

QUALITY ASSESSMENT OF PETROL AND DIESEL FUELS IN SELECTED FILLING STATIONS IN BLANTYRE CITY, MALAWI

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ABSTRACT

Malawi relies much on petrol and diesel fuels for its transportation sector. The increased population has been associated with increasing number of vehicles, therefore call for high demand for petrol and diesel fuels. Because of this, automobile fuel quality is becoming a subject of concern across the world, more likely in developing countries. A complaint of fuel contamination (which is addition of external materials to petrol and diesel to increase volume) at the point of the sale or during transportation is so common in many countries. Contaminated fuels can lead to health and environmental problems, reduced performance and lifetime of vehicle engines and other components of automobile. Some recent studies on analysis of petroleum fuel contamination does not give a clear scope of what is happening at the fuel selling stations within and outside Blantyre. This research study presents therefore the quality assessment of petrol and diesel fuels from selected filling stations in Blantyre. Seven fuels samples each for petrol and diesel fuels making fourteen in total were collected from Oil Marketing Companies which include, Total energies, Energem, Puma, Mount Meru, Petroda, Engen as well as Simso. Fuel parameters like density, octane number, cetane rating and flash point of the sampled fuels were analysed in the laboratory using fuel analyser and Energy Dispersive Ray Fluorescence measured sulphur content. The results were compared to the Malawi Bureau of Standards (MBS), and the results indicated that there were variations in some fuel properties among all the Oil Marketing Companies. The densities of almost petrol and diesel fuels among all the filling stations were within the MBS range, except about 29% which were outside the range. The flash points of petrol fuel of about 71% out of all filling stations were outside the MBS range, indicating that some stations add contaminants. Flash point for diesel, almost 57% out of all filling stations were outside the range The octane number for all filling stations, nearly 68% were within the MBS range for petrol. The cetane number of about 68% out of all the filling stations were within the MBS range. The sulphur content of almost all the fuels were found to be outside MBS range. It is therefore recommended that the government of Malawi should ensure that all the oil marketing companies are operating with specified sulphur content and flash point by MBS, and that there should be consistency implementations of all the standard regulations.

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ACRONYMS/ABBREVIATIONS

ASTM	:	American Society for Testing and Materials
CFR	:	Cooperative Fuel Research
CO	:	Carbon monoxide
CO_2	:	Carbon dioxide
CVCC	:	Constant-Volume Combustion Chamber
ESCOM	:	Electricity Supply Corporation of Malawi
HSD	:	High speed diesel oil
IQT	:	Ignition Quality Tester
IEA	:	International Energy Agency
IP	:	Institute of Petroleum
LDO	:	Light Diesel Oil
MBS	:	Malawi Bureau of Standards
MERA	:	Malawi Energy Regulatory Authority
NOCMA	:	National Oil Company of Malawi
NO(x)	:	Nitrogen Oxide(s)
OMCs	:	Oil Marketing Companies
PIL	;	Petroleum Importers Limited
PM	:	Particulate Matter
QA	:	Quality Assurance
QC	:	Quality Control
TAN	:	Total Acid Number

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1. CHAPTER 1: INTRODUCTION

1.1. Background information

Since the beginning of the industrial revolution, fossil fuel has been fast increasing. Among all, the automobile sector has merged as a major consumer of the fuel (Gupta & Sharma, 2010). The development of urban cities is associated with an increasing number of cars to serve mainly public transport and freight, and on this occurrence, Blantyre city is not an exceptional. This phenomenon therefore calls for the high demand of petrol and diesel fuels. Petroleum products and fuels, (oil and gas), in contrast to petrochemicals, are those fractions derived from petroleum and have the commercial value as a bulk product. (Speight, 2010). Petroleum products are therefore fuels that are made from crude oil, coal, natural gas or the biomass. Petroleum products include transportation fuels such as petrol and diesel, fuel oils for heating and electricity generation, asphalt and road oil, and feedstocks that are used for making the chemicals, plastics and synthetic materials (Administration, 2013). Transportation fuels such as petrol and diesel are important in most developing countries like Malawi. This is so, because they enable economic growth, social inclusion, trade as well as connectivity. Transport connects people to jobs, education, health care and each other. In this manner, transport is the crucial driver for both economic and social development. (Bank, 2019)

When different products of equal quality have different prices or the consumer does not have an effective tool to distinguish between similar products of different qualities, the chances of lowering the quality of the product are high as to obtain much profits. Petrol and diesel quality is becoming a subject of concern across the world because of potential problems associated with poor quality fuel. Fuel quality in general, can be defined as the state in which the petroleum fuels i.e., petrol and diesel are free from contaminants such as water, excess sulphur, ethanol and other petroleum products like kerosene (Kaware & Sakhare, 2013). The definition of quality of the fuel depends on the type of fuel and its intended uses. Diesel fuel quality for example, relates to its performance, depending specifically on its cleanliness and its contents. Diesel fuel also known as gas oil, produced from petroleum, can also called petrol diesel to distinguish it from diesel obtained from other sources such as biodiesel. Petrol diesel is composed of about 75% saturated hydrocarbons with a primarily paraffins and 25%

aromatics hydrocarbons which includes naphthalene's and alkylbenzenes. Chemical formula for common diesel fuel by average is $C_{12}H_{26}$, ranging by approximate $C_{10}H_{22}$ to $C_{15}H_{32}$. (Cedre, 2006). For any diesel engine to function properly for a long period of time, it needs to be well supplied with a clean and high-quality fuel, on top of other factors. Cleanliness has proven to be an important part in maintaining the performance, reliability and usable life of all diesel engines. (Cummins, 2021). The best way to measure diesel fuel quality is through cetane number, which describes the fuel's ignition quality. A higher cetane number means the fuel ignites quicker and burns more thoroughly. In that way, the cetane number rates the quality of combustion. The contaminants that mingle with stored fuel degrade its performance and quality. High-quality fuel is essential for operating generators, vehicles and other equipments. Additives and stabilizers can help to preserve fuel quality, as appropriate storage procedures are being followed. (Fuels, 2022). Quality of petrol fuel can be defined as the properties and additives of petrol that affect its performance and cleanliness in internal combustion engines. The quality of petrol can vary depending on the source, the blend and the storage conditions. Additives and blending agents are added to hydrocarbon mixture to improve the petrol performance and stability. Compounds which can be added include, anti-knock agent, anti-oxidant agent, metal deactivators, anti-rust additives, anti-icing agents, pre-ignition additives, upper cylinder lubricants and dyes. The major hydrocarbon compounds in petrol include alkanes, isoalkanes, cycloalkanes, alkenes, and aromatics. (Richardson, Simpson, & Skopek, 1986). Poor quality fuel can cause various problems such as engine malfunctioning, damage, or emission of harmful pollutants (Nyabaro et al., 2021). Petrol as a transport fuel can be defined as a refined product of petroleum consisting of different hydrocarbons, additives and blending agents containing different boiling points, ranging from between 30°C and 202°C for one to obtain a distillation curve. (Murago, 2010).

Blending process, as mentioned, determines the quality of petrol fuel to be used. Petrol is usually blended with ethanol to create a fuel mixture. Ethanol is a biofuel derived from agricultural products such as sugarcane molasses through fermentation (Express T. I., 2023). This ethanol is then used to increase the renewable energy content of local petroleum fuels at a ratio of 20% ethanol to 80% petrol (Energy, 2020). But the standard blend typically

contains 10% ethanol and 90% petrol. Ethanol has a higher-octane number than petrol, providing premium blending properties. Minimum octane number requirements for gasoline prevent engine knocking and ensure drivability. Lower-octane petrol is blended with 10% ethanol to attain the standard 87 octane (The Altenative Fuels Data Center (AFDC), 2018).

The world experienced the first truly global energy crisis, triggered by Russia's invasion of Ukraine in early 2022, which plunged global energy markets into turmoil, stoking inflationary pressures and slowing economic growth (IEA, 2022). The crisis disrupted both demand and supply patterns, leading to volatility and steep spikes in energy prices, particularly for natural gas in European markets. The crisis has also shattered energy relationships with Russia built on the assumption of trust and secure supplies, and led to a reappraisal of energy security needs in many countries. This is leading to a recasting of the energy trade and investment landscape in profound ways (IEA, 2022). The crisis has also exposed the challenges of ensuring fuel quality in different countries, especially in developing regions where fuel available is in less supply but with a high demand.

Other companies from different countries opt for different ways of increasing the volume of the fuels and thus lowering its quality, and these met with different challenges. For example, in South Asia, India has faced issues with adulteration of petrol and diesel with kerosene or other substances to increase profits or evade taxes (Ghosh, 2019). In Africa, Kenya has experienced cases of fuel contamination with water or dirt during transportation or storage. (Mwaura, 2018).

Impacts of Poor-Quality Fuel on Vehicle Performance and Efficiency

As such, quality of petroleum fuel has a significant impact on the performance and efficiency of vehicles, machinery, and power generators. Poor quality fuel can affect various aspects of vehicle performance such as power output, fuel consumption, engine wear and tear, emissions control systems, and maintenance costs (Kaware A. P., 2013). For example, excess sulphur in diesel can damage catalytic converters and particulate filters, leading to increased emissions of nitrogen oxides (NOx) and particulate matter (PM). In addition to that, the increased air pollution and health risks can also occur due to the presence of the carcinogenic pollutants in

the air. Ethanol in petrol can cause corrosion of metal components and deterioration of rubber seals and hoses, resulting in fuel leakage and reduced engine life due to corrosion, wear and tear, and clogging of fuel injectors. (Nicholas Surawski, et al., December 2017). Water in fuel can cause microbial growth and formation of sludge that can clog fuel filters and injectors, reducing fuel flow and combustion efficiency (Nicholas Surawski, et al., December 2017).

