Root Cause Analysis for Fuel Losses in Bulk Oil Storage Tanks

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Abstract

Petroleum and its products are a major source of energy that plays a vital role in society, powering many essential tools that human life depends on. Supply-chain management is very important in the petroleum industry. Few continents have petroleum reserves, hence there is a need for efficient methods of managing the sourcing, storage and distribution processes across the globe. There have been major improvements in safety management practices, during extraction and processing, in transit, and in situ distribution. Bulk storage of petroleum plays a crucial role across the world as it eases distribution hassles and can act as emergency reserves in the event of disruptions in the supply chain. However, lighter fractions of petroleum have a tendency to evaporate during storage as they are highly volatile. Although there are mechanisms such as floating roofs that have been invented to effectively reduce evaporative losses of light petroleum fractions, the percentage of losses are still high, particularly in some climatic conditions. On average, floating roofs allow leeway for loss tolerances of +/- 0.2% of throughput. Unleaded petrol tanks record significant losses beyond the acceptable tolerances. The Botswana climate is semi-arid, which makes bulk oil storage facility manager cautious about prevailing conditions at their storage reserves. Trends analysed show losses well above the stated tolerance range. This article illustrates the analysis conducted to comprehend the root cause for losses experienced by bulk oil storage tanks (BOSTs) and decision making solution to tackle the problem of excessive evaporative losses in similar climatic conditions.

Keywords: root cause analysis, petroleum, bulk oil storage tanks, semi-arid, supply chain

1. Introduction

The oil &gas industry is the powerhouse of the global, interconnected market. Supply-chain dynamics of fuel (diesel and petrol) has a significant effect on the economy. Although other products such as liquified petroleum gas (LPG) play an equally important role, this article focuses on management of storage facilities for unleaded petrol. Major parts of the African continent are landlocked, with no petroleum deposits, hence rely on imports. In order to meet ever-rising demand for fuel, road tankers and underground pipelines are used to bring in sufficient flows. Huge storage reserves are used to mitigate against emergence shortages, ease distribution hassles and hedge against price distortions in the supply-chain. The rule of the thumb is to have bulk oil storage tank reserves equivalent to at least 90 days of net imports. Other variables and uncertainties emanate from weather-related disruptions, constrained refining capacity, low macroeconomic growth, and exchange rate volatility. Bulk importation and storage are associated with economies of scale and cushions against fluctuating prices. Safety management is highly emphasised in the oil & gas industry in order to curb possible fire outbreaks and guard against spillages, which can become contaminants. Petroleum is highly inflammable; hence, the requirement for efficient storage management practices. Poor storage management can result in significant losses that disrupt the supply chain system. The holistic view of fuel industry supply-chain comprises of inbound and outbound transport logistics, fuel terminals, points of sale, data collection, visibility, and financial planning and integration. Overall supply-chain performance factors at play are optimised and integrated schedules, supply visibility, efficient supply decisions, and optimal end-to-end supply-chain management costs. Unaccountable and unimagined losses in the distribution network and storage facilities can brew chaos as days and months of supply cannot be accounted for. Although storage is mainly a responsibility of the government-run parastatals, particularly in the case study of this research, the repercussions are felt across the industry. Individual customer profitability is affected; un-optimised logistics schedules arise; distorted stock levels are reported and poor supply decisions are made to the detriment of the organization.

Accurate stock levels and subsequent end-to-end visibility of the fuel industry supply chain are key to realising smooth operations. This leads to improved decision-making, optimal inventory management, reduced costs, high return on assets and overall business integration. Whilst losses are usually quantified in terms of costs of the actual volumes lost, the life cycle costs tend to be high because of transportation through tankers or pipelines, pumping and energy costs incurred in rectifying the shortfalls created in the market. Benefits of modern technologies such as cloud computing can only be fully utilised where there are efficient methods of accounting for fuel stock, either in transit or in situ. Cloud computing can enable real-time and integrated planning, monitoring and management, hence provide the ability to adjust the upstream and downstream movement of bulk fuel. Fuel stock on hand, inbound and outbound volumes, depot capacities and carrier capacities can be easily integrated into the overall planning activities through integrated cloud-based technologies.

In order to investigate the root cause for fuel losses in bulk storage reserves, which is a major cause of supply chain disruptions, this article analyses tank records spanning over a period of a year. There is a presumed correlation between ambient temperature and losses. The article provides a decision support tool, which can be used during design of new storage facilities or as mitigation, measures in already existing facilities in semi-arid climates.

1.1 Background

The Botswana fuel industry comprises of the government and the private sector as major participants. Government storage reserves account of approximately 21 million litres. Bulk fuel storage tanks, may be constructed above the ground or underground. Designs for aboveground storage tanks include fixed roof, internal and external floating roof, closed floating roof, and several other types. Vents are used to reduce pressure build-up in fixed roof tanks. However, these become avenues of product escape, especially for petrol because of its high volatility. A mechanism known as the floating roof can be installed within fixed roof tanks to, significantly reduce the amount of evaporative losses. This study focuses on storage reserves, where floating roofs have been installed but are still experiencing losses well above allowable tolerances of +/- 0.2% of the product in the tank. This is costing the bulk oil storage company hundreds of thousands of money annually. The losses are of great concern as, they sometimes triple the allowable tolerance range. This is worth further investigation and proffering suitable solution(s). Maintaining a minimum amount of losses in the supply chain is vital since fuel is a major driver of the local and global economy. Inefficiencies in the fuel industry supply chain accelerate global warming as a result of increased transportation schedules to cater for the lost stock. Botswana uses two modes of bulk fuel transportation into Botswana, namely; road tankers, which transport approximately 15 to $50m^3$ of product and block trains, with holding capacity of about 1000 to $2000m^3$, per single load. Future plans are to expand the Feruka fuel pipeline from Zimbabwe into Botswana (Kairiza, 2018). Escape of fuel vapours into the atmosphere pollutes the environment and affects the health of people and animals around the storage facilities and the whole globe.

