

ASSESSING THE EVAPORATION LOSSES IN FIXED PETROL STORAGE TANK: A CASE STUDY OF NOCMA STORAGE DEPOT IN MALAWI

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DEPARTMENT OF EARTH SCIENCES

29th April, 2025.

Declaration

I, Eliam Mufungwe declare that this research project presents my work and that it has never been submitted to Malawi University of Science and Technology or any other institution for academic purpose. All sources of information used in this research has been correctly and fully acknowledged.

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Date: April, 2025.

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Assessor: Signature:

Disclaimer

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Abstract

Evaporation losses from fixed gasoline storage tank are major Challenge, especially in developing nations like Malawi where energy security and economic efficiency are vital. With the purpose to quantify both standing and working losses, this study evaluates the evaporation losses through quantitative analysis of fixed gasoline storage tanks at the NOCMA Storage Depot in Matindi, Blantyre. The results from the study reveal that over 2.8 million liters of petrol are lost each year, representing 1.12% of petrol loss from the depot with the working losses making up 7.68% and the standing losses 92.32%. The nation loses an estimated MWK 7 billion annually as pump selling price due to petrol evaporation losses from each storage tank deport, which have significant financial impact. The report emphasizes the pressing need for workable and affordable mitigation ways, like vapor recovery devices, nitrogen blanketing systems and better tank paint conditions. Malawi can improve fuel storage efficiency and cut down on waste of fuel from storage. On the other hand, fortify its energy security by addressing these losses. Besides that, the study will offer NOCMA useful information, it will also lay the groundwork for further research on fuel conservation in related fields by other scholars.

Acknowledgement

I want to express my gratitude and praise to GOD LORD ALMIGHTY for His mercy and kindness over my way to success at Malawi University of Science and Technology.

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Abbreviations

Ls - Evaporation Standing Losses

Lw - Evaporation Working Losses

VOC - Volatile Organic Compounds

NOCMA - National Oil Company of Malawi

SVP - Saturated Vapor Pressure

SOM - Safety Operations Manager

bbl or BB - Blue Barrel (standard unit of volume in the petroleum industry)

MERA - Malawi Energy Regulatory Authority

CS2 - Carbon Disulfide

BTEX - Benzene, toluene, ethylbenzene and xylene

MWK - Malawi Kwacha

API - American Petroleum Institute

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Chapter 1: Introduction

1.1. Background Information

Evaporation from the storage tanks is a significant spring of petroleum products losses in the crude oil industry, the process occurs naturally depends on vapor pressure in the tank with an influence of temperature (Stricklin, 2014). The losses of petroleum products are divided into qualitative and quantitative losses, whereby quantitative losses occur in form of products attrition physically like leakage or emission while qualitative losses occur when product ruin in form of quality deterioration or degradation which happens chemically (Chernyak, et al., 2010).

The study focusses on petrol evaporation losses quantitatively, which is the sum of standing and working losses processes from the storage tanks (Stricklin, 2014). The working losses occur when there is change in tank liquid level which affects the tank liquid vapor pressure, once it exceeds the tank vent set point then escape from the tank (Stricklin, 2014). The standing losses occur when the tank and the vapor involve in thermal expansion and contraction triggered by daily heating cycle, where the mixture of air and vapor expand then starts exerting pressure in the tank once found their way escape as evaporation loss (Stricklin, 2014). The evaporative losses from storage tank both the standing losses and the working losses align with economic losses once happened (Glushkov & Valeev, 2023).

There are kinds of storage tanks for petroleum products like floating roof and fixed roof tank (Maxwell & Lawal, 2016). The study focuses much on fixed storage tank evaporation loss of petrol. The precise quantification of petrol evaporative losses from storage tanks it is paramount in the petroleum industry for resource conservation, as it associates with economic losses (Glushkov & Valeev, 2023). The quest for energy security is a critical component of economic development, particularly in sub-Saharan Africa where energy infrastructure is often underdeveloped (Gwangwava, et al., 2018).

The government of Malawi constructed storage tanks for petrol and diesel to boost energy security, strategically located in three major cities: Lilongwe, the capital city; Mzuzu, located to the north of Lilongwe; and Blantyre, situated south of Lilongwe (Gwazanga, 2020). The

government move now encounter evaporation setback from the storage depot which analysed both bulk and fiscal quantification by this study and recommend applicable effective solutions to be considered and implemented for mitigations of the losses. The study also met some of the limitations clearly highlighted.

1.2. Problem Statement

Oil production has increased since the middle of the 20th century, claim (Glushkov & Valeev, 2023). Throughout the 20th century, the world's oil production increased significantly, from about 400,000 barrels per day in 1900 to over 74 million barrels by 1999 (Rapier, 2023). This expansion continued even after the two major oil supply disruptions in the 1970s (Hughes & Rudolph, 2011). Projections indicate further growth, with output expected to reach approximately 96 million barrels per day by 2035 (Hughes & Rudolph, 2011). Hydrocarbon losses linked to storage tanks coincided with the expansion of oil depots and oil storage facilities for the storage of petroleum products (Tabari, Sabzalipour, & Jalilzadeh, 2021). Due to increased temperatures, the problem of hydrocarbon losses via evaporation from storage tanks is more urgent in African locations (Gwangwava, et al., 2018). Malawi, a country in sub-Saharan Africa, built 60 million liters of storage tanks, of which 19 million liters it is for gasoline (Gwazanga, 2020). As a country that is striving hard for energy security, there is a setback of evaporation losses from storage tanks that needs to be focused on seriously (Chernyak, et al., 2010).

1.3. Main and Specific Objectives

1.3.1. Main Objective

To assess the evaporations losses in a fixed petrol storage tank.

1.3.2. Specific Objectives

- To quantify the evaporation losses in the storage tank depot annually.
- To estimate annual economic losses caused by petrol evaporation at the storage depot.

- To propose smart strategies that work together to minimize fuel loss from storage tank evaporation through evaporation.

1.4. Research Questions

a. What are the percentages annually of evaporation losses of petrol in storage tank?

b. How much money does the country lose each year because of petrol evaporating at the depot?

c. What are practical and affordable solutions can be implemented to minimize petrol evaporation losses?