Fuel Quality Standards and Regulations in Malawi

In the fuel quality industry, there are two important concepts, and thus fuel quality control (QC) and fuel quality assurance (QA). Fuel quality control is the process of ensuring that the fuel meets the required specifications and standards, whereas fuel quality assurance is the process of ensuring that the fuel quality control process is effective and that the fuel meets the required specifications and standards consistently over time. Fuel quality control is necessary since it can minimize pollutant emissions from combustion and enable the use of advanced emission control technologies, while fuel quality assurance ensures that the fuel quality control process is effective and that the fuel meets the required specifications. Fuel quality control is the subset of fuel quality assurance. (Fung, 2011).

Here in Malawi, the Malawi Bureau of Standards is responsible for handling fuel quality system, as such, they are both involved in quality control as well as quality assurance. It is responsible for the preparation and publication of Malawi standards; promotion of standards and quality in Malawi and implementation of Malawi standards through relevant conformity assessment programs through the enforcement of the MBS Act (No. 14 of 2012). As a Malawian national standards body, the MBS ensures that it provides a quality infrastructure that assists in conformity assessment of petroleum products and facilities used in Malawi, to promote fair trading practices and consumer protection. The MBS, in the quest to achieve its mandate, uses the Cess collected from fuel for purposes of standardization programs and strengthening the petrochemical testing, verification and calibration capacity. Among the over 1,300 standards the MBS has developed using funds collected as MBs Cess from the fuel pricing structure, about 30 of the standards are in petrochemical related areas. (MERA, Fuel levies in

Malawi, 2020). Cess is a form of tax charged/levied over and above the base tax liability of a taxpayer. A cess is usually imposed additionally when the state or the central government looks to raise funds for specific purposes. (Express F. , 2019)

Malawi, like many developing countries, relies heavily on petroleum fuel to power its transportation and industrial sectors. Inadequate quality control measures may lead to the distribution and sale of low-quality petroleum products (MBS, Malawi Standard MS 218:2020: Automotive fuels - Diesel - Requirements and test methods., 2020b). The Malawi Bureau of Standards (MBS) and Malawi Energy Regulatory Authority (MERA) have set standards and regulations respectively, to ensure that fuel sold in the country meets the required quality standards. The MBS standards specify the physical and chemical properties of petrol and diesel fuels such as density, viscosity, flash point, cetane number, octane number, sulphur content, water content, and ethanol content (MBS:, 2020a). The MERA regulations stipulate the procedures for sampling, testing, and reporting of fuel quality at various points of the supply chain such as import terminals, depots, and filling stations (MERA, The Liquid Fuels and Gas (Production and Supply) Regulations, 2019). Malawi Energy Regulatory Authority (MERA) is responsible for regulating the Malawi's energy sector, and also the supplying of liquid fuels and gas. MERA has established guidelines and regulations for liquid fuels and gas supply that specify the quality standards, licensing requirements, pricing mechanisms, safety measures and consumer protection for oil marketing companies (OMCs) in Malawi. If OMCs do not comply with these standards, MERA has the power to impose penalties, suspend or revoke their licenses, or take legal action against them. The following are some examples of fuel trading malpractices that MERA has cautioned. These include, the selling fuel above the maximum pump prices set by MERA, selling contaminated fuel, hoarding fuel or creating artificial shortages, selling fuel in jerrycans, drums and other such containers without authorization from MERA and operating without a valid license or permit from MERA. (https://mera.mw/).

1.2. Problem Statement:

The low-quality standard of fuels on market of petrol and diesel is experienced in many countries, and Malawi is not an exceptional. This study therefore aims to address the

following problem: The quality of petrol and diesel fuels sold in Malawi is low and inconsistent, which affects the performance of vehicles and poses health risks to consumers. However, there is little information available on the chemical composition of these fuels and the potential sources of contamination of petrol and diesel fuels here in Malawi. Previous studies are more of internationally based discoveries. Therefore, there is a need for a simple and comprehensive assessment of petrol and diesel fuel quality in Malawi using locally available tools and standards.

1.3. Main objective and Specific objectives

The availability of consistent and high-quality petrol and diesel fuels is so important for making sure that vehicles and machinery are operating efficiently. Several contaminants and other factors can affect fuel performance. By following the best practices and continuing with routine performance can help to decrease contaminants buildup and retain fuel quality. (Fuels, 2022). The purpose of this study is to assess the quality of petrol and diesel in selected filling stations in Malawi. Contaminants can also affect the chemical composition of petrol and diesel fuels in many ways, depending on the type and source of the contaminants. The specific objectives of this study include the following; to analyze the chemical composition of petrol and diesel specifically focusing on parameters such as density, octane rating and sulphur content using simple tools and compare the results with Malawi Bureau of Standards (MBS), and also to investigate the potential factors contributing to the observed variations in petrol and diesel fuel quality among the sampled filling stations through comprehensive data analysis. And finally, the study will identify some potential sources and the causes of fuel contamination and include some potential contaminants such as water and alcohol.

1.4. Research questions

i. How to analyze the chemical composition of petrol and diesel mainly on density, octane rating and sulphur content using simple tools and compare the results with Malawi Bureau of Standards (MBS)?
ii. What are the potential factors that contribute to the variations of the quality of fuels among the sampled filling stations through data analysis and correlation studies?

iii. How to identify some potential sources and the causes of fuel contamination

iv. To what extent the possible contaminants can be investigated?

1.5. Significance of study

This study will provide important insights into the potential risks associated with the use of low-quality fuel. The findings will be relevant to the Malawi Bureau of Standards as well as Malawi Energy Regulatory Authority who can use the information to continue improving the fuel quality and mitigating the potential risks that might be available. This study will contribute to the body of knowledge on fuel quality and will help to promote sustainable transportation practices by identifying the factors that can contribute to low fuel quality and exploring its effect on engine efficiency and longevity.

2. CHAPTER 2: LITERATURE REVIEW

The quality of petroleum fuel is an important aspect for the efficient and effective functioning of engines in vehicles. The quality of petroleum fuel is determined by a lot of factors, and some of them include the following; Density, which ranges from light to heavy, Sulfur content, and is characterized as sweet or sour. Other factors include: API Gravity, and it measures how light or heavy liquid petroleum is, as compared to water. The other factor is Pour Point, which measures the temperature at which the flow characteristics of a petroleum product are compromised. There is also Vapor Pressure, Viscosity and Total Acid Number (TAN), among others.

Poor quality fuel can result in engine failure, or reduce efficiency, therefore regular quality assessment of fuel sold at petrol and diesel filling stations are essential. In Malawi, there is limited research on the quality of petrol and diesel in filling stations. This literature review aims to provide a background on the importance of fuel quality, previous studies conducted on fuel quality in Malawi and worldwide, and the methods used for fuel quality assessment.

Fuel quality assessment is the process of measuring and evaluating the physical and chemical properties of fuels to ensure that they meet the required standards and specifications for their intended use. (wedocs.une). In Malawi, there is limited research on fuel quality. Research by Alinafe Mkavea on sulphur content in fuels, found out that exposure to diesel can lead to health conditions such as asthma, and respiratory illnesses, and can make worse heart and lung diseases if already existed especially in children and elderly. She also included that emissions from diesel engines contribute to the ground level ozone production, which damages crops, trees and other vegetation. (Alinafe Mkavea, 2017). The primary factor of all these causes was that of using a high sulphur diesel fuel which produces different pollutants like particulate matter (PM), nitrogen oxide (NO), carbon monoxide (CO) and carbon dioxide (CO_2) Black carbon and air toxics.

A lot of research studies on fuel quality have been made internationally. Research by (Broni Bediako, 2020), found out that there were large variations for the fuel properties among fuel selling companies, but densities and flash points of almost all the selected fuel companies were

within the normal range. But the sulphur content of almost all the fuel companies was above the maximum value of the requirement, indicating that most fuel companies in Tarkwa were not complying with the directives of the regulatory. On another research by (Nyabaro, 2021) indicates that the quality of fuel gasoline (petrol) was questionable. The results indicated that fuels sold in Kisii filling stations did not meet Kenya Bureau of Standards. The general primary factor that led to the poor quality according to the study that was made was the absence of consistent implementation of regulations in sustainable manner which left an open door on the issue and because of the complex nature of fuel quality issues. There are different reasons that contributed to the practice of fuel contamination. Some of them include the following:

i. Existence of differential tax levels among the fuels, intermediate products and by-products. Most of the contaminants are taxed lower than fuels, and when blended to fuels increases monetary benefits.
ii. Lack of monitoring and awareness of consumers
iii. Fluctuation in pricing mechanism of fuels and easy availability of the contaminants in markets.
iv. The mechanism and instruments for spot-checking the quality of fuels are poor hence their effectiveness is not very high.