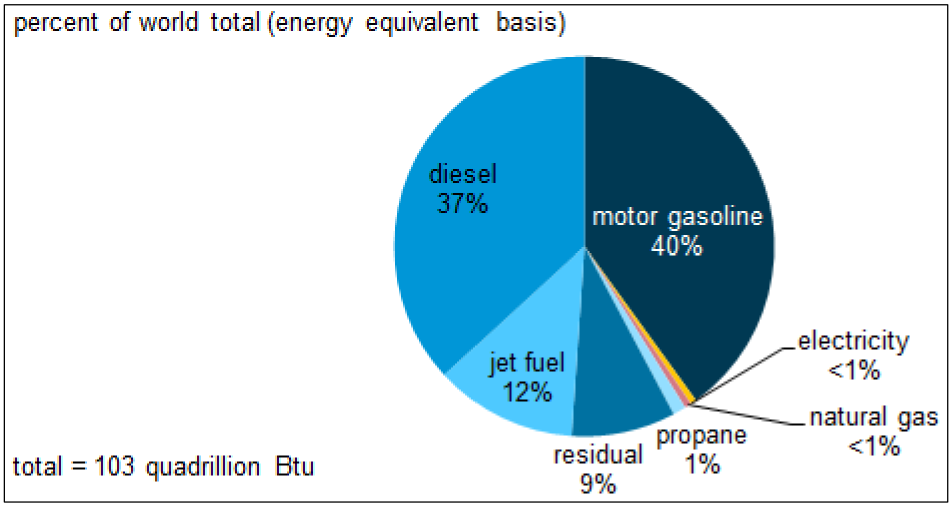


Figure 1: World transportation consumption by fuel, 2012 (Source Energy Information Administration - US Government, https://www.eia.gov)

The world statistics for fuel consumption as of 2012 shows motor petrol (gasoline) and diesel as the dominant fuels. Similar trends still prevail in the current times and depict country-specific patterns. As the workforce population increase and the cost of buying personal vehicles drops, demand for fuel consumption increases.

2. Losses in Fuel Storage

Major losses of crude oil and the refined product occur in storage tanks. Lighter hydrocarbons are vaporized during the operation of these tanks, leading to loss of valuable hydrocarbon raw material and atmospheric pollution by harmful substances (Moryakov, Tatarnikov, Kardash, & Yarmukhametov, 1979). Therefore, reducing evaporation helps preserve product quality and reduces fire risk. There are two types of losses that occur in floating-roof tanks; standing loss and working loss (American Petroleum Institute, 1997). Standing losses are due to the evaporation of stored product occurring without varying the level of the liquid in the tank. They comprise of the summation of losses due to the seal, deck fittings, and plate unions on floating decks (Cruz, 2014). Primary determinants of standing losses are temperature, wind, tank configuration, and type of product stored. Working losses are caused by the product that adheres to the walls and evaporates when exposed to the atmosphere. These occur as vapours displaced from the tank during tank filling and emptying.

2.1 Air Pollution

Evaporation of fuel into the atmosphere releases hydrocarbon radicals into the air. This causes environmental and health risks. Hydrocarbon emissions act as irritants and odorants, whilst some may be carcinogenic (Abha & Singh, 2012). Further reactions with atmospheric gases result in the formation of photochemical smog and subsequently form Nitrogen Oxides (NO_x), which affects the air quality. Hydrocarbons are volatile and also highly flammable, hence they should be stored properly to ensure that they do not escape into the atmosphere in order to guarantee the safety of the people and environment in and around a storage facility or transportation route.

2.2 Techniques to control evaporative losses

Floating roofs have been a major invention to control evaporation on the storage tanks, whilst tanker bottom loading and vapor recovery systems are used to control vapour during transportation of fuel. The floating roof tank floats on the liquid surface in the tank and is designed to move with the liquid as the level changes due to filling, emptying, contraction, and expansion (El–Samanody, Ghorab, & Noaman, 2017). Two major functions of the roof are;

- Minimizing the loss of the stored liquid product inside the tank due to evaporation by eliminating the free space above the stored liquid.
- Minimizing the fire hazard by decreasing the volatile gases inside the tank.

Two common types of floating roof tanks found in the oil & gas industry are the External Floating Roof Tank (EFRT) and the Internal Floating Roof Tank (IFRT). The floating roof is exposed to the atmosphere on an EFRT whilst an IFRT has the floating roof covered by a fixed roof at the top of the shell. The tank shell or support columns are used to support the fixed roof of the IFRT (Parr, 2002). Evaporative losses from tanks can be reduced by 95% through these preventative measures. These interventions also bring other associated economic and environmental benefits.