1.5. Scientific Significance

This study will give insights into the extent of gasoline evaporation losses from fixed storage tank and their economic losses. It offers practical and effective solutions to lower these losses and also assist to improve operational efficiency and reduce fuel waste. As reducing these losses and the ensuing better cost results has become core value for individuals working in the petroleum industry. Given the size of these losses, especially in developing nations like Malawi, a thorough examination of their scope, causes, and effects is necessary. By offering practical insights into the occurrence of gasoline evaporation losses and their economic results, this study closes the knowledge gap in this crucial field in Malawi and will be a genesis for other studies.

Chapter 2: Literature Review

Assessing petroleum losses on petrol quality is a critical research area with implications both environmental sustainability and economic efficiency. Globally, numerous studies have been conducted to understand the extent of petrol losses from storage tank and how to mitigate the losses. Gasoline is composed of different hydrocarbons with different boiling points ranging between 118 °F-787 °F (Abdelmajeed, Onsa, & Rabah, 2009). Some hydrocarbons released into the atmosphere at ambient temperature. It contains about 10% of light products that can evaporate at a temperature of about 40 °F (Abdelmajeed, Onsa, & Rabah, 2009). Gasoline is considered as VOC. Which depend on wind speed, environmental humidity and atmospheric pressure at minimal ambient air temperature variations (BATIĆ, 2022). According to Levitin and Tryascin (2016) over half of operational losses are evaporative losses, which classified into quantitative and qualitative losses. As part of methodology this study assess qualitative losses as lab tests was conducted, but quantitative losses basically calculated. To estimate losses, Saturated Vapor Pressure (SVP) is suggested as it allows for predicting quantitative changes when storing fuel. In this study an experimental unit was designed to determine Saturated Vapor Pressure based on government standards, and a series of lab tests were conducted to determine motor spirits Saturated Vapor Pressure depending on temperatures at various phase ratios within the operation range. It involves also the constant measurements of the displaced gas-vapor mixture and vapor concentration are to obtain factual values. The procedure involves constant sampling and lab analysis, which was unprofitable and labor-intensive. The Saturated Vapor Pressure (SVP) used to determine hydrocarbon tendency towards evaporation. SVP depends on hydrocarbon composition, phase ratio, and temperature and is described by dependences. This research since it involves constant sampling and lab analysis to my research are unprofitable and labor intensive, for such reason also I did not choose it.

Howari is another outstanding scientist who has investigated the dispersion of volatile organic compounds and water loss from tank farms (Howari, 2015). The study estimated the amount of volatile organic compounds (VOC) lost from organic liquids in storage tanks using fixed and floating roof equations for respiratory and working losses. The calculation took

into consideration and factored in the following: the total loss, the loss of breath, the vapour pressure, the product's molecular weight, the tank's diameter, the nighttime temperature, the tank's capacity, and the number of turnovers. The dispersion of VOCs under both normal and emergency conditions was simulated using the AERMOD and ALOHA software. Meteorological data, including solar isolation factor, average wind speed, daily minimum and maximum ambient temperatures, annual average ambient temperature, and annual average atmospheric pressure, were incorporated into the computations and modeling processes. The study employed the respiration and working loss equations for both fixed and floating roofs that were created by the EPA AP-42 reference. Total loss, breath loss, vapour pressure, product molecular weight, tank diameter, daytime temperature, tank capacity, and number of revolutions were all considered in the computations. Leakage or improper sealing of the tank's contents are the most frequent possible causes of losses from storage tanks. The models involved were as follows: LT = LR + LWD + LF + LD where LT it is total loss (lb/year), LR rim seal loss (lb/year), LWD withdrawal loss (lb/year), LF deck fitting loss (lb/year) LD deck seam loss (lb/year). Lw = Qw (1=359) (273.15/T) (V P/760) (MW) (KN) (Kp), where Lw is the working losses (lb/year). KN is the turnover factor is based on the number of turnovers per year, N, which is defined as N= Qw/VT. KN=(180+N)/6N for N>36 and KN=1 for N<36. Kp is the working loss product factor is defined as Kp= 0.75 for crude oils and Kp=1.0 for organic liquids. Ls = 365 (V v) (W v) (KE) (Ks) whereas Ls is the standing storage loss (lb/year), Vv is vapor space in tank (ft^3), Wv is vapor density (lb/ft^3), KE is vapor space expansion factor, dimensionless, and Ks is vented vapor saturation factor, dimensionless. This study despite being best research it does not fit to be conducted in Malawi as it involves tools that capture gas escaped around the storage tanks and also the use of AERMOD and ALOHA software, since our storage facilities does not have those and are expensive.

Fuel evaporation is often a loss in petrol quantity as well as quality, but its effects on petrol quality and engine performance are frequently overlooked (Chernyak, et al., 2010). When petrol evaporates, key properties such as boiling point, density, and octane number are altered, leading to reduced engine efficiency, higher fuel consumption, and potential

mechanical issues (Chernyak, et al., 2010). For instance, even a 1.2% evaporation loss can increase fuel density by 0.002 g/cm³, raise boiling points by 3°C, and reduce the octane number by 0.5 units changes that may seem minor but have significant operational consequences (Chernyak, et al., 2010). They highlighted also the factors affecting petrol quality due to evaporation. The operational performance of petrol depends on multiple factors, including detonation stability, vaporization efficiency, starting properties, and engine response. Evaporation primarily occurs at the fuel's surface, where lighter hydrocarbons diffuse into the air. This preferential loss alters the fuel's composition, degrading critical parameters like octane number and fractional distillation properties. There findings on evaporation effects were also discussed.

As part of methodology study used A-92 petrol (TU U 00149943.501-98) sample examined to find out evaporation's impact by analyzing fuel samples before and after controlled evaporation (Transport, 2010). Chromatographic analysis (using a Crystal-2000 chromatograph) revealed that 42.3% of the fuel evaporated, with alkanes being the most volatile. These lighter components either escaped or transformed into cyclic alkanes and aromatic hydrocarbons, modifying the fuel's chemical profile. Where the key changes observed included: increased density and boiling points, reduced octane number, higher aromatic hydrocarbon content and altered fractional composition and flash temperature. Which are not in align with my research basically on objectives that determined the results and also it confirm that evaporation doesn't just reduce fuel volume. But fundamentally changes its combustion behavior, potentially leading to engine knocking, poor acceleration, and higher emissions. Which is contrary to what my research aimed as its main purpose was to quantify losses basically there must be changes in volume.