A study by (Kaware A. P., 2013) on fuel adulteration in India founded that the impact can lead to significance consequences in engine performance. He defines that, adulteration is the practice of mixing adulterants (contaminants) with fuels resulting in substandard fuels. This contaminated fuels then cause engine damage, reduced performance and increased maintenance cost. Contaminants in fuel can also clog fuel injectors and filters, leading to decreased engine efficiency and potential breakdowns. In his study, he included that the availability of several petroleum products which are closer substitute of gasoline and diesel, and that the products are available at the low price.

Another study by on fuel detection system, stated that one of the major reasons for increased emissions in vehicles is adulteration of automotive fuel. Blending or mixing of adulterants/contaminants (as used in our country), into petrol and diesel fuels exist into

different forms and both the type and quantity of adulterants may differ from place to place. However, the profit which can be made, availability as well as blendability are the driving factors governing the choice of the contaminants (Dutta, 2003). The common adulterant used, that is mixed with petrol and diesel is kerosene. People used kerosene because of its low cost, but the results include, reduced performance, and the lifetime of engine and other components of an automobile. (V. Jersha Felix, January 2015).

If fuel fails to meet any of its specifications, is referred to as a nonconformity, which simply mean that the fuel is not fit for use. Nonconformity is not always due to adulteration, which is the deliberate and illegal addition of lower-cost substances to a fuel, usually with tax evasion, all with the purpose of increasing the profit margin by illicit means, resulting in reduced tax revenues, unfair competition, harm to the environment, and increased wear and tear of vehicle engines. In fact, a fuel may be adulterated and yet stay within its specifications, in which case the only detrimental effect is on tax revenues. It is a challenge to detect the adulteration of fuels or fuel contamination, because adulterants usually include compounds that are already present in the fuels themselves. Fuel quality can therefore be monitored using a color detection technique. When the fuel contains a detergent-dispersant additive, a colored ring is formed when the indicator changes color enabling qualitative identification by the naked eye. The quality of the fuels, petrol and diesel, are explained according to their specifications in different countries. (Amanda Pereira Franco dos Santos, 2019).

Diesel fuel storage is important for a greater range of industries. Proper fuel storage methods provide a better preserving fuel quality between uses. Monitoring regularly will help to ensure the access to usable fuel when needed. There are a lot of contaminants that affect the quality and diesel fuel performance. Improper storage or increased lack of use of diesel can cause these particles to appear. The most threats to fuel quality include the following; water, dirt and microorganisms. Water presence in the diesel degrades its quality by causing a reaction process called hydrolysis. This is a chemical reaction in which water breaks chemical bonds. Condensation is a common problem when it comes to diesel tanks. The fuel does not have the vapor pressure to replace the air. If the tank heats up, the expanding air will be pushed out. Then, as the tank cools, moist air is sucked back in, causing the water inside to condense.

Avoiding condensation buildup is one reason why proper diesel fuel storage is necessary. On microorganisms, because microbial life requires water to live and reproduce, these tiny organisms accumulate when water interferes with diesel fuel. Bacteria, fungi and other microbes degrade fuel quality and performance. Microbial contamination: Generates acids that corrode diesel fuel, clogging the filter tank, limiting filtration, restricts the flow of liquid into and out of the tank and corrosion of the tank itself. Dirt is another major threat to fuel quality. Sediment buildup in the form of sand, dust, rust and other debris can cause serious performance problems during use. Using dirty diesel fuel can cause the engine to perform poorly, have problems starting, stall, misfire and damage parts. In this way, dirt contained in diesel fuel can reduce the life of the equipment.

Other factors affecting quality of diesel fuel include, time, which explains that the longer sit of stored fuels is likely to undergo a decline in quality, temperature, humidity, and on humidity, the amount of water in the air correlates to the amount of water condensing in a diesel storage tank. Diesel fuel in storage will maintain its quality longer in low-humidity settings and oxidation, which is due to oxygen exposure. (Fuels, 2022)

Importance of fuel quality

Quality of the fuel should have to pass rigorous inspection of its quality control process in any country to help minimizing any chance of producing or distributing fuel of inferior quality. The petrol shall be a hydrocarbon fuel which has been added additives to improve its performance or its storage stability and shall be suitable for use in spark-ignition internal-combustion engines than aviation piston engine. The petrol must comply with requirements given in table 1 below, relevant to the type of petrol. (Laws of Malawi, Liquid Fuels and Gas Regulations, 2009 as amended in 2010).

Table 1: Requirements for inland grade unleaded petrol R93 and coastal unleaded petrol R95

Property	R93 Unleaded	R95 Unleaded	Test method	
			ASTM	IP
Octane rating				
a. Research octane number (RON), min.	93	95	D2699	237
b. Motor octane number (MON), min.	83	85	D2700	236
c. Motor octane number for blends containing more than 2% (v/v) alcohol, min.	85	87	D2700	236
Colour	yellowish	Yellowish	Visual	
Density at 20°C, kg/l	0.710-0.785	0.710-0.785	D1298 D4052	160 365
Sulphur content, % (m/m), max	0.05	0.05	ISO 2192, D1266, D3120	107, 243, 336

The diesel fuel has two important grades. High speed diesel oil (HSD) and light diesel oil (LDO). High speed diesel oil covers distillates of low volatility whereas light diesel oil covers the class of more viscous distillate and blends of these distillate with residuum oil. The high-speed diesel shall not contain any residuum oil. The diesel fuel shall be a hydrocarbon distillate fuel derived from petroleum and other sources to which the small number of additives may have been added to improve ignition, its storage stability and other characteristics. The diesel fuel shall comply with requirements given in **table 2** and shall be clear and free from visible water, grit, suspended matter and any other contaminant which may cause malfunctioning

of equipment designed purposely to use this fuel type. (Laws of Malawi, Liquid Fuels and Gas Regulations, 2008 as amended in 2015)

Table 2: Requirements for diesel fuels

Characteristics	Requirements		Method of Test
	HSD	LDO	
Acidity, inorganic.....	Nil*	Nil*	IS 1448, P2
Acidity, total mg of KOH/g mass, max.....	0.50	-	IS 1448, P2
Ash, percent by mass, max.....	0.01	0.02	IP4
Carbon residue (Ramsbottom) percent by mass, max.....	0.20	1.50	IS 1448 P8,
Cetane number, min.....	45	-	IS 1448 P9 IP41, ASTM D976/613
Pour point, °C, max.....	5	-	IP 15
Copper strip corrosion for 3 hours at 100 °C, max.....	2	2	IP 15 ASTM D130
Flash point (Pensky-Marterns), °C, min.....	60	-	ASTM D445
Sediments, percent by mass, max.....	0.03	0.01	ASTM D473/1744
Total sulphur, percent (m/m), max.....	-	0.05	IP 61
Water content, percent (v/v), max.....	-	0.05	IP 74
Total sediments*,mg per 100 mℓ.....	1.0	-	Appendix A
Distillation temperatures for 90 percent recovery °C, max..	-	362	IP123
Final boiling point, °C, max.....	-	385	1P123
Density at 20 °C, Min.....	0.820	-	ASTM D 1298
max.....	0.870	-	

* This test shall be carried out only at the refinery

\- means not specified to that grade of diesel

* Nil means not detectable

In 2010, the National Oil Company of Malawi (NOCMA), a state-owned company was established under the Companies Act of 1984. NOCMA is responsible for managing the country's Strategic Fuel Reserve Facilities (SFRs) and ensuring the availability of fuel in the country (NOCMA, 2020). The National Oil Company of Malawi supplies oil to all oil marketing companies in Malawi as well as other customers like Malawi Defense Force (MDF), Electricity supply Corporation of Malawi limited (ESCOM) among others. According (Laws of Malawi, Liquid Fuels and Gas Regulations, 2020), all oil marketing companies are required to buy 50% of their fuel volumes at NOCMA. The other percentage they may buy by themselves or at Petroleum Importers Limited. At the depots of NOCMA, there are fuel quality analysis that are conducted before fuels are sold to these companies, to check the fuel contamination, in case of transportation, or any other related factor. There have been some fuels which were contaminated, indicating that fuel contamination is a real matter, even here in Malawi. The figure below, shows contaminated fuels at NOCMA, Blantyre depot.



Figure 1: Photos of contaminated fuels at NOCMA, Blantyre depot.