Although the above techniques help reduce losses, they cannot entirely eradicate evaporation of fuel from the bulk oil storage tanks and also in transit carriers. External conditions influence the evaporative losses differently. Methods used to construct the floating roofs also influence the losses incurred. EFRTs and IFRTs are built using welded and bolted roofs respectively. The rim space, standard roof deck fittings, the tank shell, and tank operations can still allow fuel vapour to escape (Petrowiki, 2017). However, ambient wind, which effects evaporation rate, has less of an impact on IFRTs due to the shielding effect of the fixed roof (Parr, 2002).

Efficient Fuel Stock Management Systems are used to control anomalies that can worsen the side effects of losses in fuel storage. They ensure quicker detection of unusual trends and responsive actions taken to prevent pollution or fire or/explosion, as well as saving costs due to fuel losses (Health and Safety Authority, 2013). Manual tank dipping or automatic tank gauging (ATG) can be used to gather information regarding the quantity of stock in the tank and any other information such as the fuel temperature, density, and water content. The routine practice is to do manual tank dipping twice a day; before and after the day's operations. The practice makes it easier to account for daily receipts, sales, and losses or gains. Automatic methods are more efficient compared to the manual dipping system. Automation has advantages of easy integration into the holistic supply-chain for visibility and quicker response. Vulnerability to human error and abuse is less in the automated system than the manual method.

2.3 Variables that affect losses

Research conducted on different configurations of tanks in different Spanish cities highlighted the following as major variables that affect evaporative losses (Cruz, 2014);

- Ambient temperature.
- Wind speed.
- Tank type.
- Type of seal.
- Stored product.
- Tank paint colour
- Tank volume/ capacity
- Location effect

Vapour pressure and roof fittings also determine the emissions from a tank (Chamberlain, 2015). Wind speed influences evaporative losses both directly and indirectly through the temperature as it affects the heat balance of the storage tank. Solar radiation is the main cause of evaporative losses in the floating roof tanks (Wang, Kendrick, Ogden, & Maxted, 2008). Weather condition and geographic location are important factors in most engineering models for estimating solar radiation on the earth's surface (Zekai, 2008).

3. Method of Study

This article is based on a case study of bulk oil storage tanks for petrol in Botswana. The country lies in the southern hemisphere, south of the equator. Botswana is a semi-arid country; with warm winters and hot summers. The storage tanks considered in the study are located in the city of Gaborone, which is located in the southern part of the country.

Gaborone's average maximum temperatures can reach about 31°C in January, with the average minimum being 20°C, while in June the average maximum temperature is 23°C and a minimum of 4°C. Quantitative and qualitative research methods are used to study the root cause of fuel loss in the storage tanks. The context of the case study is based on the analysis of losses experienced at the fuel storage facilities over a period of one year, from February 2017 to February 2018. The site of the study has storage tanks for unleaded petrol coded as R2, R4 and R5. Data was collected from the tanks and evaluated to determine trends and variances. Data collection methods used include, but are not limited to questionnaires, interviews, past tank inspection records and dip sheets. Details about the context surrounding the case (R2, R4 & R5); historical data, information about the physical environment, past operational methods, and other factors that may have had a bearing on the situation are considered as well.

A broad aspect of the research involved a thorough review of the literature surrounding the case of petrol losses in storage facilities. Where the following questions are used to guide the direction of the research;

- Why do the petrol tanks experience losses well above the allowable tolerance?
- To what degree does ambient air temperature contribute to the losses?
- What is some state of the art management techniques to reduce losses?
- What is the cause of these losses?
- How much do the losses experienced by the storage tanks cost the company?
- What intervention measures of losses can be recommended?
- Operational and engineering practices for curbing losses

3.2 Data Gathering

In order to establish the root cause(s) for excessive losses in bulk oil storage tanks, a number of steps and activities were carried out. The following data collection techniques were used;

- Documents and records: dip sheets for a period of a year,
- A questionnaire was sent out to the depot manager and engineering team to gather primary data on the petrol tank losses and the probable causes,
- An informal interview was carried out with the depot manager and engineering manager to gain understanding on the enormity of the issue at hand, and
- The broad span of the research has involved a thorough review of the literature (case studies) on petrol losses in storage facilities.

3.3 Response to Selected Questions

Responses to a sample of questions asked during interview sessions with the management and engineering team are itemized below;

i. On a scale of 1 to 5, express the stance the company has over the current petroleum products losses experienced by all the tanks housed at the Gaborone depot. (1 unbothered-5 high concern)
    - ➢ 3.5

ii. What do you think is the major contributor to the current losses?
    - ➢ Suspect the tank calibration charts which might be giving errors in conversions and the high temperatures of the day.

iii. What measures are currently in place to mitigate the losses?
    - ➢ Internal floating roofs for ULP tanks.

iv. Are there any operational efficiency targets in place? If yes, what are they and how does the company intend on achieving them?
    - ➢ Yes. To limit ULP losses to <0.2% and <0.15% for diesel through sound maintenance.

v. Where there any indicative factors of tank degradation during the last inspection on R4 and R5?
    - ➢ Only modifications and minor repairs.

vi. When last was R2 opened for inspection?
    - ➢ 2013

vii. What types of seals are fitted in R2, R4 and R5 floating roofs?
    - ➢ Mechanical seal (R4, R5), Foam (R2).

