. due to gravity = 9.81ms^{-1}

Therefore,

$$P_{PMSvapour} = 737.22*9.81*1.8 = 13.02 \text{ KNm}^{-2}$$

Let Z_1 be the calibration of the pressure plate of the primary relief valve the relief pressure must therefore be set between the minimum pressure exerted by the product vapour and the maximum allowable stress on the shell plates from the product vapour.

Assume maximum allowable stress on the roof shell plate is $0.8\sigma_{roof}$ (i.e. ($13.02 \leq Z_1 \leq 0.8\sigma_{roof}$) KNm^{-2}). The pressure plate of the primary relief valve must be set to relief at a minimum pressure of 13.02 KNm^{-2} and at a maximum of $0.8\sigma_{roof}$.

C. *Secondary Relief Valve*

The secondary relief valve is designed to release pressure built up due to possible failure of the primary relief valve and also a sudden rise in pressure from a possible fire. Upon lifting of the pressure plate in the relief valve, a circuit is simultaneously closed which automatically opens a hydrant valve which sprays “foaming agents” inside the tank. To determine minimum safe pressure and calibration for secondary relief valve, the following calculations were considered. However, to know the proper and adequate calibration to be set for the secondary relief valve, it is necessary to know the minimum pressure exerted on the walls of the shell plates and roof shell plates upon sudden pressure build up.

Assuming initial atmospheric conditions of 1bar (1*10^{5}KNm) and 20ºC, using universal gas law. From API 650, operating temperatures of low pressure tanks are not to exceed 93.3ºC. Therefore, let 93.3ºC be the highest flash point temperature of PMS (i.e. $P_1V_1/T_1 = P_2V_2/T_2$). Assuming constant volume, $P_1/T_1 = P_2/T_2$;

Therefore,

$$(19.53*10^5)/20 = P_2/93.3 \Rightarrow P_2 = 91.11\text{KNm}^{-2}$$

Let 42ºC be the least flash point temperature of PMS (i.e. $P_1V_1/T_1 = P_2V_2/T_2$). Assuming constant volume, $P_1/T_1 = P_2/T_2$

Therefore,

$$(19.53*10^5)/20 = P_2/42 \Rightarrow P_2 = 41.01KNm^{-2}$$

Let G_1 be the calibration of the pressure plate of the secondary relief valve;

Therefore,

$$(41.01 \leq G \leq 91.11)\ KNm^{-2}$$

The pressure plate of the secondary relief valve must be set to relief at a minimum pressure of 41.01KNm^{-2} and at a maximum of 91.11KNm^{-2}.

The Thickness and number of plates is calculated as follows;

D. *Tank Shell Course Calculations*

According to API 650 [1], section 5.6.2.3, the required minimum thickness of shell plates shall be the greater of the values computed by the following formula

$$t_d = 4.9D(H-0.3)G/S_d + CA \quad (3)$$
$$t_t = 4.9D(H-0.3)G/S_t \quad (4)$$

where

t_d = design shell thickness in mm
t_t = hydrostatic shell thickness in mm
D = nominal tank diameter in m = 27.4m
H = height of tank in m = 17.5m
G = design specific gravity of the fluid (PMS) = 0.77
CA = corrosion allowance in mm = 3mm
S_d = allowable stress for design condition = 160MPa for ASTM A 36 carbon steel
S_t = allowable stress for hydrostatic condition = 160MPa for ASTM A 36 carbon steel
Dimension of selected jumbo plate = 2.5m X 10m,
Therefore,

number of shell courses = 17.5/2.5 = 7 shell courses.

Using equations (3) and (4), each level of shell course thickness may be calculated.

1st shell course – corrosion allowance = 3mm
t_d = {[4.9*27.4(17.5-0.3)*0.77]/160} + 3mm = 14.11mm
t_t = {[4.9*27.4(17.5-0.3)*0.77]/160} = 11.11mm
Since $t_d > t_t$ using the design thickness as basis, a shell plate of 14mm thickness is selected.