3. CHAPTER 3: METHODOLOGY

3.1. Research design

The study area

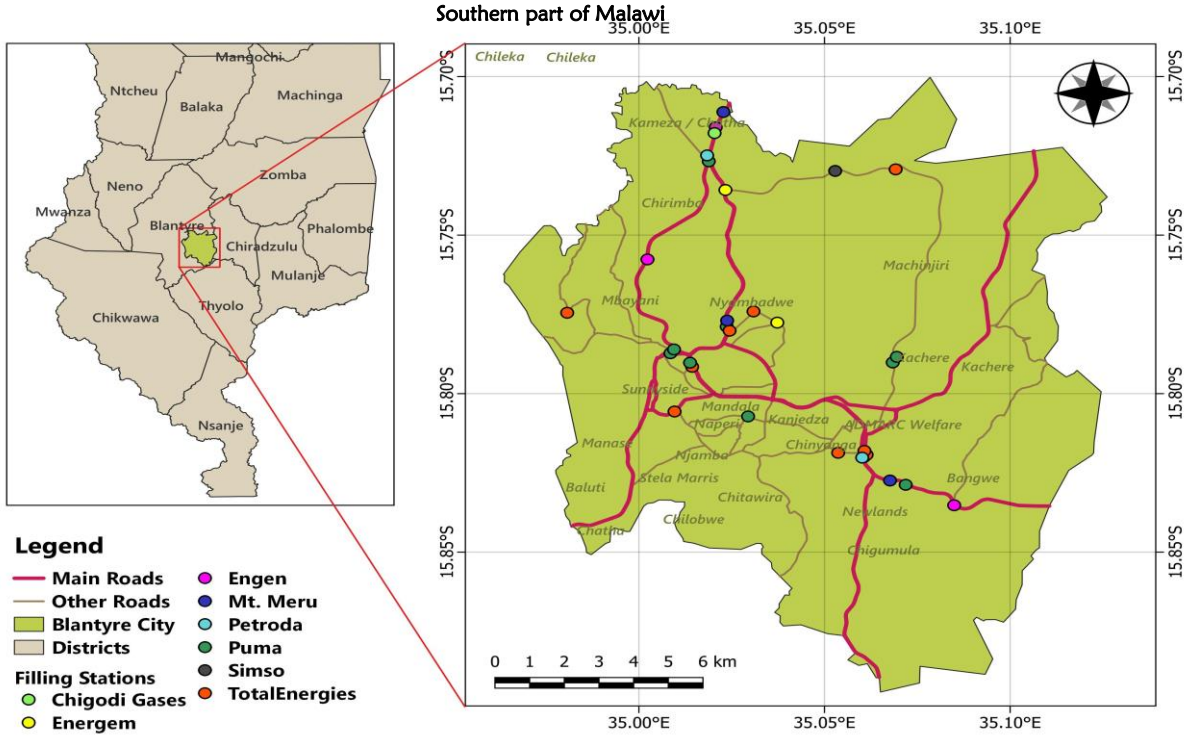


Figure 2: Showing map of study area

The area where the study has been conducted is in Blantyre city. This is so because Blantyre city is the commercial center in Malawi, with a large number of filling stations owned by different companies and such, this can provide at least a better result for the study. These samples will be obtained from the following filling stations, Total filling station, Energem filling station, Puma filling station, Mount Meru filling station, Petroda filling station, Engen and Simso filling station.

This chapter presents the methods, materials and technical approach that were used to attain the objectives of this study. The study employed a sampling research method technique in order assess the quality of petrol and diesel in filling stations in Blantyre city in Malawi. Two different fuel samples were taken for petrol and diesel, one for each, from each and every filling station.

3.2. Materials and methods

Materials

According to (Laws of Malawi, Liquid Fuels and Gas Regulations, 2008 as amended in 2015), when sampling fuel from petrol pumps, sampling cans of 5 liters and 1 liter capacity should be used, a stock of cans kept solely for the purpose of taking fuel samples, while the sampling procedures not be carried out in direct sunlight. If carried out in the direct sunlight, changes in fuel quality, especially octane level, could have occurred.

New cans were rinsed with petrol before being used, in order to remove any residue traces of oil left during manufacturing operations, and then the cans were allowed to dry. Before use, the cans also were checked to ensure that they are sound and free from leaks. And then, 1 liter for each fuel sample were obtained from seven (7) filling stations in Blantyre city, Malawi. Samples were labeled as shown below;



Figure 3: Shows labelled samples of diesel obtained from 7 different filling stations.

The samples were then sent to a laboratory by road, while complying to the general regulations covering transportation of flammable materials and with the requirements of the transport authority concerned. The tested parameters were then compared with the requirements of Malawi Bureau of Standards (MBS).

Table 3: Standard requirements for petrol and diesel

Parameters	MBS Requirements			
	Petrol		Diesel	
	Min.	Max.	Min.	Max.
Density	710kg/m^3	775kg/m^3	820kg/m^3	845kg/m^3
Sulphur content	0.0015% (15ppm)		0.0015% (15ppm)	
Octane rating	93 RON	95 RON	-	-
Cetane number	-	-	45	55
Flash point	-43˚C		52˚C	

Methods used

This research used density, sulphur content, octane rating, flash point and cetane number testing to determine the quality of petrol and diesel fuels. The laboratory analysis was conducted and the obtained results were compared with the MBS.

Density measurement: The density of fuel is the mass per unit volume of the fuel of liquid at 15 ˚C and 101.325 kPa with the standard unit of measurement being kg/m^3, and it varies depending on the type and quality of the fuel. The ASTM D1298 method covers the laboratory determination using a glass hydrometer of the density, relative density (specific gravity, SG) or American Petroleum Institute, API gravity of crude petroleum and liquid petroleum products. (Tamson Instruments, 2019). The density of both petrol and diesel samples were measured using a fuel analyzer.

Measurement of octane rating: The octane rating of petrol is a measure of its ability to resist knocking or pinging during combustion in an engine. Knocking occurs when the fuel-air mixture detonates prematurely and can damage the engine. Higher octane ratings mean higher resistance to knocking and more stability under higher compression. (ScienceDirect, 2022). The same fuel analyzer was employed to test for octane rating.

Measurement of cetane number: A cetane number also called cetane rating is a measure of how easily diesel fuel ignites when injected into hot air. The higher the number, the shorter the ignition delay and the better the fuel burns. It is similar to octane rating for gasoline. (Werner Dabelstein, 2007). There are different methods that are used to measure cetane number, such as using a Cooperative Fuel Research (CFR) engine, a constant-volume combustion chamber (CVCC) device, or an Ignition Quality Tester (IQT), but in this study, fuel analyzer was used.

Measurement of flash point: flash point is the lowest temperature of a liquid fuels at which its vapours will form a combustible mixture with air. There are three main categories of flammability of substances, categorized as extremely flammable with flash point below 0°C, highly flammable with a flash point below 21°C and flammable with flash point below 55°C. Flash point is therefore a convenient and reliable classification of these substances (Stanhope-Seta, 2019). The flash point was used to check for contamination of fuel samples. The flash points for both petrol and diesel were tested using a fuel analyzer. Figure below shows a multipurpose fuel analyzer that measures different parameters.



Figure 4: Shows Eraspec Fuel analyser (Measures both Density, Cetane and Octane number, Flash point)

Measurement of sulphur content: Sulphur is a natural component of crude oil that can cause air pollution and damage vehicle engines. Different countries have different standards for the maximum allowed sulphur content in petrol and diesel fuels. For example, India specifies **10 ppm** (parts per million) sulphur for both fuels, while Australia allows up to **150 ppm** for petrol and **10 ppm** for diesel (policy.net, 2018). The lowest sulphur content is known as **ultra-low-sulfur diesel (ULSD)**, which has less than 15 ppm (Omidvarborna & al., 2014). Sulphur content was measured using energy dispersive ray fluorescence, figure below shows the tool.



Figure 5:Energy Dispersive Ray Fluorescence

Contaminants detection techniques

Petroleum and other chemical industries often use flash point testing to check for fuel contamination. Changes in flash point may indicate that a sample may have been contaminated (Stanhope-Seta, 2019). As such, flash point was used to check if there was any contamination act done.

Water Finding Paste was also used to test the presence of water in the bottom of petrol and diesel tanks. Water was also detected by shaking a closed glass bottle containing diesel and allow it to settle for some minutes. After that, some water bubbles were suspended in the bottle, indicating the presence of water.

Ethanol content tester was used to detect the amount of ethanol present in the fuels. This device can measure the percentage of fuel sample, just like the graduated measuring cylinder.

Ethanol is a type of alcohol that can be blended with gasoline to produce a cleaner and more efficient fuel. However, ethanol can also cause problems for some engines, especially if the ethanol content is too high or too low. Therefore, it is important to know the ethanol content of your fuel before using it in your vehicle.



Figure 6: Ethanol Content Tester

Graduated measuring cylinder in mixture with water, alcohol and fuel samples, were used to detect the amount of alcohol in percentage, present in both petrol and diesel fuels.



Figure 7: Graduated measuring cylinder

Fuel contaminants detection methods

i. Alcohol

Ethanol can be tested in the fuel in a simple way using simple tools.

Equipments which can be employed include,

- Graduated measuring cylinder
- Water, alcohol and fuel samples
- Beaker

Procedures

a. Pouring 10 milliliters of petrol/diesel into at least 50 ml graduated cylinder and 2 milliliters of water. Cover the cylinder with a cap or your hand and shake it well for about a minute. Then let it stand for up to 15 minutes.
b. After 15 minutes, you will see that the water sinks to the bottom of the cylinder and forms a clear layer. The alcohol in the fuel will dissolve in the water, while the gasoline or diesel will float on top. Take a reading where the water and alcohol layer separates from the fuel layer.
c. If there is no alcohol in the fuel, the separation line will be at the 2 milliliters mark, which is the amount of water you added. If there is alcohol in the fuel, the separation line will be above the 2 milliliters mark, depending on how much alcohol is present.

