DESIGN OF A 60,000 LITRES UNDERGROUND HORIZONTALLY LAID PETROL STORAGE TANK

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Abstract

This work is on the design of a sixty thousand litre underground horizontally laid petrol storage tank. The length of the tank, the internal pressure acting on it, Cylinder Thickness, Induced Hoop, Longitudinal Stresses and the Von-Mises stress were avaluated. Moreso, the wall thickness was varied to check its effect on the hoop and longitudinal stresses. From the analysis, it was seen that a total of 12 plates of 6m x 1.5 m and 0.007m thickness are required to fabricate the underground storage tank. The induced hoop, longitudinal and Von-Mises stresses will keep reducing with increasing tank wall thickness keeping the internal pressure constant. The implication is that with the same internal pressure of 0.061MN/m^2, greater material cost will be required to produce the [redacted] *tank because of the higher cost of plates with thicker dimensions. The design is safe due to the induced Von-Mises stress of 11.3MN/m^2, a value much lower than the maximum allowable stress of 160.8 MN/m^2 for the selected material.*

KEYWORDS:
Design, Petrol, Underground, Horizotally, Storage.

INTRODUCTION

Fuel storage tanks are pressure vessels of commonly elliptical or circular cross section for the containment of fuel resources such as petrol, Diesel, liquefied petroleum gas (LPG), etc. Industrial settings run their plants from fuel stored in these tanks to keep operations going. It is the norm for filling stations operating in the country to receive delivery of petroleum fuel products in storage tanks. Basically, fuel storage tanks include underground storage tanks and above ground storage tanks (and mobile storage tanks-tankers). Most petrol and Diesel filling stations store these products in underground storage tanks, while the delivery of these products is achieved using tankers that get the products from the depots for transportation to the filling stations. There are industry standards and regulations in dealing with fuel storage tanks aimed at controlling risk and protecting the environment. Recently, attention has been drawn to the safety risks of the complex cylindrical-shaped system and its surrounding environment due to contamination resulting from unwanted surface leakage (Ooi, Ngui, Hui, Lim & Leong, 2018). It is essential to properly design underground storage tanks holding petroleum products, including material selection and observe relevant regulations to avoid harmful impact on the environment. American Society of Mechanical Engineers (ASME) standard is a generalization of simple formulas and has limitation in terms of specifying actual fluid content on the pressure vessel, hence, design by analysis which requires the creativity and action of the designer is needed (Ugochukwu, Oluwole & Odunfa, 2018). Steel is a widely used material for the construction of fuel storage tanks. This is due to its high strength and ductility properties, availability and low cost. But corrosion is the main cause for underground storage tank failure (GOV.UK, 1996). Although, there is also glass fibre reinforced plastics available for the construction of underground fuel storage tank, with pros of being light weight, resistant to corrosion, but its brittleness is a disadvantage. A typical underground storage tank can be constructed from any of fibreglass-reinforced plastic, steel with approved cathodic protection, steel-fibreglass-reinforced-plastic composite, and metal without additional corrosion protection if the lack of such protection is viable (Stevens, n.d.).

A report shows that significant damage to the environment may occur from small discharge as little as half a gallon of hydrocarbon per day from corroded or poorly designed tank (Dowd, 1984; Ahmed, Abdulkarim, Taiwo, Aremu, & Alabii, 2014). One of the ways of avoiding the harmful

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environmental impacts is to control corrosion of the material of construction of the storage tank. Corrosion control measure should comply with American Petroleum Institute (API) 651 or similar internationally recognised standards (Regulation and Supervision Bureau, 2009). Cathodic protection is prominent among corrosion control methods usually applied to underground petrol storage tanks made from steel, and another way of controlling corrosion is the use of corrosion resistant material. The norm of inspection practice includes cathodic protection technique (Ooi et al, 2019).

MATERIALS AND METHODS

Theory/Design Calculation

Determining the Length of Tank

The relation of volume, length and diameter of a tank of circular cross section is given as

$V = (\pi\, D^2/L)/4$ (1)

(Barderas, Stephania and Rodea, 2015).

where, $D =$ external diameter of tank, $L =$ length of tank, and $V =$ volume of tank.

The consideration of this project is a tank to hold 60, 000 litres of petrol

60,000 litres= $60m^3$; taking an air space of 5 percent of total volume of product,

$(5/100) * \ 60m^3 = 3m^3$,

so that the total tank capacity is

$(60 + 3) = 63m^3$.

Choosing a tank diameter of 3m, and applying equation (1), then

$63 = \pi * 3^2 * L/4$

$L = 8.81m$.