The general conclusion from the interview indicates that the management is worried about current losses, which are beyond the average expected losses. Measurement and calibration are suspected to be a source of error leading to exaggeration of losses incurred. The responses tally with findings from literature where construction methods for the tanks and floating roofs are cited as potential sources of evaporative losses. Sufficient maintenance and management practices are already in place, and may not be the likely culprits for excessive losses.

3.4 Fishbone Analysis

The fishbone analysis diagram is a visual diagram used to describe the cause of a problem, pioneered by the Japanese Professor, Kaurou Ishikawa in the 1950s (Phillips and Simmonds, 2013). The diagram resembles the skeleton of a fish, hence the source for its name. Fishbone analysis is a key diagnostic tool for analysing problems within root cause analysis and is also useful in service improvement projects (Galley, 2012). The analysis method, relying on a team approach and a facilitator, begins by agreeing on a problem, followed by evoking ideas and issues (causes) that are related to or affect the problem (effect). The interviews provided an insight to the authors and have helped in categorising the causes for evaporative losses. There are six categories of causes for excessive evaporative losses in fuel storage tanks, as per the material flows and operations involved in use and management of the depots. The categories are listed as follows;

- Equipment
  The depot under study follows a maintenance schedule, where preventative maintenance is carried out periodically, e.g vertical tank inspection carried out every 3 months, an in-service inspection every 5 years and out of service inspection every 10 years, while product lines and valves are inspected every month. The maintenance carried out on the tanks seems to be up to recommended API standards.
- Materials
  The tanks are made of steel sheets and unleaded petrol tanks fitted with floating roofs of aluminium. A vertical tank inspection is carried out every 3 months, an in-service inspection every 5 years and out of service inspection every 10 years in order to determine the tanks integrity. Inspection reports have not indicated any major issues with regards to the tank integrity. All minor issues such as the painting of tank roofs have been addressed.
- Measurement Process
  Tank contents are measured twice daily by "dipping". Dipping is done by taking readings of the products temperature, water content, density and capacity (length). The tools used for dipping are fairly new and in good condition, so there is little room for error.
- Environment
  Several environmental factors such as temperature, rainfall and wind speed can have an effect on losses.
- People
  Plant operations are carried out by well-trained and skilled operators who undergo further training periodically to enhance their skills. Also to reduce the risk of misinterpreting values and any errors, operations such as dipping are done by at least two people.
- Management
  Oil and gas facilities are administrated under strict security protocols because of the risks involved. Because of this security personnel and equipment are present in all parts of the depot with most areas under strict surveillance and restricted access and hence there is little to no room for theft.

All possible causes of excessive evaporative losses were explored using the "five whys" – an open question approach to analysis using critical analysis questions starting with *why*, *what*, *when*, *who* and *where*. The process is helpful in determining the root causes from the probable causes. Figure 2 below shows the fishbone diagram drawn up as part of analysing the problem of excessive evaporative losses.

After agreeing on all the possible causes of excessive evaporative losses, each cause was revisited to understand why and how it affected the problem. As summarised in the category of causes for the problem in the previous paragraph, some of the causes identified seem not to have any significant contribution. Tank integrity, management, and maintenance are confirmed to be within acceptable practices. Since allowable tolerance of losses or gains of +/- 0.2% for petrol and +/- 0.15% for diesel are being exceeded, there is the need to investigate environmental-related causes. Going further, data for climate conditions within the location of the fuel depot are gathered and analysed together with the fuel loss data.

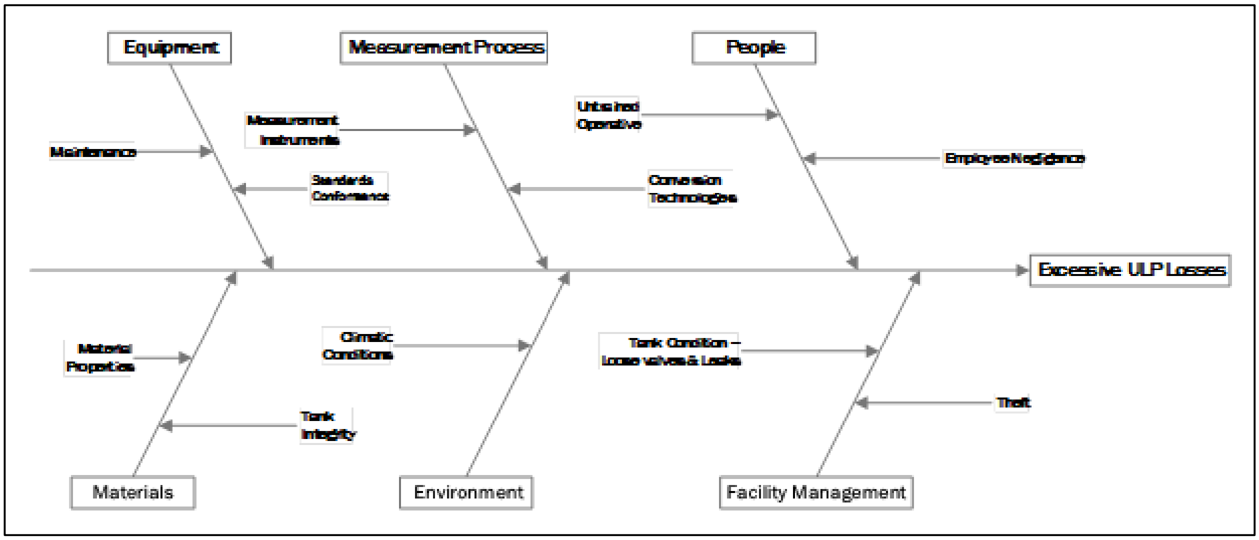


Figure 2: Fishbone diagram for excessive evaporative losses

4. Results and Findings

This section shows data to substantiate the amount of losses revealed over the period February 2017 – February 2018. Data on climate conditions around the location of the storage tanks were collected from the Meteorological Services department. The data was analysed to check for any relationships with the recorded losses.