To calculate the percentage of alcohol in the fuel, subtract 2 milliliters from the reading at the separation line and multiply it by 10. For example, if the separation line is at 4 milliliters, then the alcohol content is (4 - 2) x 10 = 20% (Equation 1: alcohol content calculations). Similar steps are followed when using ethanol content tester.

ii. Water

- Water can be easily detected by shaking a closed glass bottle containing diesel and allow it to settle for 5 minutes. Then after 5 minutes some water bubbles will be suspended in the bottle, indicating the presence of water.

- Another method to detect water quality of the fuel is to use water finding paste. Water finding paste is a water detection system used to aid in the detection of water within fuel supplies.
- **Procedure to follow:** The brown paste is applied to a weighted string or rod, and dipped to the bottom of the tank. The section of the paste that touches water will immediately turn a brilliant red upon contact, then, once the rod is removed, you can determine the depth of the water by the paste that has changed colour. There are different types of water finding paste available, such as Sar-Gel Blue Water Finding Paste and Gasoila Water Finding Paste.

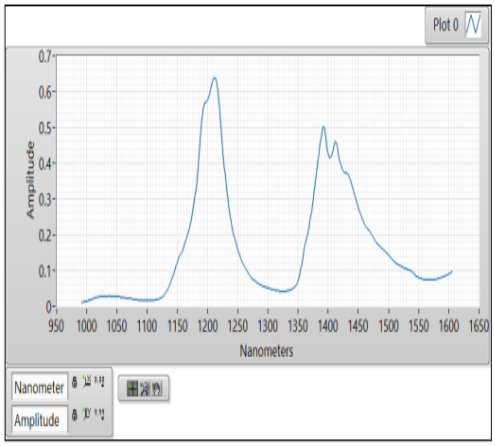
  Other methods which were used in detecting fuel contamination were as follows;

  i. **Eye detection**. This is achieved by comparing the color itself of the diesel and petrol fuels. This method is not an absolute one since other companies can use branding technique for their fuel without much affecting fuel quality, therefore a greater need for other methods like flash point testing.
  ii. **Time settling**. When the fuel samples allowed to settle, heavier particles are set at the bottom of the sampling glass cylinders, and fuel being lighter is at the top. Cylinder being clear to be seen what's in the inside, the formed layers are able to be seen.

By chemically analysing the samples, the common contaminants which might be used could be ethanol, alcohol, blackstrap and kerosene. The chemical composition of blackstrap molasses contained more of sulphur, and this type is called sulphured molasses made from sugarcane that has not yet matured. Ethanol is due to the blending outside the 80:20 ratio. Fuels outsourced by National Oil Company of Malawi and Petroleum Importers Limited found to be far better than those fuels which were not outsourced by them, for according to this study, their fuels were less contaminated. Due to the lack of foreign exchange, the government has given an opportunity to all the companies to outsource fuel on their own, without even following the 50:50 ration, that is, 50% of their fuels to buy at NOCMA.

4. CHAPTER 4: RESULTS AND DISCUSSION

The fuel analyser conducts tests for both petrol and diesel at a separate time. Both fuel analyser and Energy Dispersive Ray Fluorescence were used under the supervision of MBS petrochemicals lab Technician. The fuel analyzer automatically printed out the results within the period of less than 2 minutes, as shown below, while Energy Dispersive Ray Fluorescence, typical analysis time is 1 to 5 minutes per sample.



Sample ID: T394 DRR COMP 3
Method: Diesel
Q & T2 Value: 1.1
Integration Time : 175
Accumulations: 8
Device SN: 1047

Property	Measured
Density, g/mL	0.830
Cetane Index	55.941
Viscosity+40C, cSt	3.204
Aromatic, V%	23.886
Saturates, V%	66.463
IBP, C	187.096
D10%, C	226.519
D20%, C	243.447
D50%, C	280.203
D90%, C	326.774
FBP, C	351.689
Flash Point, C	74.137
Cloud Point, C	-6.156
Net Heat, MJ/Kg	43.233

Figure 8: Diesel printed results from fuel analyser.

The procedures were conducted again and again for the interested parameters for both petrol and diesel. And then, the laboratory analysis results were recorded in the tables as shown in the figures below;

Table 4: Presents the laboratory experiments result for petrol conducted on the density, sulphur content and octane rating from Oil Marketing Companies (OMC) in Blantyre City, Malawi.

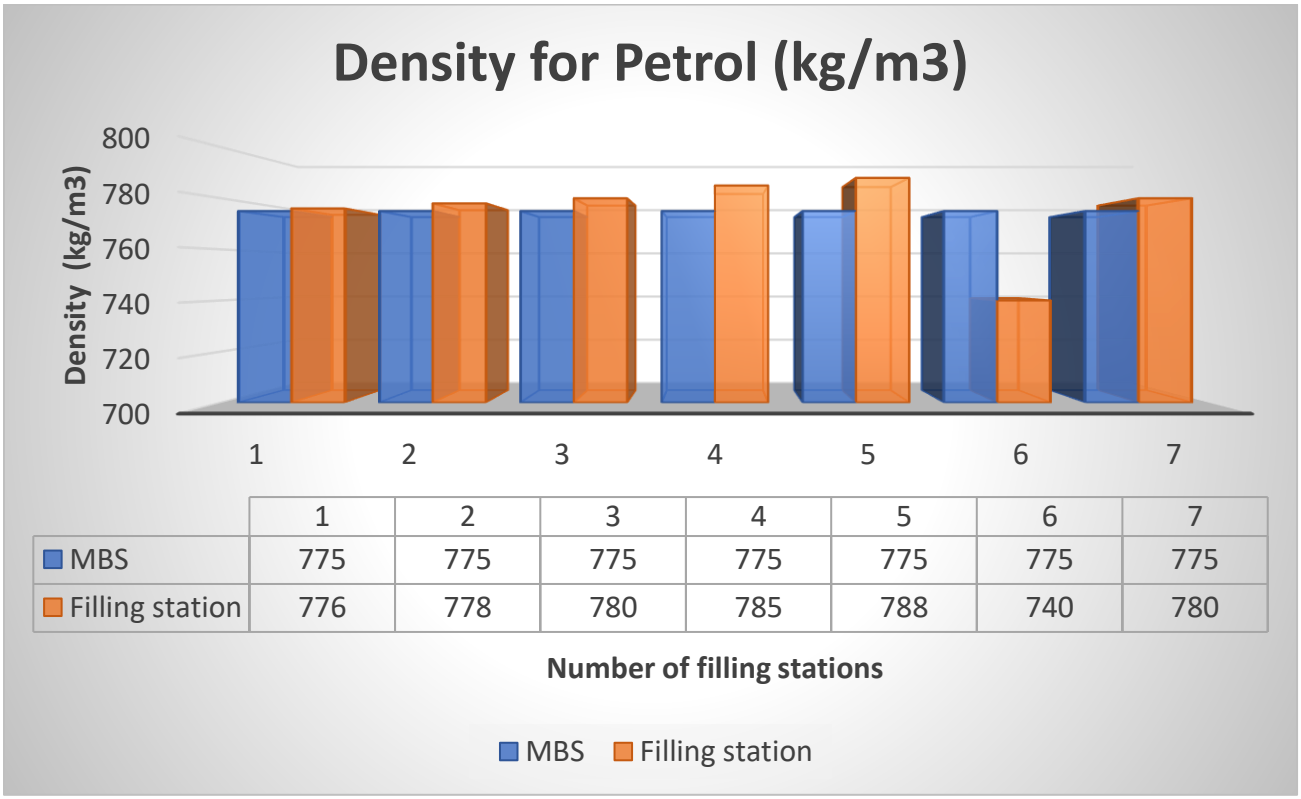
Sample codes	Density (kg/m³) at 15°C	Sulphur Content (% wt.)	Octane Rating (RON)	Flash Point (°C)
1	776	0.0026	90.3	-40
2	778	0.0024	91	-38.4

3	770	0.0021	93	-42.8
4	785	0.0020	90.6	-30
5	760	0.0023	92	-32.6
6	740	0.0025	91.5	-31.7
7	780	0.0022	94	-32.9

Table 5: Results for Density, Sulphur Content, Octane Rating and Flash Point tests for Diesel fuel from selected filling stations in Blantyre City.

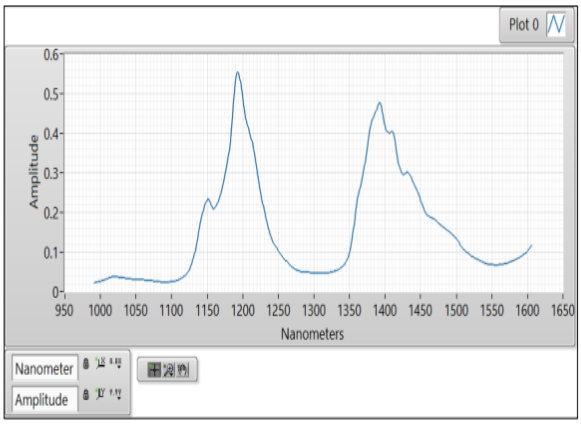
Sample codes	Density (kg/m^3) at 15°C	Sulphur Content (% wt.)	Cetane Rating	Flash Point (°C)
1	846.2	0.0023	58	64.3
2	858	0.0021	50	59.4
3	847.5	0.0026	56	60.8
4	855.8	0.0024	57	66
5	845.7	0.0027	57.8	70.6
6	850.6	0.0020	55.9	63.7
7	848	0.0022	53	69.9

Then the results were presented in the graphical format in order to show the range of variations from different oil marketing companies, and the range of Malawi Bureau of Standard.