Determining Internal Pressure

The equations (2) and (3) are for mass and pressure respectively,

$M = \rho * V$ (2)

$P = F/A$ (3)

(Ugochukwu et al, 2018)

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where, $M = mass(kg)$; $\rho = 700kg/m^2 =$ density of petrol; $V = 63m^3$ = volume; P = internal pressure acting on wall (N/m^2); $A =$ area (m^2).

Using equation (2),

$m = 700 * 63 = 44,100kg$

$44,100 * 9.81 = 432,621N.$

But since the storage tank is cylindrical, the area is

$$A = \pi D^2/4 \qquad (4)$$

$A = \pi 3^2/4 = 7.07m^2$.

From equation (3),

$P = 432621/7.07 = 61,191.09N/m^2 = 0.061MN/m^2.$

Cylinder Thickness, Induced Hoop and Longitudinal Stresses

The hoop stress σ_h, also called the circumferential or tangential stress is essential to resist the bursting tendency of the cylinder due to exerted internal pressure P, as indicated in Figure 1. In general, the cylindrical shell is made of a uniform thickness which is determined by the maximum circumferential stress due to the internal pressure which exerts a vertical force on the cylinder wall, balanced by the tangential hoop stress (Dubal, Gajjal & Patil, 2014; Masikh, Tariq & Sinha, 2014). The action of the hoop stress is perpendicular to the axis of the cylinder. But the other stress for consideration is the longitudinal stress σ_l, which acts along the length of the tank. The relevant equations for the hoop and longitudinal stresses are given in equations (5) and (6) accordingly,

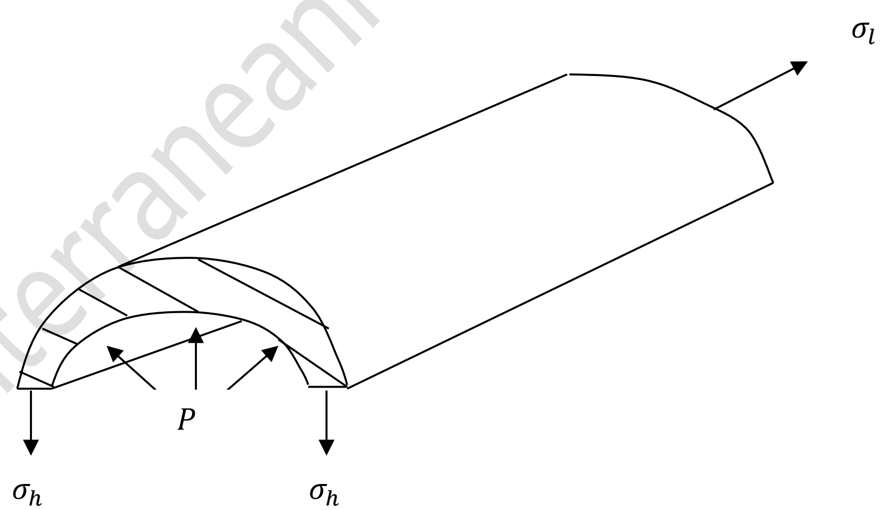

Figure 1: Stresses Acting on a Pressure Vessel

$\sigma_h = Pd/2t$ (5)
$\sigma_l = Pd/4t$ (6)
(Masikh, Tariq & Sinha, 2014),
where, $P =$ internal pressure (N/m^2); $d = internal\ diameter\ (m)$; σ_h = hoop stress (N/m^2); σ_l = longitudinal stress (N/m^2). The design for the tank is to have a longitudinal stress of 13.5 MN/m^2 and a reliability of 95 percent.
The working stress is
$\sigma_w = \sigma_l * K * K_d/n$ (7)
where, $\sigma_w =$ working stress (N/m^2); $\sigma_l = 13.5 * 10^6 N/m^2$; K_i =reliability factor; $K_d = 1 =$ temperature factor (between $20 - 70^oC$); $n =$ 1.5 =factor of safety.
The reliability factor is given as
$K = 1 - 0.08Z_R$ (8)
$Z_R = 1.96$,
hence,
$K = 1 - 0.08 * 1.96 = 0.84$.
Putting values in equation (7), then,
$\sigma_w = (13.5 * 10^6 * 0.84 * 1)/1.5$
$\sigma_w = 7,560,000N/m^2$.
The internal diameter of the cylinder is
$d = D - 2t$ (9)
where, $t =$ thickness of plate, $d =$ internal diameter of tank
applying the working stress (equation 7) and equation (9) to equation (6), then,
$t = P(3 - 2t)/4\sigma_w$ (10)
$t = (3 * 61,191.09)/4 * 7560000 + 2 * 61191.09$
$t = 0.00605m = 6.05mm$, take $7mm$.
So that $d = 3 - (2 * 7) = 2.986m$.
The induced hoop stress is
$\sigma_h = 61,191.09 * 2.986/2 * 0.007 = 13,051,185N/m^2$,
the induced longitudinal stress is,