2nd shell course – corrosion allowance = 3mm
t_d = {[4.9*27.4(15-0.3)*0.77]/160} + 3mm = 12.50mm
t_t = {[4.9*27.4(15-0.3)*0.77]/160} = 9.50mm
Since $t_d > t_t$ using the design thickness as basis, a shell plate of 12mm thickness is selected.

3rd shell course – corrosion allowance = 3mm
t_d = {[4.9*27.4(12.5-0.3)*0.77]/160} + 3mm = 10.88mm
t_t = {[4.9*27.4(12.5-0.3)*0.77]/160} = 7.88mm.
Since $t_d > t_t$ using the design thickness as basis, a shell plate of 10mm thickness is selected.

4th shell course – corrosion allowance = 3mm
t_d = {[4.9*27.4(10-0.3)*0.77]/160} + 3mm = 9.27mm
t_t = {[4.9*27.4(10-0.3)*0.77]/160} = 6.27mm.
Since $t_d > t_t$ using the design thickness as basis, a shell plate of 10mm thickness is selected.

5th shell course – corrosion allowance = 3mm
t_d = {[4.9*27.4(7.5-0.3)*0.77]/160} + 3mm = 7.65mm
t_t = {[4.9*27.4(7.5-0.3)*0.77]/160} = 4.65mm.
Since $t_d > t_t$ using the design thickness as basis, a shell plate of 8mm thickness is selected.

6th shell course – corrosion allowance = 3mm
t_d = {[4.9*27.4(5.0-0.3)*0.77]/160} + 3mm = 6.04mm
t_t = {[4.9*27.4(5.0-0.3)*0.77]/160} = 3.04mm.
Since $t_d > t_t$ using the design thickness as basis, a shell plate of 6mm thickness is selected.

7th shell course – corrosion allowance = 3mm
t_d = {[4.9*27.4(2.5-0.3)*0.77]/160} + 3mm = 4.42mm
t_t = {[4.9*27.4(2.5-0.3)*0.77]/160} = 1.42mm.
Since $t_d > t_t$ using the design thickness as basis, a shell plate of 6mm thickness is selected.

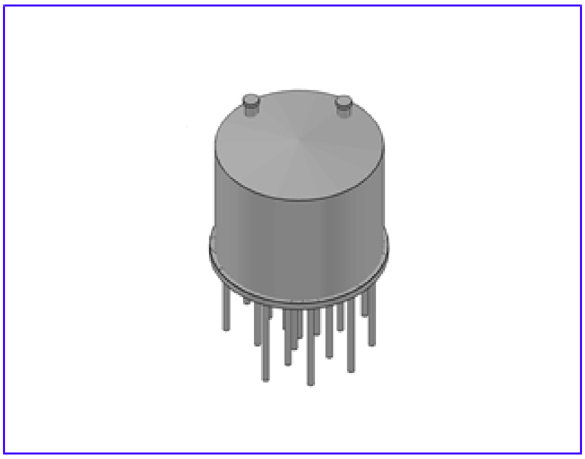

Fig 2. Diagram of tank showing primary and secondary relief valves

E. *Quantity of Plates Required for Shell Course*

In order to optimize materials used in construction, the total number of shell plates is to be determined. Using simple mathematical formula, we may obtain the number of shell plates required for each shell course and hence the total number of shell plate required for the construction.

Circumference of tank = πD = 3.142*27.4 = 86.10m
Length of shell plate = 10m.
Therefore,

number of plates required for each shell course= 86.10/10 ≈ 9 plates

1. 1st shell course: 9 number of 14mm thickness 2.5m X 10m shell plates.
2. 2nd shell course: 9 number of 12mm thickness 2.5m X 10m shell plates.
3. 3rd shell course: 9 number of 10mm thickness 2.5m X 10m shell plates.
4. 4th shell course: 9 number of 10mm thickness 2.5m X 10m shell plates.
5. 5th shell course: 9 number of 8mm thickness 2.5m X 10m shell plates.
6. 6th shell course: 9 number of 6mm thickness 2.5m X 10m shell plates.
7. 7th shell course: 9 number of 6mm thickness 2.5m X 10m shell plates.