According to Mihajlović et al. (2013). This section discusses the use of the TANKS 409d software to quantify evaporative losses in oil storage tanks, which is essential for environmental preservation and balance considerations. In summary, evaporative losses were assessed for different kinds of tanks with fixed and floating roofs. Crude oil losses for fixed roof tanks are approximately 0.05 kg/ton, while for floating roof tanks, the losses are

approximately 0.01% kg/ton. The losses from diesel and fuel oil are very small, about 10^-3 kg/ton. Compared to dome-roof tanks, which have losses of approximately 0.004 kg/ton, tanks with fixed roofs experience significant losses of up to 2.07 kg/ton. For design purposes, estimates form the foundation of techno-economic and environmental protection analyses. The study also addresses the effects that oil and derivatives storage's volatile organic compounds, which are produced by industrial and traffic activity, have on the environment and public health. Highlights include: Under sunlight, VOCs combine with nitrogen oxides to create photochemical smog. Significant sources of VOCs include industrial sectors such as refineries and solvent industries. VOC emissions are a contributing factor to global problems such as the greenhouse effect, ozone layer depletion, and global warming. The section also describes how to estimate evaporative losses, making a distinction between theoretical, experimental, empirical, and combined methods. The features and applications of both vertical and horizontal oil storage systems are also described.

This section describes the methodology used in this study as follows: Evaporative loss calculations were performed using the TANKS 409d software, which was developed by the US Environmental Protection Agency to assess losses from tanks that contain organic materials. Based on tank specifications, structural features, geographic location (including weather), and the particular kind of liquid being stored, the software generates loss estimates. The American Petroleum Institute's equations, which provide monthly, seasonal, or annual emission estimates for each component, serve as the foundation for the computations. For a medium-sized refinery that runs for eleven months a year, with one month set aside expressly for maintenance, the analytical input data was chosen. Vapor pressure values are directly impacted by the types of fuel that are stored; gasoline is classified as either summer or winter grade depending on its vapor pressure properties. To properly evaluate evaporative losses, meteorological data from Serbia was used. The study focused mostly on vertical cylindrical tanks with domed roofs, which are widely used in the industry because they are cost-effective and require little additional equipment. The methodology goes on to describe the different kinds of tank roofs and how they affect evaporative loss.

The research uses software to assess losses from the tank which I found it coasty to use this methodology research and the study focuses much on safety measures to prevent leakage losses but does not include predictions of such losses, as they are unpredictable and beyond the scope of this study hence, I did not prefer this study.

Other scholars also done well on determine the emissions of volatile organic compounds (VOCs) from the storage tanks at Iran's Abadan Export Port of Mahshahr, with a focus on benzene, toluene, ethylbenzene, and xylene (BTEX) emission from storage tanks (Tabari, Sabzalipour, & Jalilzadeh, 2021). TANKs 4.0 was used to determine the VOC leakage rate from 32 external floating storage tanks that held seven distinct kinds of organic liquids. The most valuable. As methodology 9D software used in both the winter and the summer. The AERMOD template was then used to analyze the dispersal of these pollutants. To confirm the findings of the AERMOD simulation, field measurements were conducted at six sites throughout the study area in both the hot and cold seasons. The most polluting locations were found to be points 5 and 6 during the hot season and points 2 and 4 during the cold season, based on the 8-hour and 24-hour emissions of BTEX pollutants in the export port area Pollutant concentrations were experimentally measured using a carbon-based adsorbent and a SKC sampling pump in compliance with NIOSH1501. With a sample air volume of roughly 60 l, samples were collected at a flow rate of 1 l per minute. Solvent extraction was then used to remove the pollutants that had been adsorbed from the adsorbent. The thickened laure laurel leaves were dissolved using 1 milliliter of carbon disulfide (CS2). Liquid noble gas profiling was used for the adsorbate analyses. A versatile catalyst (neutrality agent) was used to analyze the adsorbent using a noble noble principle. Ten tanks of various sizes (three samples per season) of the two components of the deck protector and rim sealant were used for the field measurements. ignored. Other observations Eight and twenty-four hours after the tanks were collected, the metadata was gathered. Temperatures during the hot season ranged from 303 to 320 degrees Celsius, with wind directions ranging from 270 to 350 degrees and speeds ranging from 2 to 15 meters. The winter months had temperatures between 289 and 293 degrees Celsius, wind speeds between 0 and 15 m'philes, and wind directions between 0 and 310 m'philes. Other. 2.3. Additionally demonstrates that wind

speeds fall between 8 and 24 hours during the hot and cold seasons. Model input data TANKs 4.0 was used in this study to calculate the emission rate of the diffuse noble gas from the floating bulkheads. 9d. TANKS 4.0. The EPA and API developed 9d software to calculate surface runoff emissions from organic liquid storage tanks. The Tank Identification and Physical section of the software must contain the following data: identification, tank dimensions, paint characteristics, roof characteristics, rim seal system, and deck configuration. This is one of the details required to run the TANKs 4.0. The hydrocarbon mixture properties are entered into the 9d software, which uses all of the supplied data to determine the tank's vapour emissions. if you decide on the legendary.

Though this study was paramount in a way that it helps to calculate some of the dimensionless parameters and model constants from tanks at my study area. It was much focus on amount benzene, toluene, ethylbenzene, and xylene emitted to the environment not quantification in general. The study also uses 32 external floating storage tanks and advanced software while in my study area there are fixed tank with manual operations.

The total evaporation losses according to Eric Stricklin (2013) are calculated through the sum of mathematical models of Ls (standing losses) and Lw (working losses). The models are applicable in fixed roofing types of tanks, which are currently used in Malawi. After petrol has stabilized in the storage tank, evaporative gases are safely contained within the tank until the internal pressure surpasses the predetermined threshold set by the tank's ventilation system (Stricklin, 2014). The evaporative losses typically occur in two main ways: standing losses (LS) and working losses (LW). According to Eric Stricklin,

$$LT\,(\text{annually}) = LS + LW$$

The standing losses occurrence in storage tanks is predominantly governed by the processes of thermal expansion and contraction, in conjunction with the vapor mixture produced during the daily thermal cycling, (Stricklin, 2014). As the temperature escalates, the air-vapor amalgamation undergoes expansion, resulting in an elevation of pressure against the

structural confines of the tank. When this pressure exceeds the predetermined threshold of the vent, vapor is released, culminating in evaporative losses. A multitude of variables contribute to these losses, encompassing tank geometry, liquid column height, and thermal conditions, all of which was clarified through designated mathematical expressions. Below it is the expression;