	1	2	3	4	5	6	7
MBS	775	775	775	775	775	775	775
Filling station	776	778	780	785	788	740	780

Figure 9: Graph showing density for Petrol, laboratory test results vs. density standard for MBS.



Sample ID: T 339 DPX CP 3
Method: Gasoline_MTBE
Q & T2 Value: 10.1
Integration Time : 175
Accumulations: 8
Device SN: 1047

Property	Measured
RON	90.298
MON	83.038
RVP ASTM	8.697
Density, g/mL	0.740
API Gravity	56.990
MTBE, V%	3.663
Benzene, V%	0.693
Ethylbenzene, V%	0.250
Toluene, V%	7.369
Total Xylene, V%	10.402
IBP, C	35.115
D10%, C	49.033
D50%, C	107.396
D90%, C	167.761
FBP, C	204.748

Figure 10: Petrol printed results from fuel analyser.

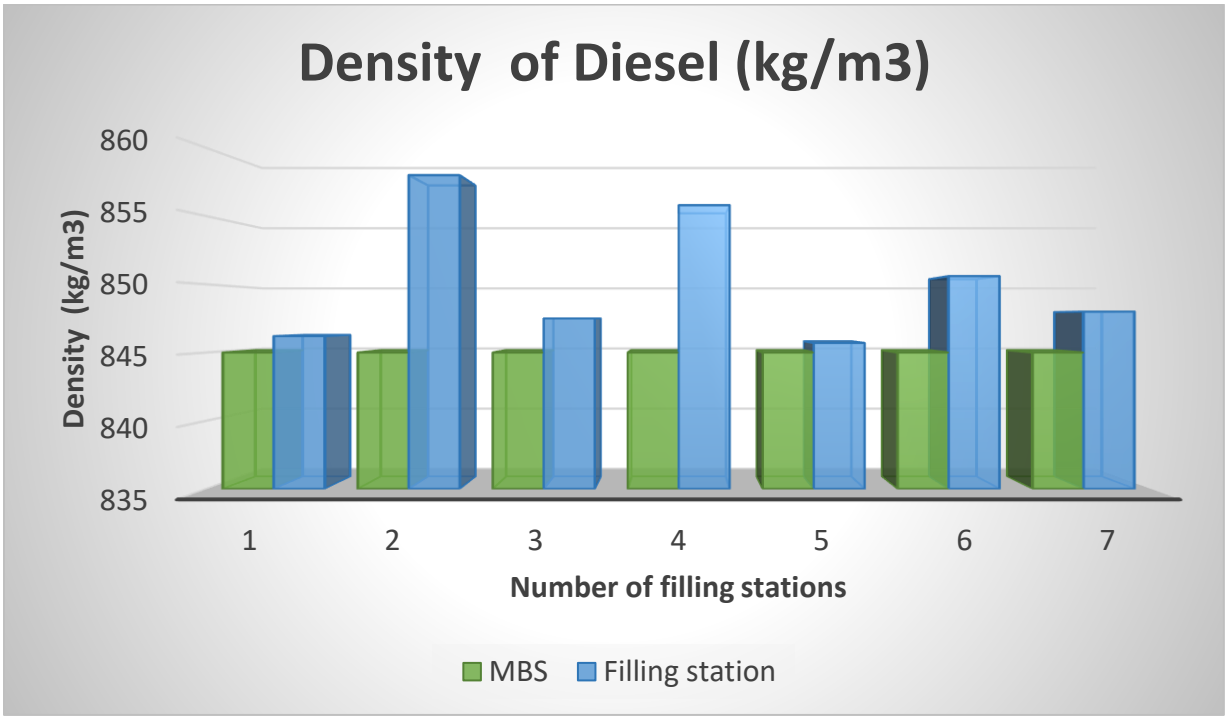


Figure 11: Graph showing density for Diesel, laboratory test results vs. density standard for MBS

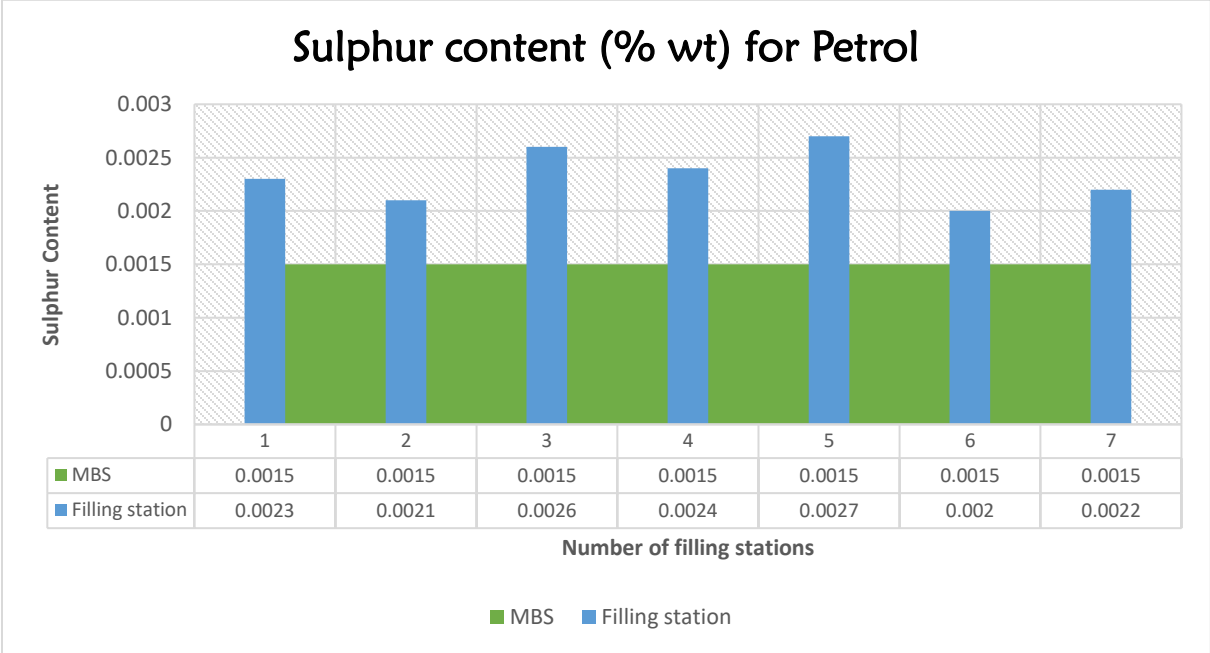


Figure 12: Graph showing Sulphur content for Petrol, laboratory test results vs. Sulphur content standard for MBS

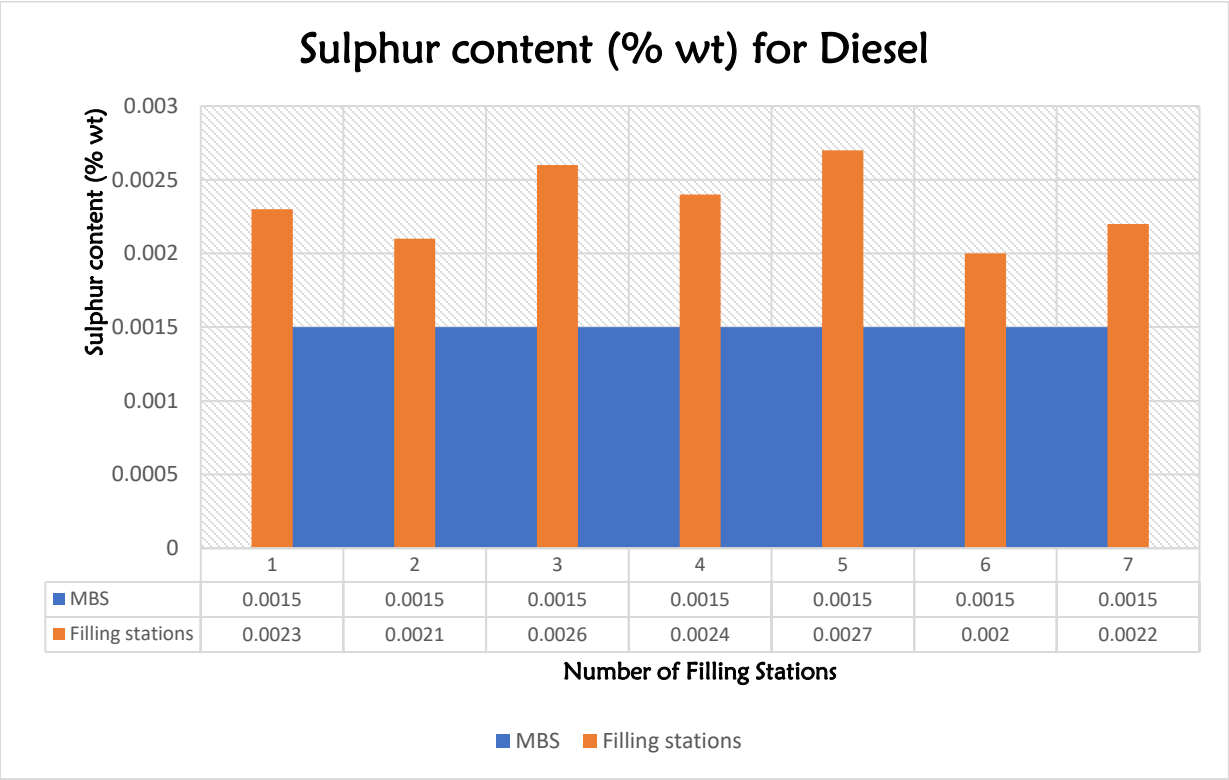


Figure 13: Graph showing Sulphur Content for Diesel, laboratory test results vs. Sulphur content standard for MBS