4.1 Recorded Evaporative- and Financial- Losses

Figure 3 below shows a comparison of monthly expected (allowable) versus actual losses incurred over the study period. The actual losses are high through most parts of the year, except for the months of June – August (winter period).

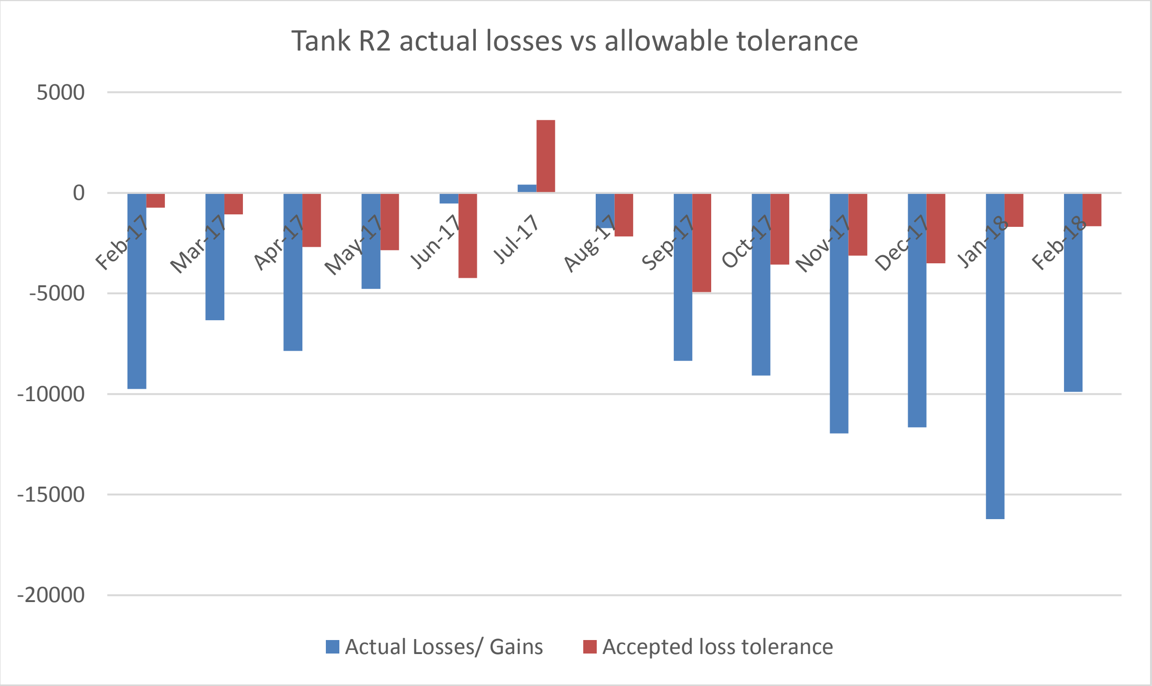


Figure 3: R2 actual losses vs allowable tolerance

Tanks R4 and R5 were open for the most part of 2017 for modifications and began operating in December 2017, hence they are excluded from the recorded data. However, to substantiate the general trend of excessive losses; measurements were carried out for the three consecutive months (December 2017 – February 2018) and the revealed losses were identified to be above the tolerance level for both tanks.

The losses incurred in tank R2 only (holding ULP 95) were converted into financial losses for the annual period of February 2017 - February 2018, as presented in Figure 4 below. Hence, the total losses quantified to an amount of P583k. If contributions from all other tanks were added up and 100% availability is considered, then the total evaporative losses would run into millions.