(a) $LS = 365\ Hvo\ KE\ (\frac{\pi}{4}\ D^2\ )\ Ks\ Wv$ (BATIĆ, 2023)

Whereby,

LS = total standing losses (lb./yr)

KE = vapor space expansion factor (dimensionless)

HVO = vapor space height between tank roof and liquid surface (ft)

D = tank diameter (ft)

WV = stock vapor density (lb./ft³)

(b) $Ks = \frac{1}{1+(0.053\text{Pva Hvo})}$

KS = vented vapor saturation factor (dimensionless)

The working losses in storage tanks primarily caused by fluctuations in liquid levels, which can lead to increased vapor pressure and subsequent evaporative losses. When the liquid level rises, it compresses the vapor which potentially causes liquid exceeding the tank's venting set point, causing vapor to escape. Several factors influence these working losses, including: Stock turnover rate, annual throughput, tank diameter, liquid height, liquid surface temperature, vent settings, vapor density and vapor pressure (Stricklin, 2014).

Stock turnover rate where the higher turnover can lead to more frequent filling and emptying, increasing the potential for losses. Secondly, annual throughput in the sense that the greater throughput may correlate with increased evaporation due to more frequent liquid level changes. Thirdly, tank diameter has an influence in such a way that larger diameters can

result in more significant vapor space, affecting pressure dynamics. The other one is liquid height, in a way that increased height raises vapor pressure, heightening the risk of venting. Liquid surface Temperature, the higher temperatures can increase vapor density and pressure, leading to more losses. In addition, vent settings whereby properly calibrated vents can mitigate losses by controlling pressure release while the opposite is true. Lastly, vapor density and pressure are such a way that these properties directly affect the likelihood of vapor escaping during pressure fluctuations (Zhou et al., 2007).

This working loss was estimated through the equation below (Stricklin, 2014).

According to Eric Stricklin; $LW = N\ HLx\ (\frac{\pi}{4} D^2)\ KN\ KP\ KB\ WV$

Whereby,

LW = total standing losses (lb./yr)

N = stock turnover rate (turnover/yr)

HLx = stock maximum petrol height annually(ft)

D = tank diameter (ft)

KN = working loss turnover factor (dimensionless)

KP = working loss product factor (dimensionless)

KB = venting setting correction factor (dimensionless)

WV = stock vapor density (lb./ft³)

This study is the best which fit in to my study that will help to meet all my specific and main objective. it uses the above mentioned models which are align with tanks designs at my study area. Data collection procedures and tools are also feasible to my study area depot and not exorbitant.

The quest for energy security is a critical component of economic development, particularly in sub-Saharan Africa where energy infrastructure is often underdeveloped (Gwangwava, et al., 2018), The government of Malawi constructed storage tanks for petrol and diesel,

strategically located in three major cities: Lilongwe, the capital city; Mzuzu, located to the north of Lilongwe; and Blantyre, situated south of Lilongwe (Gwazanga, 2020).

The Malawi Energy Regulatory Authority (MERA) announced a significant price hike on November 10, 2023, Malawians faced higher fuel costs (Ngwira, 2023). This occurs when the money corrected from selling does not match with amount money to procure fuel again, it can be due to various reasons one of which is due to losses. According to Ngwira. R (2023) the price risen from MWK 1746 to MWK2530. This gives a picture in mind that must be properly handled and considered seriously when stored.

Chapter 3: Methodology

3.1. Study Area

The study carried out at Matindi NOCMA depot located in Blantyre district, southern part of Malawi. The area was chosen because of the presence of the petrol storage tanks, where mass petrol storage activities occur once imported and pends for distribution activity. The area is subjected to variation in season being winter season and summer season whereby there is great evaporation on petrol due to such changes.

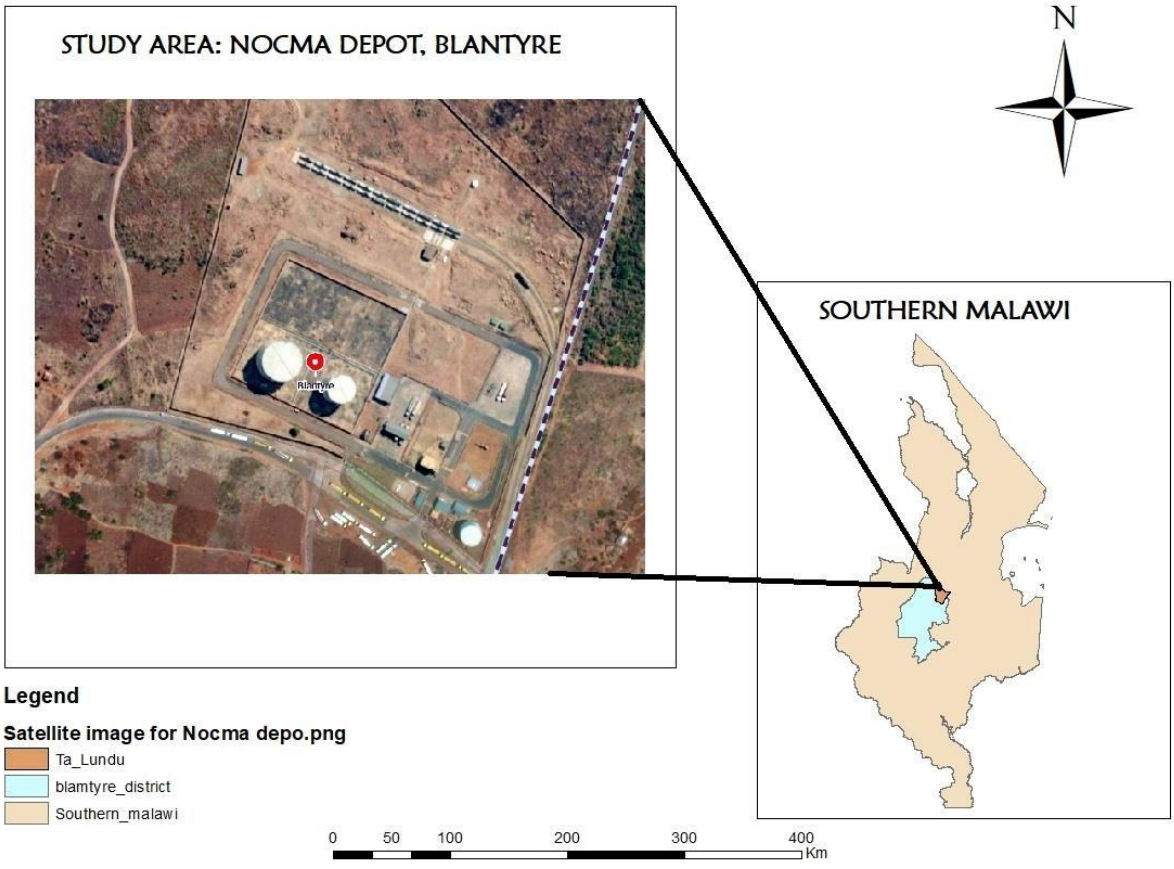


Figure 1: Map of the study area

3.2. Research Design

This section outlines the research methodology and the approach taken in this study.