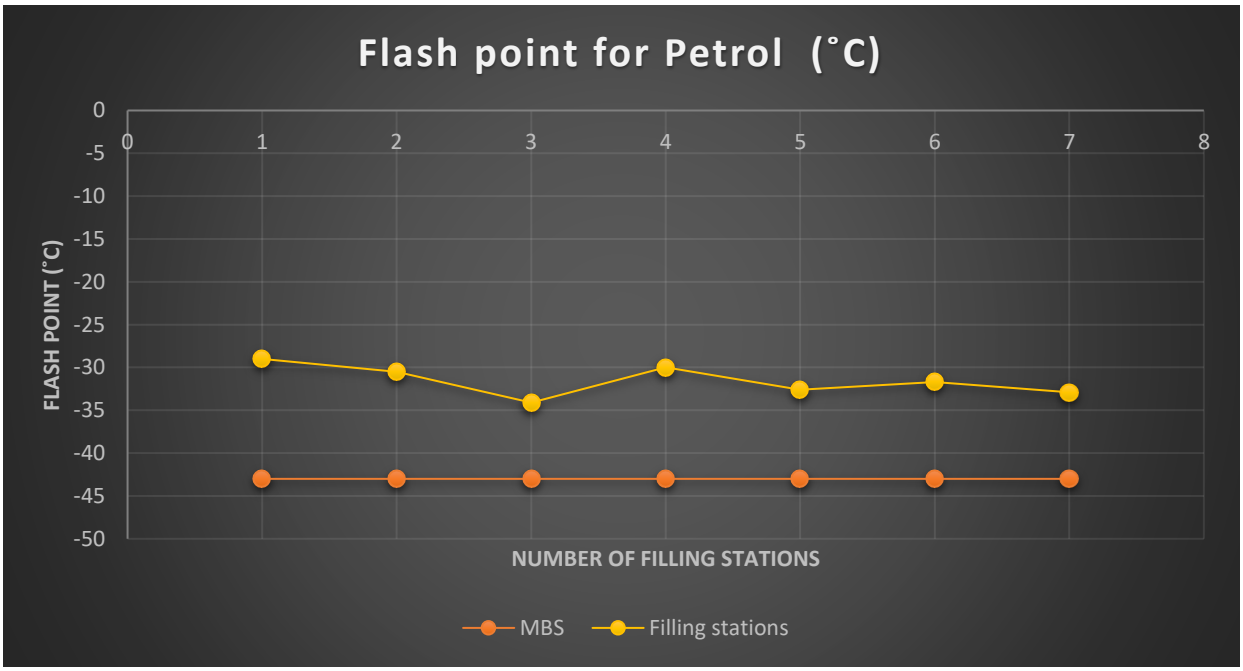


Figure 14: Graph showing Flash point of petrol for laboratory test results vs. Flash point standard for MBS

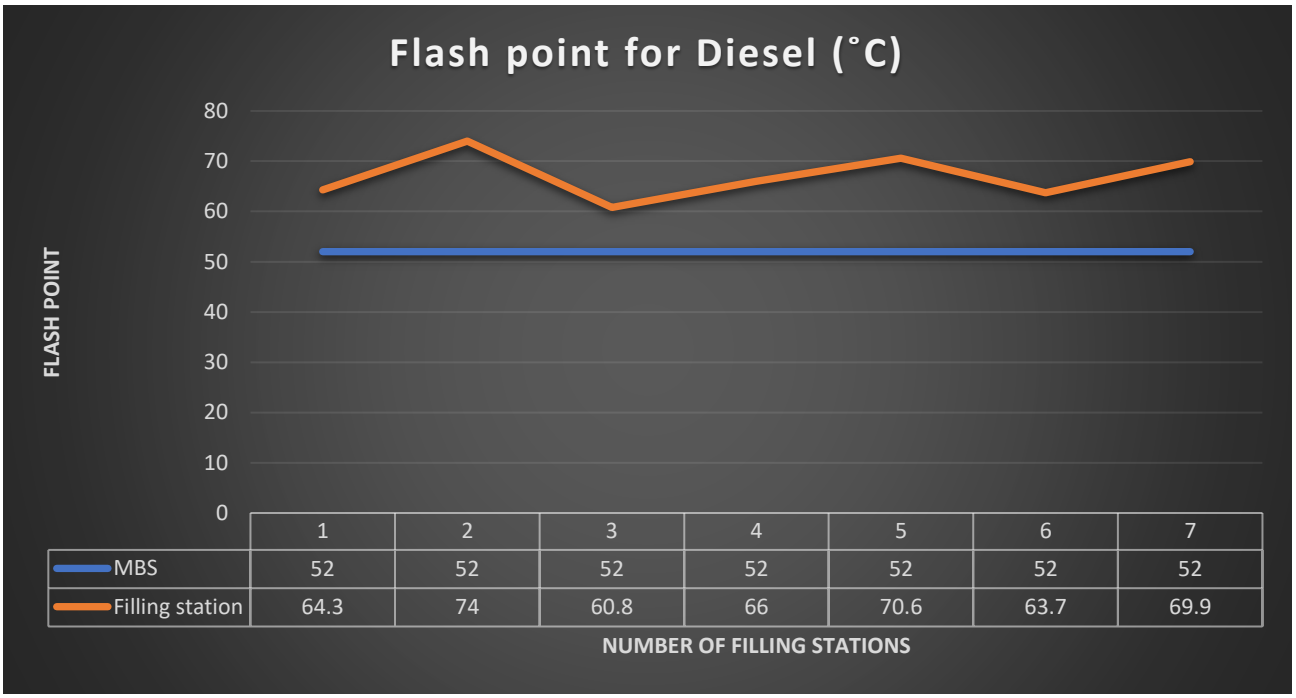


Figure 15: Graph showing Flash point for Diesel, laboratory test results vs. Flash point standard for MBS