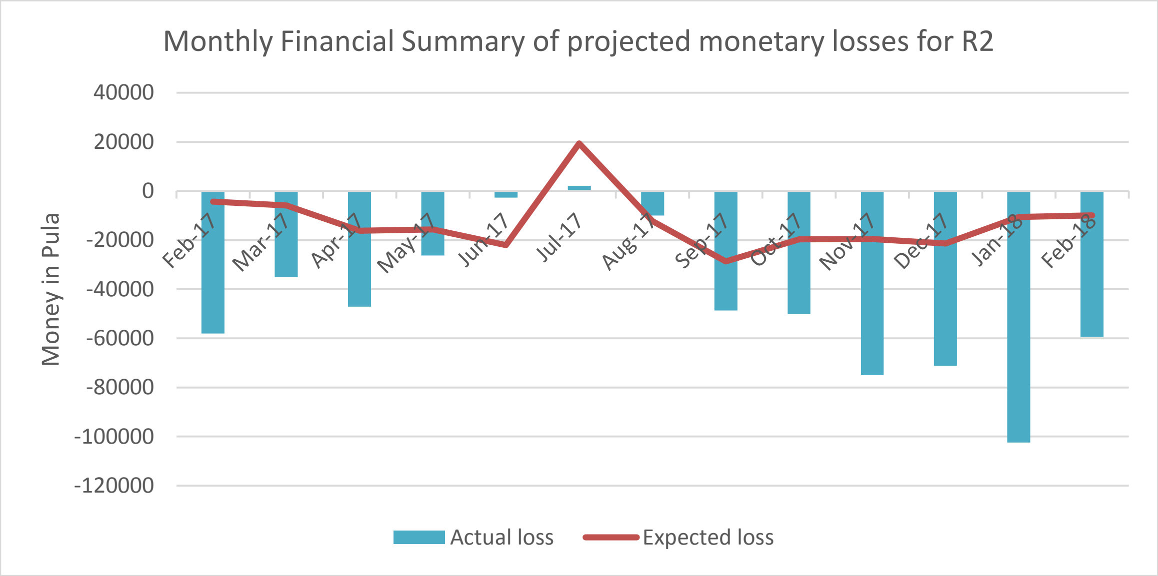
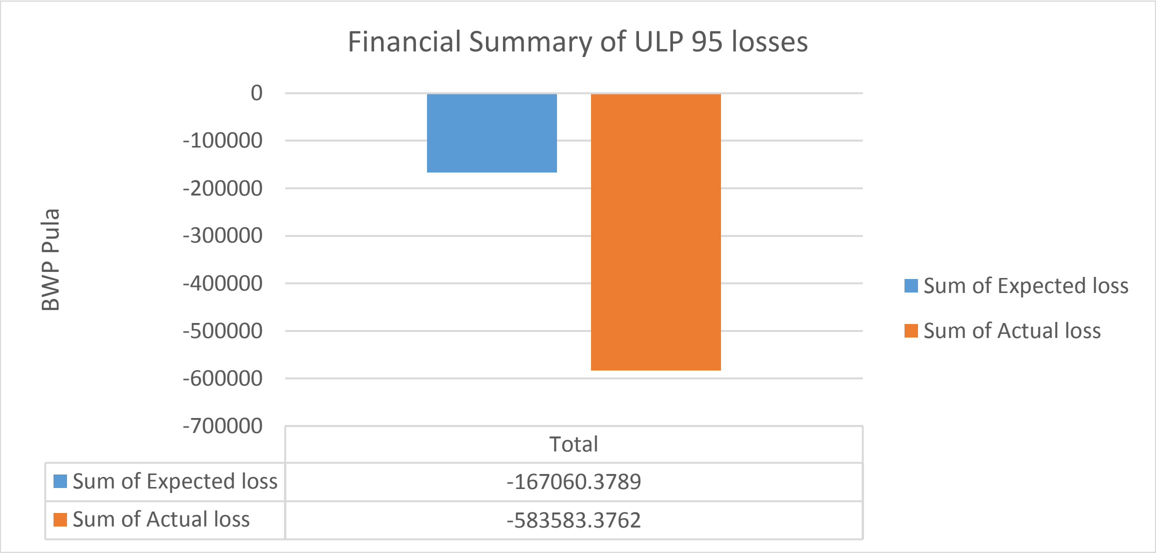


Figure 4: Financial losses due to evaporative losses



	Total
🟦 Sum of Expected loss	-167060.3789
🟧 Sum of Actual loss	-583583.3762

Figure 5: Annual cumulative financial loss

From the graph above we can conclude that the company experienced an approximate financial loss over three times the allowable losses.

4.2 Climatic Conditions and Loss Correlation

Climate data for the city of Gaborone, where the depot is located, was recorded over the study period and plotted against the losses incurred. Figure 6 below shows the average ambient temperature in Gaborone.

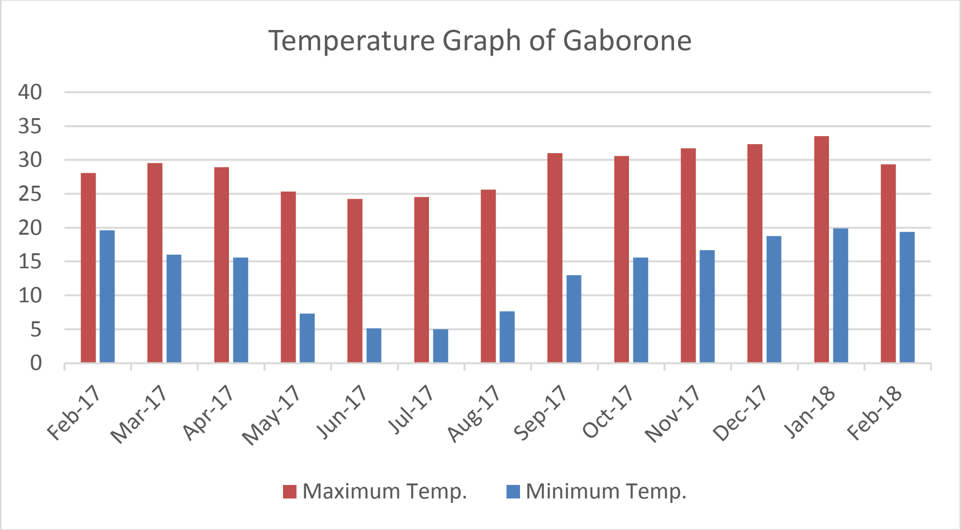


Figure 6: Average min & max temperatures at Seretse Khama International Airport. Based on weather reports collected from the Department of Metrological Services

When comparing the correlation between the average ambient temperature and losses experienced in the petrol tanks, losses are greater in the months with a high ambient temperature than in cooler months, as shown in Figure 7 below. With a properly functioning floating roof, the losses experienced by the tank should not vary that much as the floating roof would restrict a high proportion of the evaporative emissions.