F. Bill of Material for the Fabrication of the Tank

Tank Height – 17.5m
Tank Diameter – 27.4m
Tank Circumference – 86.1m
Tank Capacity – 10 million litre
Material – ASTM A36
Design Template – API 650

TABLE I: BILL OF ENGINEERING MEASUREMENT AND EVALUATION FOR THE TANK.

Serial	Item/Description	Quantity	Rate (₦)	Cost (₦)	Cost of Fabrication(₦)
(a)	(b)	(c)	(d)	(e)	(f)
1.	Bottom plate: 8mm x 2.5m x 10m	24	645,000.00	15,480,000.00	2,887,500.00
2.	Annular Plate 10mm x 2.5m x 10m	8	800,000.00	6,400,000.00	1,086,750.00
3.	Course 1: 14mm x 2.5m x 10m	9	1,100,000.00	9,900,000.00	2,620,800.00
	Course 2: 12mm x 2.5m x 10m	9	900,000.00	8,100,000.00	2,620,800.00
	Courses 3 & 4: 10mm x 2.5m x 10m	18	800,000.00	14,400,000.00	4,347,000.00
	Course 5: 8mm x 2.5m x 10m	9	645,000.00	5,805,000.00	2,620,800.00
	Courses 6 & 7: 6mm x 2.0m x 10m	22	482,000.00	10,604,000.00	5,313,000.00
4.	Roof Plate 6mm x 2.0m x 10m	37	482,000.00	17,834,000.00	2,409,750.00
5.	Roof Structure and Stairs: Angle bars, handrails, square pipes and handrails	-	-	8,354,500.00	4,042,500.00
6.	Sand Blasting and Coating	-	-	5,300,000.00	2,025,000.00
7.	Accessories: Man Holes, Dip Hatch, Sprinkler, Relief Valves and Drain Sump	-	-	5,967,500.00	4,177,250.00
8.	Testing: Virtual Simulation X-ray/ NDT Hydrostatic Testing Calibration Vacuum Box Test Dye Penetrant Test	-	-	3,906,000.00	1,890,000.00
9.	Earthing	-	-	976,500.00	500,000.00
10.	Corrosion Prevention (Cathodic Protection) Zinc Anode	-	-	1,024,600.00	399,000.00
11.	Foundation Construction	-	-	6,660,000.00	5,620,300.00
	Total	-	-	**120,712,100.00**	**42,560,450.00**
	Grand Total (₦)				**163,272,550.00**

Note: Prices are subject to change in relation to current market prices.

IV. RESULT AND DISCUSSION

The result of the designed tank components was established and confirmed. The tank diameter was calculated to be 27.4m, the height 17.5m, number of shell courses 7 and the height of shell course 2.5m. The diameter and height were selected to optimize the available space keeping the tank within acceptable height considering wind speed and dead loads. The varying shell thickness was established at 14mm, 12mm, 10mm, 10mm, 8mm, 6mm and 6mm from bottom to top for the shell courses respectively. A total of 9 shell plates are to be used round each course. A fixed cone roof was select to cut cost even though a floating roof would have been more appropriate in resolving the challenges of vaporization for PMS tank. The later was mitigated by the design of a relief valve working in consonant with an automated hydrant sprinkler system to keep the temp below 45°C thus minimising vaporization, pressure build up and loss of stored product.

V. CONCLUSION

Nigeria is one of Africa's major producers of crude oil and largely depends on it for economic stability. The petroleum industry is one that flourishes every facet of the Nigerian economy from raw materials to processed product. At various stage of production is the need to store this product in large capacity tanks. Several challenge border on the storage of petroleum products ranging from corrosion, vaporization, to cost of constructing of tanks. The API 650 (12^{th} Edition) was used as a guide in the design of the 10 million litre capacity storage tank that can mitigate the challenges observed in the industry within the minimal cost limits while delivering high standard. Other relevant standards such as IS 03 was also adhered to established the standard of the design.

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