$\sigma_l = 61,191.09 * 2.986/4 * 0.007 = 6,525,592.7 N/m^2$. And further application of equations (5) and (6) by increasing wall thickness leads to reducing induced hoop and longitudinal stresses.
The Von-Mises stress is given as

$$\sigma_v = \sqrt{\sigma_1^2} - \sigma_1\sigma_2 + \sigma_2^2, \quad (11)$$

(Ugochukwu et al, 2018),
where the principal stresses $\sigma_1 = \sigma_h$; $\sigma_2 = \sigma_l$; $\sigma_v =$ Von-Mises stress, and applying equation (11), the Von-Mises stress developed 11.3MN/m^2.

Material Selection

Low alloy steel (LAS) specification SA-516 grade 70 has been chosen due to its high strength and other desirable properties, such as good hardenability, toughness, corrosion resistance, ductility and oxidation resistance. The maximum allowable stress for pressure vessel wall thickness given in ASME code for SA-516 grade 70 is 160.8 MN/m^2 (Engineers Edge, n.d.). Steel is normally robust but retains a degree of ductility. These two properties produce a material that is resistant to both damage and brittle fracture under normal underground storage tank operating conditions (GOV.UK, 1996). Moreover, research results and analysis of different materials indicate that ductile materials for vessel walls should be less thick than that of brittle materials (Masikh et al, 2014).

Determining the Number of Plates

The circumference of the plate to be rolled is given as

$C_t = \pi D$

$C_t = 3.142 * 3 = 9.4m,$

but the plate dimension is

$(6 * 1.5)m.$

Circumference $(9.4m)$ – Plate length $(6.0m)$.

The extra plate length required is the difference $= 3.4m$.

Recall,

length of tank $= 8.9m$

width of plate $= 1.5m$

Number of plates based on width of 1.5m is
$8.9/1.5 = 5.93$ plates,
but extra 3.4m is required per plate, hence,
$3.4 * 5.93 = 20.16m.$
Since the length of the plate is 6m, the extra number of plates required is
$20.16/6$ = 3.36 plates.
The diameter of the vessel is already known to be 3m, and the plate dimension is
$6 * 1.5m,$
this means that the length of the plate will take twice the diameter of the vessel, while the width will take only half the diameter of the vessel. Therefore, to fully account for the two ends of the storage tank, two plates are required.
To fabricate the storage tank,
The total number of plates required $= (5.93 + 3.36 + 2)$
$= 11.29$ plates.

RESULTS AND DISCUSSION

Table 1: Thickness Induced Stresses and Number of Plates; Internal Pressure of 0.061MN/m²

t (m)	σ_h (MN/m²)	σ_l (MN/m²)	σ_v (MN/m²)	No. of Plates
0.007	13.1	6.5	11.3	11.29
0.008	11.4	5.7	9.9	11.29
0.009	10.1	5.1	8.7	11.29
0.010	9.1	4.6	7.9	11.29
0.011	8.3	4.1	7.2	11.29
0.012	7.6	3.8	6.6	11.29
0.013	6.9	3.5	6.0	11.29
0.014	6.5	3.2	5.6	11.29
0.015	6.1	3.0	5.3	11.29

11.29 plates of 6m x 1.5 m and 0.007m thick are required to fabricate the underground storage tank. Although, the induced hoop and longitudinal and Von-Mises stresses will keep reducing with increasing tank wall thickness (Table 1) for the same internal pressure of 0.061MN/m^2, greater material cost will be required to produce the tank because of the higher cost of plates with thicker dimensions. Moreover, the design is safe due to the induced Von-Mises stress of 11.3MN/m^2, a value much lower than the maximum allowable stress of 160.8 MN/m^2 for the selected material.

CONCLUSION

The 60, 000 litres underground tank will require a total number of 11.29 plates of SA-516 grade 70 carbon steel with dimensions 6m x 1.5m and 7mm thick to fabricate. The design is safe due to the induced Von-Mises stress of 11.3MN/m^2 being much lower than the maximum allowable stress of the material.

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