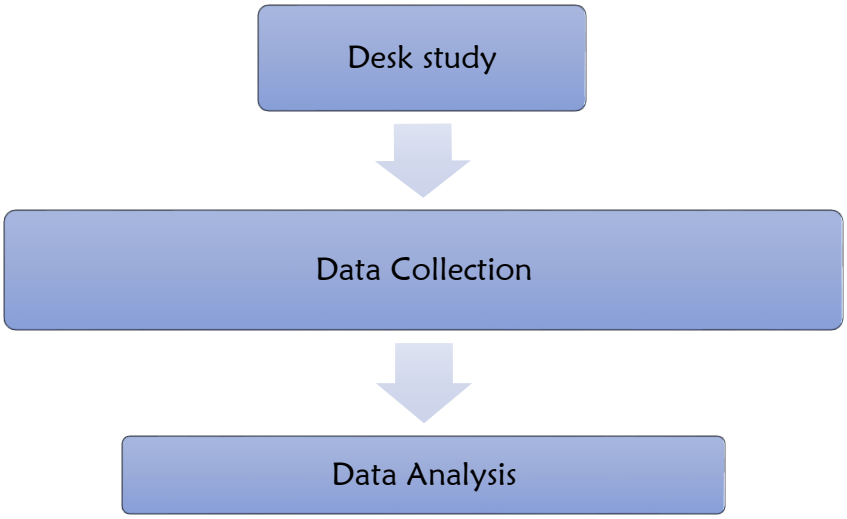


Figure 2: Research design skeleton

3.2.1 Desk Study

The desk study conducted prior any action in form of literature review. This helped to come up with specific and relevant kinds of data to be collected to meet the objectives at the end of business, the manual script produced. Where to collect relevant data and to whom the permission for data collection required to be addressed for go ahead, also the other authorities to be contacted for secondary data.

As quantitative approach the study involves measurement and analysis of the evaporation losses from data obtained and their economic impact. Provision of practical and affordable solutions to minimize losses. This design once there are reckless human errors can distort research viridity.

3.2.2. Data Collection

The data collection process was much focused on measurable, objective data related to evaporation losses models aligned to parameters they incorporate for estimation while other parameters like the dimensionless factors obtained theoretically from various research articles from my literature review. The data collected through tank gauging system measurement by manual dipping and observation parameters of petrol in storage tanks (Tabari, Sabzalipour, & Jalilzadeh, 2021).

Searching manually as well as online for historical data and review for annual trends data used on analysis of financial records to estimate the economic losses caused by evaporation (Andalucia, 2023).

All tank parameters were independents except the ambient temperature, Annual percentage of petrol evaporation losses, and annual economic loss due to evaporation.

3.2.3. Data Analysis

Quantitative analysis through spreadsheet modeling to calculate annual evaporation percentages. Integration of the market price using current petrol prices from MERA (Ngwira, 2023) and calculate monetary value loss annually. Thematic analysis to identify and categorize practical, affordable solutions.

3.3. Materials and methods

This chapter presents the structured analytical technique used in the study to investigate its core research objectives.

3.3.1. Data collection procedures and tools

The permission from relevant authorities to access storage depot data and conduct interviews were requested first. Formally I communicated first to the Safety Operations Manager (SOM) from NOCMA headquarters in Lilongwe. Then I was referred to the Depot Manager at Matindi depot, the protocol was followed for sake of ethical Consideration to ensure confidentiality of sensitive financial and operational information. The depot comprises of fixed petrol storage tanks which aligned with this study needs to meet the successful results.

The permission granted and field observations followed at the Matindi storage depot. The following are the procedures and tools involved in the study to meet the main research objective: direct measurement with reference to the manual script made during desk study which guided the relevant data needed. The tape measure and manual deep tape was used to deep the level of petrol in the tank and parameters like vapor space (Vv or Hvo) and tank diameter (D), while vapor density (Wv) and molecular weight of the petrol (Mw) was measured using digital density meter.

Digital thermometer and digital pressure gauge were used to obtain: ambient temperature (T), pressure of vapor space at normal operation condition (Pvi), Stock vapor pressure at daily average liquid surface temperature (Pva), breath vent pressure setting (Pbp), atmospheric pressure (Pa), and vapor pressure at ambient temperature (Vp) (Stricklin, 2014).

3.3.2. Data analysis activities

The following section showcases the data analysis activities that drove the study to produce results.