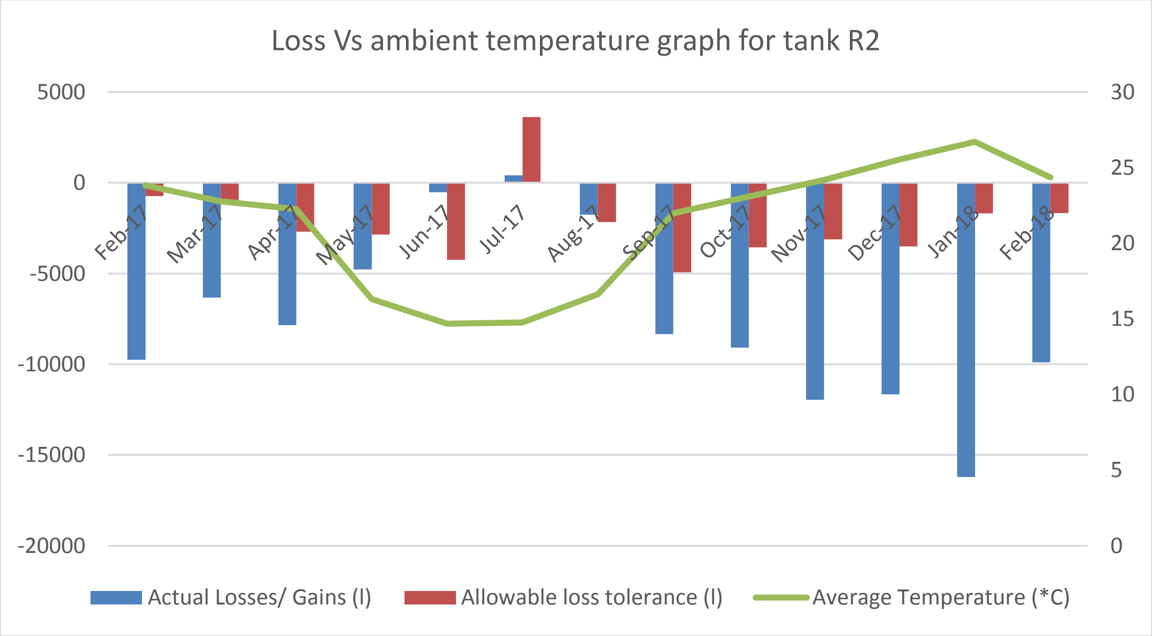


Figure 7: Graph showing a correlation between ambient temperature and losses for tank R2

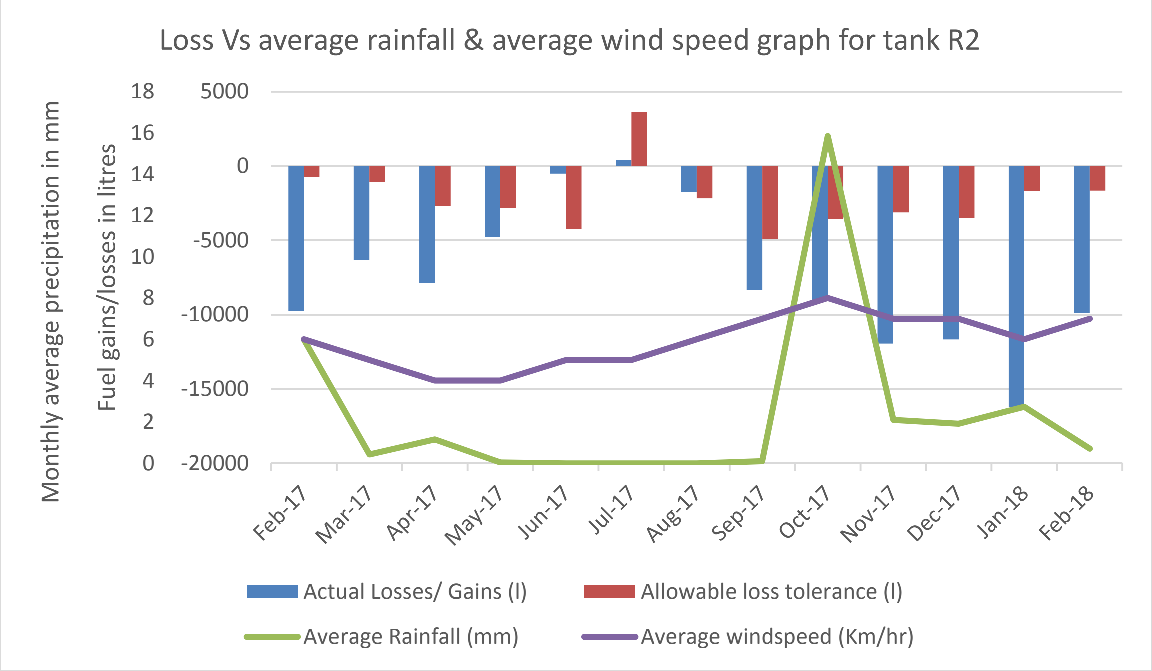


Figure 8: Graph showing correlation between average rainfall, wind speed and losses for tank R2

When comparing the correlation between the average rainfall, wind speed and losses experienced by R2 during the period under observation, on months with little to no rain and reduced wind speed, the losses on the tank seem to be reduced as compared to months with more rain and wind, with the exception of January 2018, see Figure 8 above.

