UNIVERSITY OF NAIROBI

ASSESSMENT OF THE QUALITY OF GASOLINE AND CROSS-CONTAMINATION ACROSS THE KENYAN MARKET

BY

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DECLARATION

I declare that this thesis is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people´s work or my own previous work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi´s requirements.

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DEDICATION

This project is dedicated to my wife and to my parents, brothers and sister for their continued unwavering support and presence throughout my Academic journey, and for being my pillar through life's journey.

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ABSTRACT

Small and medium-sized motor cars are the majority of the vehicles found in urban areas around the world are often the main sources of air pollution, good-grade gasoline is fit-for-purpose fuel that complies with the technical parameters and requirements set forth in the design for the vehicle or equipment it is being used in. The Kenya Standard KS EAS 158: 2019 for Automotive Gasoline Specification specifies the legal and accepted requirements for gasoline qualities in Kenya. The engine performance, efficiency, and output suffer when the aforementioned qualities stray from the established specifications. This leads to the raise in the cost of service and maintenance. It also contributes to increased air pollution.

The study aimed to comprehensively outline the petroleum supply chain in Kenya, covering the entire process from importation to consumer distribution. To assess the properties and regulatory compliance of Kenyan gasoline, the study focused on key parameters, including density, atmospheric distillation, research octane number, and unwashed gum. Samples were collected from various points in the supply chain, including the top, middle, and bottom of tanks and pump nozzles. To prevent the loss of light hydrocarbons, the samples were securely corked. The tests were conducted using American Standards for Test and Materials protocols for evaluating density, distillation, research octane number, and unwashed gum.

The Kenyan petroleum supply chain, starting from importation, includes several depots such as Mombasa, inland deports: Konza, Nairobi, Nakuru, Nanyuki, Eldoret, and Kisumu, as well as intermediary stations. Throughout the supply chain, gasoline density ranged from 0.7498 to 0.7521 g/cm3, within recommended limits. Final boiling points at the Kenya Pipeline Company Kisumu depot remained within authorized ranges despite an increasing trend from 189.8 °C to 210.5 °C due to changes in atmospheric pressure. It is worth noting that the RON were within the KPC's approved range of 93.2 to 94.9. Unwashed gum levels at pre-discharge were permissible of 5 mg/100 mL but exceeded limits of 7 to 41 mg/100 mL during delivery, especially from KPC Mombasa. Increasing distances correlated with higher deviations, indicating greater pollution as gasoline interacts with delivery vehicle and pipeline walls. Notable deviations occurred from Mombasa to Kisumu, including a high final boiling point deviation of 21.7 in 2021 and 17.8 in 2022, a 32-unit unwashed gum deviation in 2021 and 12 in 2022, and a -1.0, research octane number deviation in 2021 and -1.5 in 2022. This implies an increase in gasoline pollution with prolonged exposure to delivery systems.

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LIST OF ABBREVIATIONS AND ACRONYMS

API	American Petroleum Institute
ASTM	American Society for Testing Materials
DHA	Detailed Hydrocarbon Analyzer
FBP	Final Boiling Point
FID	Flame Ionization Detector
GC	Gas Chromatography
HPLC	High-Performance Liquid Chromatography
IBP	Initial Boiling Point
ISO	International Standards Organization
KEBS	Kenya Bureau of Standards
KPC	Kenya Pipeline Company
KS EAS	Kenya Standard - East African Standard Specification
Max.	Maximum
Min.	Minimum
MON	Motor Octane Number
MW	Molecular Weight
RON	Research Octane Number
UV	Utraviolet
UWG	Unwashed Gum
WHO	World Health Organization
CSV	Comma delimited text
SDGs	Sustainable Development Goals

PAHs	Polycyclic Aromatic Hydrocarbons
GC-FID	Gas Chromatography coupled with Flame Ionization Detector
NO	Nitric oxide
NO_2	Nitrogen dioxide
CO	Carbon monoxide
CO_2	Carbon (IV) oxide
KPC	Kenya Pipeline Company
SO_2	Sulphur (IV) oxide
N_2O	Nitrous oxide