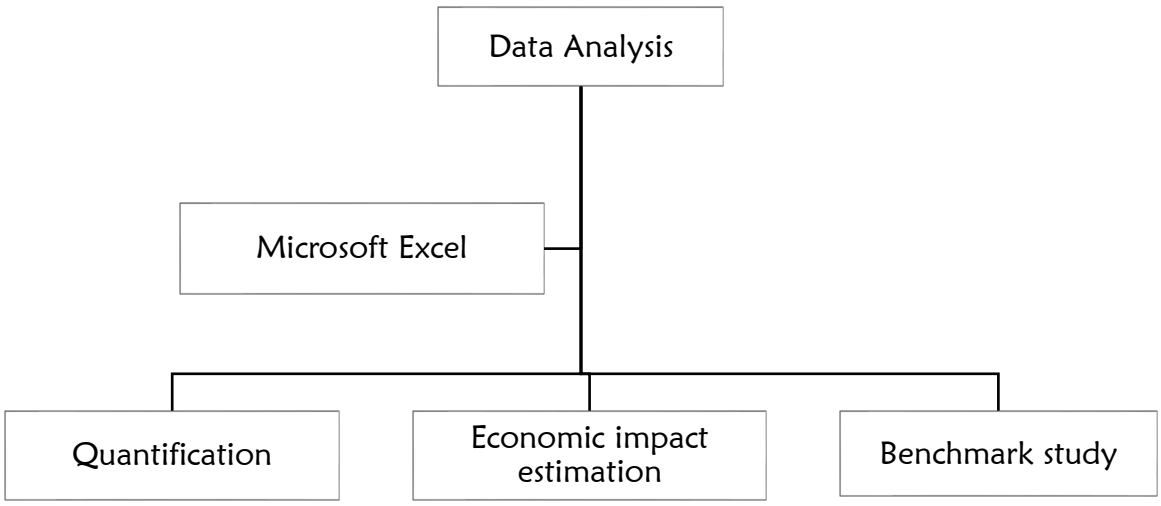


Figure 3: Activities involves in data analysis

Quantify evaporation losses were followed as part of data analysis, the data collected were used for analysis in the mathematical models (i), (ii) and (iii) developed in Microsoft Excel (Howari, 2015). Those are best fit for the data that presence at my study area and not coasty as to compare with other equations. The parameters were organized at an excel spreadsheet and calculated by applying its systematic approach. The results were obtained in barrel (bbl) annually then converted to liters (Andalucia, 2023).

(i) LT (annually) = LS + LW

(ii) LS = 365 Hvo KE ($\frac{\pi}{4}$ D^2) Ks Wv

(iii) LW = N HXL ($\frac{\pi}{4}$ D^2) KN KP KB WV

Estimations of the economic impact were conducted. Using excel Microsoft spreadsheet, annual economic loss calculated. It was calculated through multiplication of annual petrol losses in liters by current petrol procurement price per liter (MWK/liter) (Ngwira, 2023).

Benchmarking study were conducted as part of thematic analysis on the storage tank depot. The process involved gaps identification for improvements strategies. The literature review conducted on various scholars including from the API 653 Certified Storage Tank Inspector Syllabus (Matthews, 2011). This was done by comparing current and desired states fuel storage tanks. The key inefficiencies and developed practical solutions to address them both was identified.

Chapter 4: Results and Discussion

The results and discussion that follow are thoughtfully organized around central themes, offering a unified and comprehensive account of the research achievements. The **Tables 1** and **Table 2** illustrates the quantity of petrol lost annually and the distribution percentage between standing losses and working losses from a fixed storage tank.

Table 1: Standing Losses Calculations

PARAMITERS	VALUES	Ls MODEL	PERCENTAGE %		
KE = vapor space expansion factor (Dimensionless)	0.04			Ks	0.9297
Hvo = height of vapor space between tank roof and petrol surface (ft)	9.84			Pi	3.1416
Wv = stock vapor density (lb/ft³)	0.025			D²	6196.8
D = tank diameter (ft)	78.72			Pva	0.145
Ks = vented vapor saturation factor (Dimensionless)	0.9297			1 bb	159
Pva=stock vapour pressure (psig)	0.145			%	100
The Standing Losses, Ls (bb)		16,251.33			
Total Standing Losses in Liters (L)		2,583,961.92	92.32		

Table 2: Working Losses and Total Evaporation Losses Calculations

PARAMITERS	VALUES	Lw MODEL	PERCENTAGE %		
N = stock turnover rate (turnover/yr)	0.00781			Kp	0.015
Qw = stock maximum petrol height annually (ft)	55.76			R^2	1549.2
D = tank diameter (ft)	78.72			N	0.0078
Kn = working loss turnover factor (dimensionless)	1709.57				
Kp = working loss product factor (dimensionless)	0.01496				
Kb = venting setting correction factor (dimensionless)	1				
Wv = stock vapor density (lb./ft^3)	0.02497				
The Working Losses, Lw(bb)		1,352.57			
Total Working Losses in Liters (L)		215,057.86	7.68		
TOTAL EVAPORATION LOSSES (L)		2,799,019.78	100		

The outcomes of the study after data analysis have shown from the **Table 1** and **Table 2** that the petrol storage tank from Matindi Blantyre depot. The evaporation from tank distributed as 7.68% working losses while 92.32% as standing loss from the tank, about 2,799,019.78 liters lost annually from working and standing evaporation processes. The standing loss process contributes 92.32 % while working loss process contributes 7.68 % to the total to

the total evaporation losses from fixed storage tank. According to NOCMA, Malawi procures petrol annually about 600 million liters of which half of 500 million liters passes through Matindi depot Blantyre and the other Kanengo depot Lilongwe, while the other 100 million at Mzuzu depot before distribution across the country. This represents 1.12% from only Matindi Blantyre depot as the **Figure 4** below, which implies that from only Matindi and Kanengo deports the country lost annually 2.24% of petrol through evaporation except Mzuzu depot. The above quantificatins of the petrol percentage distribution between matind Blantrye and Lilongwe depot. These evaporations are as the result of the following; average daily tank temperature (Stricklin, 2014). The higher the empty space between the liquid surface and the roof (vapor space), the greater the potential for petrol evaporation in the storage tank tank. The color of the tank, the paint from the walls of the tank the darker the colour absorb more heat (Andalucia, 2023).