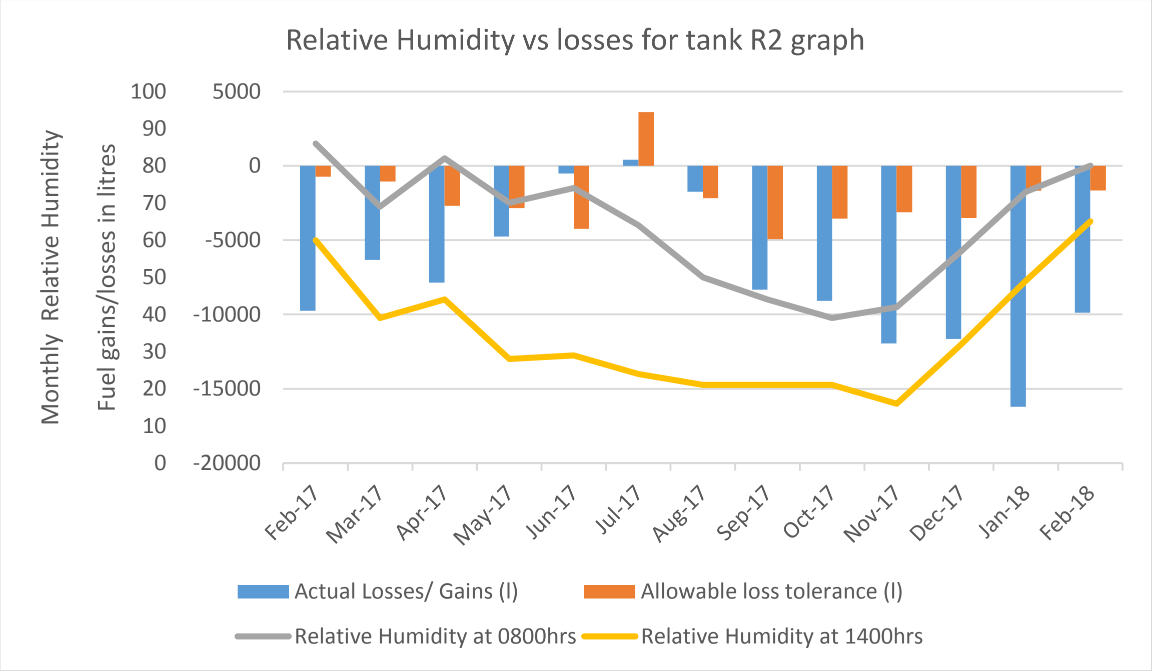


Figure 9: Graph showing correlation between relative humidity and losses for tank R2

With regards to relative humidity, no clear correlation can be established with the losses, see Figure 9 above.

4. Conclusion

Based on the data analysis in the previous sections, it can be concluded that the root cause for excessive evaporative losses from storage tanks comes from high ambient temperatures and associated climate conditions. The floating roof method, although it curbs escape of petroleum vapour, the method falls short in semi-arid regions. Regular inspection of the floating roofs at the study site proved a proper integrity of the system analysed. A feasible resolve has therefore been reached for a robust technical solution. This feasible resolve would suppress the excessive losses to within allowable limits. Further endeavours to solve the problem of excessive losses in bulk oil storage tanks will explore various methods of recovering the vapour. Thus, enhancing the integrity of current floating roofs, and reviewing results oriented innovative methods available in the oil and gas industry. This will go a long way in improving the supply-chain management system for the oil and gas industry.

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Biography

Norman Gwangwava is a professional Engineer with experience from industry and academia. He is currently a lecturer at the Botswana International University of Science and Technology (BIUST), Department of Mechanical, Energy and Industrial Engineering. He has presented and published many research papers at conferences and refereed journals. Research interests are in; Reconfigurable Manufacturing Systems (RMS), Cyber-Physical Production Systems (CPS), Collaborative Product Design and Closed Loop Life-Cycle Systems, Manufacturing Information and Database Systems. He holds a PhD in Industrial Engineering from Tshwane University of Technology, South Africa and a Master of Engineering in Manufacturing Systems and Operations Management from the National University of Science and Technology, Zimbabwe. He is a member of the SAIIE-*Za* and ZIE-*Zw*.

Taboka Motlhabane is a final year Energy Engineering student at the Botswana International University of Science and Technology (BIUST) with a record of academic and extracurricular success. She has extensive leadership experience, especially within a higher education setting having volunteered with the BIUST Engineering Students Association (BESA) as a committee member, within various Student Representative Council (SRC) Ministerial committees rising up to become a Minister of Health and Safety in the 2016/17 SRC. Taboka has experience in the Oil and Gas Industry, where she did internship. Taboka has training in leadership, emotional intelligence, fire safety, defensive driving, among many others. She is passionate about issues involving energy generation, use and management, the environment, climate change and sustainable development. She is a self-driven individual, who is highly motivated, works well in teams and alone, and who enjoys solving problems and learning.

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