CHAPTER 1: INTRODUCTION

1.1 Background information

Transportation is regarded as one of the key drivers in economic growth. Rapid efficient and cost-effective conveyance of persons and goods is a chief component of a vibrant economy (Rabajczyk & Swiercz, 2018). Major cities and towns in Kenya are not an exception to the fact that population growth, industrial activity, and an increase in the number of automobiles in large urban metropolises are the primary drivers of pollution globally. Top soils, roadside and street dusts, and other environmental pollutants are among the main markers of urban systems (Adipah, 2018; Saeedi *et al*., 2012). The environment and human health are both negatively impacted by some of these contaminants, including heavy metals and gasoline hydrocarbons (Chopra *et al*., 2009). To achieve desired vehicle emissions and reduce maintenance costs, it is crucial to dispense automobile fuels of the proper quality (Simons & Gbadam, 2010).

In the developing world, energy needs are rising quickly, which is driving up the usage of fossil fuels. Global energy sources, gross consumption across various sectors, and predicted future needs have all been taken into account by the International Energy Agency (Wright, 1986). Transport is one of the most energy-intensive industries in the world, and fossil fuels are primarily used to meet its needs (Hopkins & Brand, 2021). Sub Saharan countries like Kenya, have policies that help improve vehicle fuel economy by reducing air pollutants like greenhouse emissions, from results of petroleum-based combustion in vehicle engines (Schipper, 2011). The quality of petrol in the course of its delivery to consumers is an important factor to consider as these characteristics are altered to effect a significant change in the overall result when combusted.

The Kenyan government has developed and implemented standards targeting fuel consumptions in order to limit pollutants which are as a result of various petrol characteristics. Governments all across the world are using similar strategies (Ribeiro *et al*., 2008). The Kenya Bureau of Standards (KEBS) provides standards for gasoline quality in the country. This is deliberated by the government to tackle possible environmental and health effects that can result from using “unclean” gasoline exhaust emissions. For instance, KEBS standard - KS EAS 158: 2019, is an automotive gasoline specification document stipulating requirements of an ideal automotive gasoline such as marketable odor, clear and bright appearance, and free from suspended particles on visual inspection (Uganda National Bureau of

Standards, 2019). It continues by outlining certain parameters (Table 1.1), which will be relevant to this research.

Table 1.1: Parameters of interest, requirement range and test methods (Uganda National Bureau of Standards, 2019)

Serial Number	Parameter	Requirement		Test Method
		Min.	Max.	
1	Research Octane Number (RON)	93	-	ISO 5164 American Society for Testing Materials (ASTM) D2699
2	Unwashed gum	-	5	ISO 6246 ASTM D381
3	Density (at 20 ºC), g/cm^3	716	771	ISO 3675 ASTM D4052
4	Distillation			ASTM D86 IP 123
	Initial Boiling Point (IBP)	-	-	
	Evaporated at 10 ºC (%v/v), E 10%	-	71	
	Evaporated at 50 ºC (%v/v), E 50%	77	115	
	Evaporated at 90 ºC (%v/v), E 90%	-	180	
	FBP	-	210	

A healthy, clean environment is one of the fundamental rights guaranteed by the Kenyan constitution to its people. Regulations that regulate safe emissions from vehicles have been drafted. The present air quality guidelines limit dangerous vehicle emissions and other environmental issues (Odote, 2020). The complete execution of these regulatory frameworks, however, faces difficulties. For example, neither the general public nor policy makers are fully aware of the issues brought on by vehicle emissions (Bell & Lederman, 2003). Furthermore, present governmental institutions lack the necessary resources to improve environmental standards in the transportation business. As a result, there is disparity about air quality and how it has been affected by emissions from automobiles (Romero *et al*., 2020).

These shortcomings hinder the nation's efforts to achieve clean and healthy environment that is guaranteed by its constitution. The use of cars, trucks, and buses for transportation on roads around the world contributes significantly to air pollution. Consequently, diseases linked to air pollution have caused deaths in developing nations like Kenya (Mayosi *et al*., 2009). Furthermore, according to estimates from the World Health Organization (WHO), ambient (outside) air pollution causes 4.2 million premature deaths annually worldwide, both in urban and rural regions ((WHO, 2016). As much as 91% of outdoor air pollution occurs in these nations, including Kenya, people in low- and middle-income countries bear a disproportionately heavy weight from it. The most recent burden estimates show how seriously air pollution affects cardiovascular disease and mortality. Evidence showing associations between ambient air pollution and the risk of cardiovascular disease is becoming more and more available (WHO, 2016; Kumar *et al*., 2015).