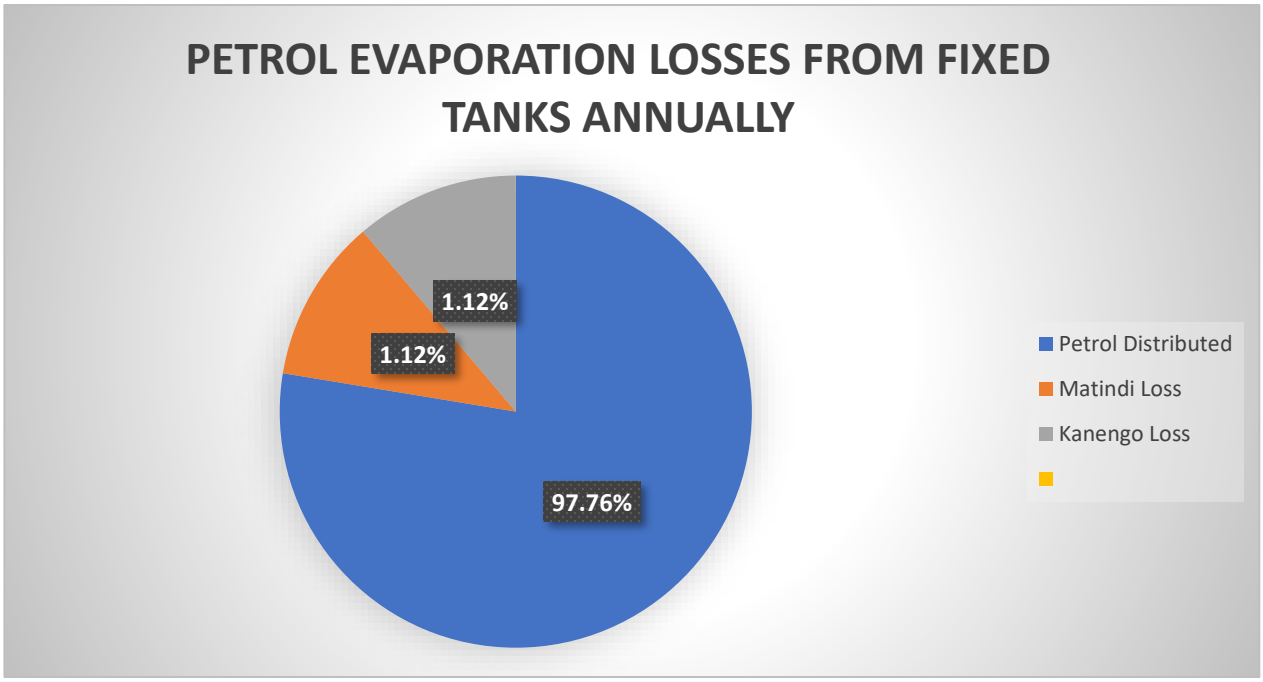


Figure 4: Petrol Evaporation Losses from a Fixed Tank Annually from Lilongwe and Blantyre Depot.

The economic impact is one of main focus in the study, from economic impact conducted the study produces estimations (Andalucia, 2023). Regarding the annual evaporation loss, the country losses a lot of money could have been used in other developing agenda. Below is the **Table 3** which shows the fiscal muscle losses annually from Matindi, Blantyre Depot.

Table 3: Currencies Conversions and Fiscal Losses Estimations

FISCAL LOSSES ESTIMATIONS			
PARAMITER	AMOUNT	CONVERSIONS	
Saudi Petrol per Gallon (SAR)	7.9	US Dollar (MKW)	1720
Tank (L)	250,000,000.00	SAR TO MKW	458.22
Evaporation loss	2,799,019.72	USD to SAR	3.75
		Petrol Gallon to (L)	3.785
		1L (SAR)	2.33
		1L (MKW)	2530
	PROCURMENT PRICE	PUMP SELLING PRICE	
Amount of Money Annually Lost (MKW)	2,988,380,681.51	7,081,519,891.60	

According to the study conducted, there is a certain fiscal muscle the lost as shown in the **figure 6** above, with a reference of actual international prices and foreign currencies **Appendix A**. The country suffers financial losses from both working and standing evaporation losses from single storage depot amounted to MKW 7,081,519,891.60 (seven billion and eighty one million five hundred nineteen thousand eight hundred ninety one Malawi kwacha sixty tambala) as pump selling prices after all government expenses to reach and be ready at pumps. On the other side equivalent to MKW 2,988,380,681.51 (two billion nine hundred eighty

eight million three hundred eighty thousand six hundred eighty one Malawi kwacha fifty one tambala) as procurement price on international market. This amount is more than that since a country procures 600 million liters of petrol annually (NOCMA, 2024), the study only shows only 250 million liters of petrol produces the above losses. Having similar tank properties with very minimal atmospheric different conditions, Kanengo depot aligned to Matindi depot on evaporation losses estimations. The losses doubled that a country suffered financial losses of MKW 5,976,761,363 (five billion nine hundred seventy six million seven hundred sixty one thousand three hundred sixty three Malawi kwacha) as procurement amount losses, while it is approximate to pump price MKW 14,163,039,782 (fourteen billion one hundred sixty three million and thirty nine thousand seven hundred eighty two Malawi Kwacha) once the losses multiplied by two since both Kanengo and Matindi tanks are capacity and functionality resembled while considering that on average annual atmospheric conditions are alike only differ on daily basis. excluding evaporation losses from annual amount stored at Mzuzu depot. This is how serious the loss is at this angle of view needs to be mitigated or reduced to have a colored progress on energy security (Andalucia, 2023).

Chapter 5: Conclusion and Recommendations

5.1. Conclusion

The study main aim was met through a thorough and vigorous investigation and estimations, producing vivid and vital findings which contributes something to the body of knowledge in this petroleum field. The study found that the annual evaporation losses of petrol from the storage tank at Matindi depot is 1.12% of procured petrol that passes though there, resulting in substantial economic losses the country suffer estimated at MKW 7,081,519,891. 60 from single petrol storage tank at Matindi per year. These findings highlight the urgent need for effective strategies to minimise petrol evaporation losses, not only to mitigate financial losses but also to reduce the environmental impact of these emissions. This dissertation has successfully assessed the extent, economic implications, and potential mitigation strategies for this crucial issue. It is important to be familiar with the potential evaporative losses from fixed storage tank. The equations in this paper provide a starting point for having clear picture evaporation losses estimation and the impact on fiscal losses as a country. As an integrity citizens, let us adopt and implement effective ways to reduce losses which drains our economy and promote energy security.

The limitations to this study, mainly were lack of funds to be uterised in support of data finding, collection and analysis process. It was really a challenge reaching extent of lacking internet bundle, delayed access to data due to lack of allowance for people who worked with me particularly at the depot tank during data collection process and on the other hand lack of financial muscle to support field trip to collect data at NOCMA Mzuzu depot. Lastly, the block also was that this study associates with sensitive issues with the government, thereby they do not release data easily which impacted the study not to propel as planned.