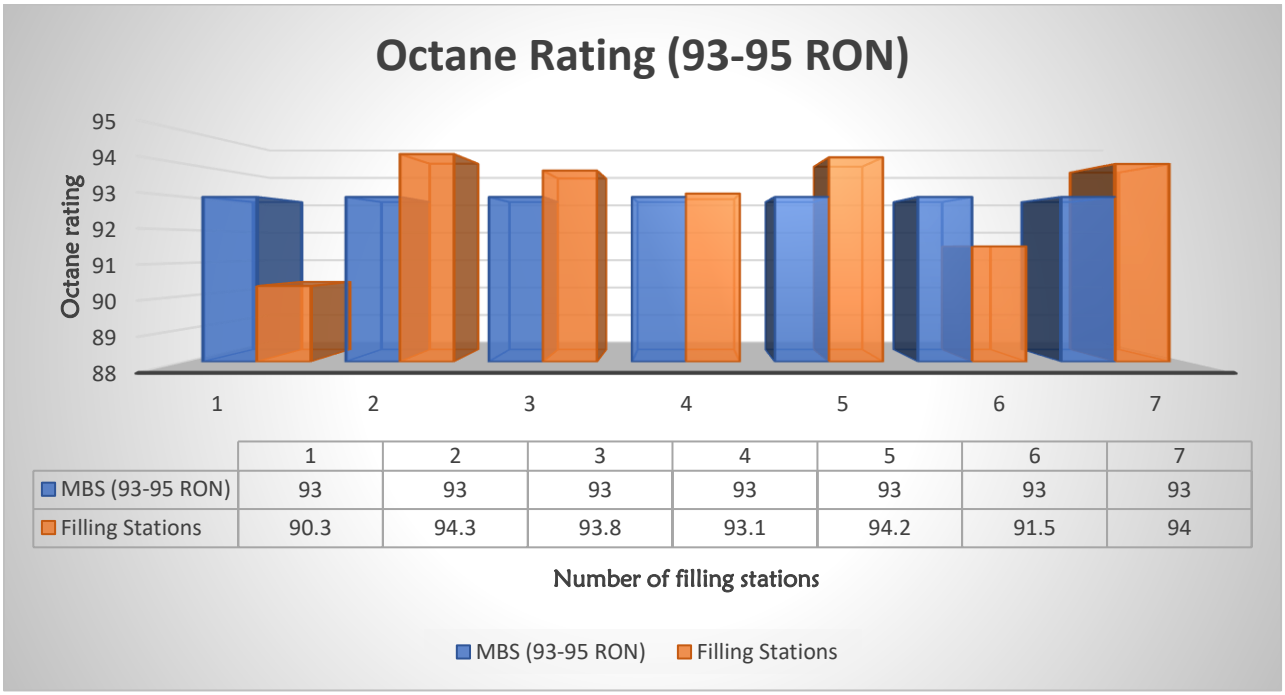
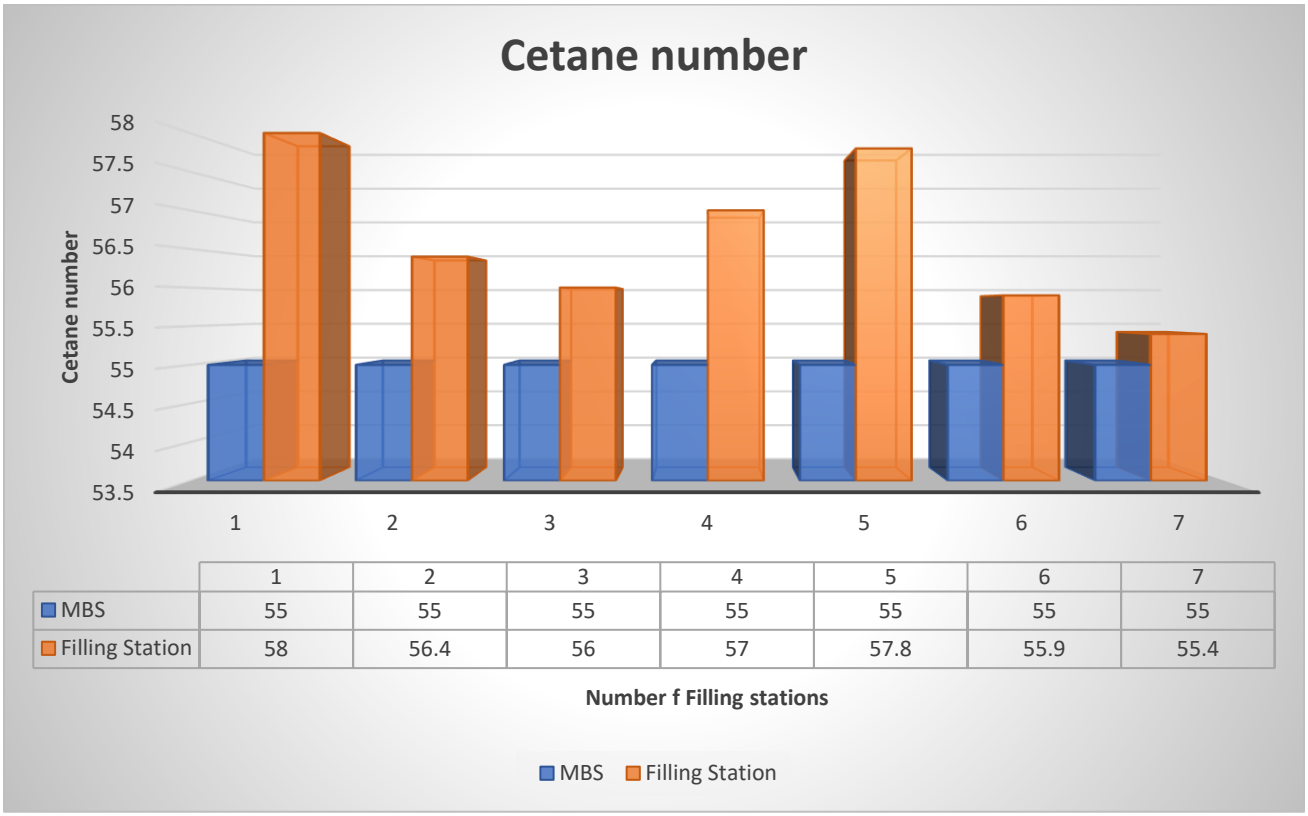


Figure 16: Graph showing Octane Rating, laboratory test results vs. Octane Rating standard for MBS.



	1	2	3	4	5	6	7
MBS	55	55	55	55	55	55	55
Filling Station	58	56.4	56	57	57.8	55.9	55.4

Figure 17: Graph showing Cetane Rating, laboratory test results vs. Cetane Rating standard for MBS

Ethical considerations

The results of the laboratory tests by any means will not be publicized but rather the average recommendation of the results of the laboratory tests will be made while comparing to the Malawi Bureau of Standards. And the findings of the contaminants will be represented in the form of average ratings as well. It will be therefore the duty of Malawi Energy Regulatory Authority (MERA) and Malawi bureau of Standards (MBS) to take any responsible action. The sample codes are representing the oil marketing companies, one filling station for each.

5. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The result of the study was an indicative that the quality of petrol and diesel fuels on the market is somehow open to doubt due to the variations on the parameters assessed. From the study, the following conclusions were made using the formula; $(\frac{number\ of\ filling\ stations\ outside\ the\ range}{total\ number\ of\ samples} \times 100\%)$. Equation 2: Contaminants percentage

1. The densities of almost petrol and diesel fuels among all the filling stations were within the MBS range, except about 29% which were outside the range.
2. The flash points of petrol fuel of about 71% out of all filling stations were outside the MBS range, indicating that some stations add contaminants.
    - Flash point for diesel, almost 57% out of all filling stations were outside the range
3. The octane number for all filling stations, nearly 68% were within the MBS range for petrol.
4. The cetane number of about 68% out of all the filling stations were within the MBS range.
5. The sulphur content of almost all the fuels were found to be outside MBS range.
    - This indicates that majority of the oil marketing companies are not complying with the regulator's directives. The summary of conclusion is represented in the graph below;

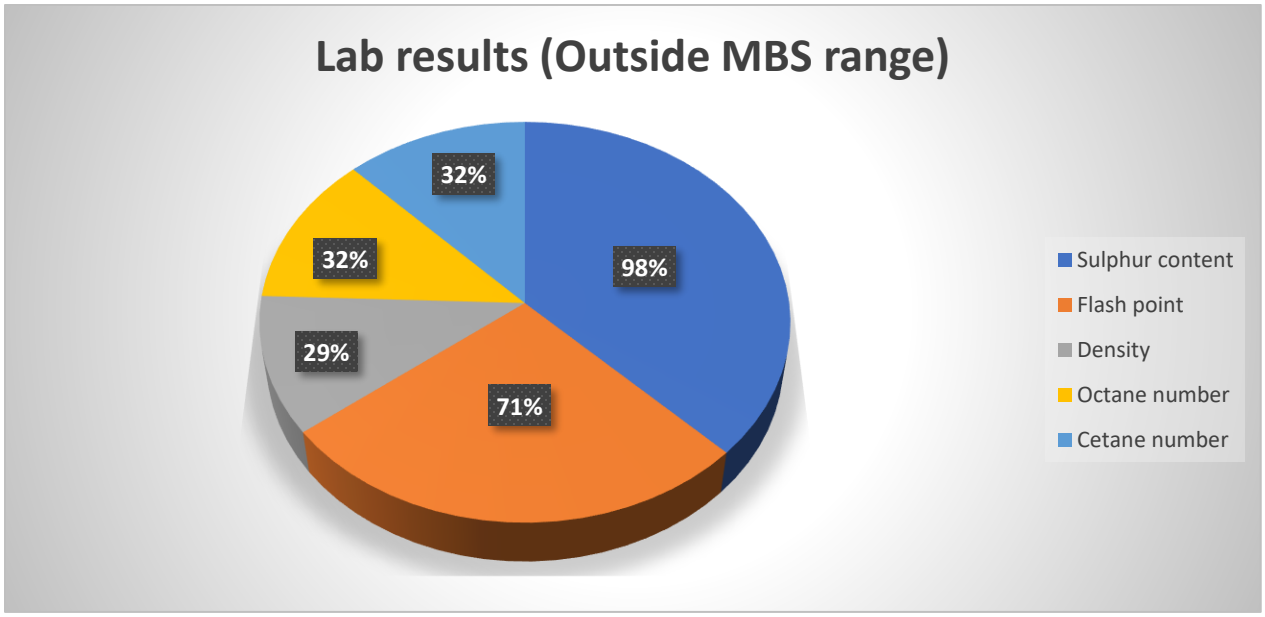


Figure 18: Graph shows the results of average filling stations in Blantyre running outside the MBS requirements ranging.

From the graph above, the percents are representing the contamination percentage from the sampled filling stations running outside the Malawi Bureau of Standards specifications. This simply mean that, out of all sampled filling stations, 32% were outside octane number and also 32% were running outside cetane number set by MBS specification, 98% were outside MBS sulphur content specification, 29% were outside MBS density specification and finally 71% were outside MBS flash point specification.

RECOMMENDATIONS

Those who use petrol and diesel for transportation and other purposes should be able to request from Oil Marketing Companies information in regard to their fuel quality, and should also request for the specific information in regard to issues which require mechanical intervention on their vehicles.

The Government of Malawi should ensure that oil marketing companies are operating within the acceptable sulphur content limit and range assigned by Malawi Bureau of Standards (MBS), even though there is a challenge with Forex. Those companies who are outsourcing fuels, should make sure that fuels are complying to the requirements set by Malawi Breau.

If all the specific requirements for both diesel and petrol properties are being complied to, it will be so difficult for those companies to add some contaminants by any means. As such, the government should ensure that there's consistent implementations for quality fuel analysis within the oil marketing companies.

The project for establishing petrochemical laboratories at NOCMA which has already started should be hastened so that the task of analyzing fuel quality should be tasked for both Malawi Bureau of Standards (MBS) and National Oil Company of Malawi (NOCMA). This will help in the consistency of the implementations.

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