In the future years, this declining air quality in emerging nations is expected to have a significant negative impact on economies and health, with people who live, work, walk, or play in metropolitan centers being the most vulnerable (Zou *et al*., 2016). Despite Nairobi having a smaller population than other global megacities known for their high emissions, black carbon concentrations have been reported (DeSouza, 2020). This study will therefore be significant in identifying potential sources of air pollutants and examining the components of gasoline as it is spread around the country because the data currently available on vehicle emissions is insufficient and fragmented.

1.2 Statement of the Problem

The biggest environmental and health risk is air pollution, which is mostly brought on by motor vehicles and the activities that support them. About 95% of the hydrocarbons in gasoline are aliphatic and alicyclic compounds, with less than 2% being aromatic compounds. Vehicles, primarily automobiles, are responsible for around two thirds of the air pollution in urban areas (Gupta & Sharm, 2010; Tabinda *et al*., 2019). Pollutants including carbon monoxide, a significant greenhouse gas and irritant, are partly the outcome of diesel contaminating gasoline due to incomplete fuel combustion. Polycyclic aromatic hydrocarbons (PAHs) are mostly discharged into urban environments as a result of the burning of fossil fuels and vehicle emissions. Cancer and genetic alterations are two undesirable health outcomes of PAHs (Essumang *et al*., 2006; Jiries, 2003).

Petroleum products are transported through a pipeline in Kenya, which is run by the Kenya Pipeline Company (KPC), from the port of Mombasa to depots inland and upcountry. Unfortunately, even though they are not transported simultaneously through the same conduit, gasoline and diesel can come into contact with one another and get contaminated. Furthermore, before being dispersed, petroleum is carried from the Kipevu port to inland depots while being held in storage tanks. The walls of these storage tanks may erode as a result, which could lead to the production of compounds that could alter the integrity of the fuel. Contaminated gasoline can seriously harm the engine and fuel injection system when it is ignited in an automobile. This causes gasoline to burn inefficiently, resulting in the emission of greenhouse gasses such as carbon monoxide. Regarding the quality of Kenyan gasoline across the supply chain, no reported scientific study has been published as of yet.

1.3 Objectives of the Study

1.3.1 General Objective

To analyze quality parameters and characteristics of petrol across the Kenyan market and assess the levels of contaminations along the supply chain.

1.3.2 Specific Objectives

Specifically, this study was designed:

1. To map out the Vivo Energy petroleum supply chain in Kenya showing the locations from the point of import all the way to the consumer.
2. To carry out tests for density, atmospheric distillation, research octane number (RON), and unwashed gum on the points sampled.
3. To identify and report the levels of selected quality parameters in each step,the deviation points and the possible sources of the identified deviations.

1.4 Justification and Significance of the Study

It follows that if the aforementioned parameters are not checked, air pollution levels, particularly in urban centers, could exceed the maximum allowable levels. In Kenya, strict enforcement and follow-ups on exhaust emissions, catalytic converter efficiency, and monitoring of the levels of the individual emitted gases is not done regularly. Therefore, the objective of this study is to determine and provide the levels of the chosen quality metrics along the entire Kenyan gasoline supply chain, from the ship's discharge in Mombasa through the Kenya Pipeline Company's network of distribution up to the user at the service station.

This study will be able to pinpoint the sources of the cross - contaminants and their concentrations by sampling and testing the gasoline at each stage. Additionally, it will be able to identify any areas that significantly deviate from the norm and are more likely to experience high levels of air pollution. Further, it will be able to provide information that will be used in the future to regulate the quality of fuel products and enhance the nation's transportation system. Finally, findings from this study will significantly impact some important Sustainable Development Goals (SDGs) of the United Nations, including sustainable cities and communities, responsible consumption and production, and climate action (SDGs 11, 12 and 13, respectively). In order to evaluate the degree of compliance with regulatory standards, this study therefore examined various aspects of gasoline, primarily density, atmospheric distillation, research octane number, and unwashed gum across the Kenyan supply chain.