5.2. Recommendations

There are number of things needed to implement as a way of mitigate and reduce this setback not only focus on fighting against tank corrosion in our storage depot. These are some of the practical and affordable solutions can be implemented to minimize petrol evaporation losses

at storage depot in Malawi; Tank paint condition and color, appropriate condition and color of the tank's shell and roof can significantly reduce evaporation losses (Andalucia, 2023). Since evaporative losses are proportional to the temperature of the stored liquid, reducing the temperature of the stored liquid can reduce evaporative losses (Stricklin, 2014). Solar radiation will heat the petrol in a storage tank, but the extent of heating is determined by the color and condition of the paint on the tank walls and roof. Paints with a high solar reflectance which are shinny will heat up less than paints with high solar absorptance. Thereby, the petrol in a storage tank with low solar absorptance paint which maintain lower temperatures and lower evaporative losses, rather than paint dark silver or ash grey to prevent tank corrosion. White paint is highly reflective and commonly used also recommended to use as it lowers the tank shell temperature thus reducing standing losses.

The preventative maintenance of the tank, vapors from the tank released to the atmosphere via the tank vent, thief hatch, and leakage (Stricklin, 2014). These three emission mechanisms can be prevented or at least reduced through good preventative maintenance practices at our depot. Tank vents are purposely designed to vent tank vapors to avoid unsafe pressure in the tank. Thief hatches are opened, releasing tank vapors, to manually gauge or sample the tank liquids. And leaks randomly occur when valves, gaskets, flanges, and connections on tanks malfunction and allow tank vapors to pass to the atmosphere (Stricklin, 2014). Thief hatch releases can be minimized by reducing the time the hatch is open or by using external gauges. Thief hatch seal leaks are a common source of tank emissions. Premium hatches are available to provide an appropriate seal, but frequently surveying tank seals and relief valves is the best method to reduce emissions from leaks.

Nitrogen blanketing system is the best applicable and affordable solution which reduces approximate to 70% of the evaporation losses from fixed storage tank (BATIĆ, 2023). The enable to store the petrol for number of years without experience much lost due to evaporation. It works once the nitrogen injected in the tank to cover the gas space which forms a barrier that reduces the vapor pressure not allowing free entry of air and emission of vapor (BATIĆ, 2023).

Vapor recovery units is the best solution to mitigate evaporative losses from storage tanks simultaneously as there is capturing of vapor escape from tank redirect back or package and sell (Andalucia, 2023). In a way that vapor space in tanks can be connected via a large diameter pipe and joined to a small compressor unit where the gas is compressed and sale or used as fuel. however, evaporative losses are also reduced with their installation. When designing tank vapor recovery and combustion systems, the appropriate balance must be established between the set points on the tank vents and the minimum tank pressure necessary for the vapor recovery compressor to run. Maintaining this balance is essential to ensuring the successful operation of any vapor recovery system (Stricklin, 2014).

In case of future plans to build other storage tank depot to promote energy security, I advise to go for floating roof tank with proper seal (Gwangwava, et al., 2018). The floating roof mechanism reduces tank petrol vapor space for particles expansion in the tank, the reduction in vapor space the minimal vapor escape as there will be no room for molecules expansion to exert pressure (Stricklin, 2014).

I recommend the others to do studies on diesel, paraffin and jet fuel evaporation losses whereby this study did not reach those areas of study. They can also conduct a study to estimate petrol evaporation losses all the fixed tanks in Malawi as this study only focus much estimations from Matindi depot situated in Blantrye district.

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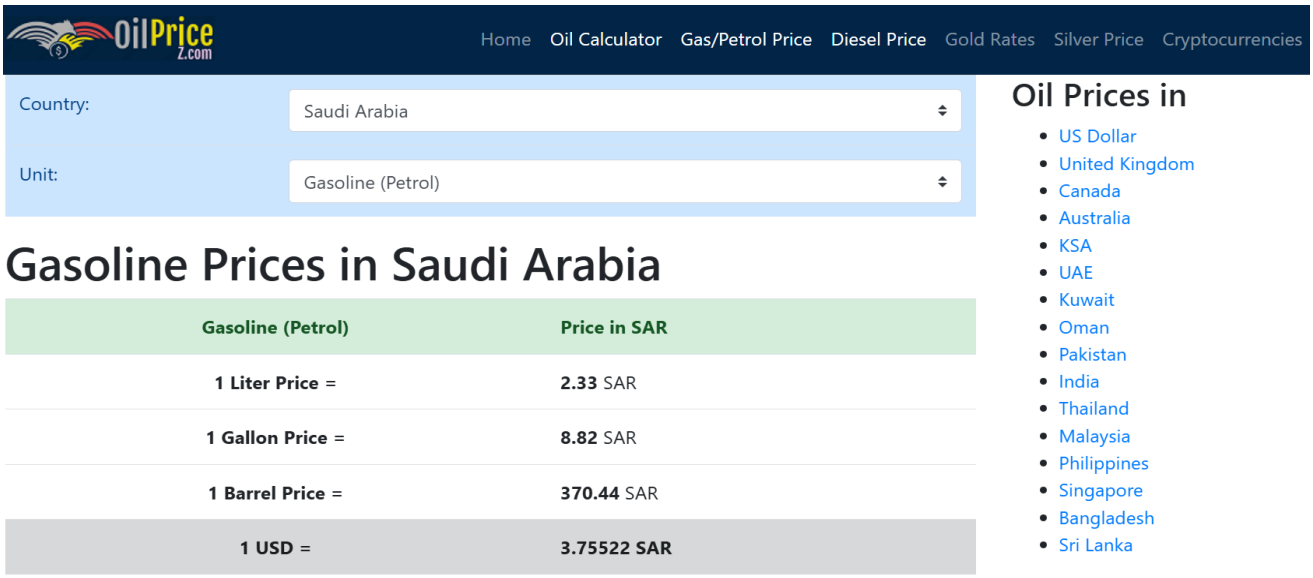
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Appendices

Appendix A: Petrol procurement prices and currencies used in procurement of petrol.



OilPrice Z.com

Home | Oil Calculator | Gas/Petrol Price | Diesel Price | Gold Rates | Silver Price | Cryptocurrencies

Country: Saudi Arabia

Unit: Gasoline (Petrol)

Gasoline Prices in Saudi Arabia

Gasoline (Petrol)	Price in SAR
1 Liter Price =	**2.33** SAR
1 Gallon Price =	**8.82** SAR
1 Barrel Price =	**370.44** SAR
1 USD =	**3.75522 SAR**

Oil Prices in

- US Dollar
- United Kingdom
- Canada
- Australia
- KSA
- UAE
- Kuwait
- Oman
- Pakistan
- India
- Thailand
- Malaysia
- Philippines
- Singapore
- Bangladesh
- Sri Lanka