CHAPTER 2: LITERATURE REVIEW

2.1 Petroleum

Petroleum is a fossilized substance that is found in geological formations under the surface of the earth. Crude oil is its unprocessed state and is mostly made up of hydrocarbons with different molecular weights (MW) and other organic components (Chaudhuri, 2016). Carbon (85-90%), hydrogen (10-14%), sulfur (0.2-3%), nitrogen (0.1-2%), oxygen (1-1.5%), and metals: nickel (2.8 - 3.68 ppm), vanadium (0.56 - 0.97 ppm), silver (0.03 - 0.04 ppm), lead (0.18 - 1.16 ppm), and other trace metals make up its usual elemental composition. According to American Petroleum Institute (API), gravity together with sulfur content determines price on the global market. Crude oils are also referred to as light, medium, or heavy (Speight, 2006). The average gravity of light, medium, and heavy crude oils is greater than 40, between 15 and 40, and less than 15 respectively (Mohammadi *et al*., 2020).

Paraffins (alkanes), naphthenes (cycloalkanes), and aromatic hydrocarbons are the main hydrocarbon families found in crude oil, whereas olefins (alkenes) are produced during the refining process (Kuppusamy *et al*., 2020). The petroleum refinery uses a number of procedures to create various kinds of hydrocarbon fuels and other valuable components. The process yields a range of final goods, including fuel gas, liquefied petroleum gas, kerosene, aviation fuel, gasoline, diesel, lubricants, waxes, and so forth (Speight, 2006). The separate petrochemical complex found in modern petroleum refineries allows for the formation of crucial precursors like ethylene and propylene throughout various cracking and reforming operations. Aromatics and these precursors are the raw materials for many different businesses, including those that produce solvents, polymers, adhesives, paints, detergents, rubber, and dyes (Chaudhuri, 2016).

Before being sold on the market for their intended end use, hydrocarbon fuels from all refining streams must be compliant with the current worldwide regulations (Szklo & Schaeffer, 2007). Diesel and motor spirit are two common automotive fuels that are utilized for transportation all over the world. Gasoline is suited for spark ignition type engines because it is a mixture of low boiling hydrocarbons, which causes an electrical spark to ignite the mixture of fuel and air vapors (Chaudhuri, 2016; Heywood, 1988).

2.2 Fuel Adulteration and Contamination

Adulteration is the unauthorized addition of any foreign substance to a product that results in a deviation from the product's established specifications. It is common in the gasoline and diesel market for automobiles in poorer nations, which lowers the quality of the fuel (Simons & Gbadam, 2010). It hinders the engine's ability to operate at its best and could harm its components. Additionally, adulteration increases vehicle particulate emissions, which are harmful to the environment and other living things. Further, it has a detrimental effect on governments' tax policies and economic growth (Kalligeros *et al*., 2003). Almost every country in the world, including Kenya, is seriously concerned about the adulteration and contamination of petroleum-based automobile fuels. For the emerging economies, the fuel quality is a crucial metric for environmental assessment and a gauge of public health (Fonseca *et al*., 2007; Gedik & Uzun, 2015).

The selection of fuel adulterants is based on a number of factors while bearing in mind the requirements for the finished product. The significant price differential between adulterant and gasoline is considered in terms of financial gains. A profitable scenario is where less expensive supplies with qualities similar to finished fuel are available (Ehsan *et al*., 2011; Kumar & Pillai, 2020). Most of the time, chemicals and solvents produced during the refining of petroleum meet the criteria and are employed as fuel adulterants in diesel or gasoline (Simons & Gbadam, 2010). Naphtha, kerosene, diesel, as well as other cheaper solvents intended solely for industrial end uses are frequently added to gasoline to make it less pure. Conversely, home kerosene fuel that is readily available and inexpensive is frequently used as an adulterant in diesel fuel (Cunha *et al*., 2016; Yadav *et al*., 2005).

2.3 Environmental Concerns

Vehicle exhaust emissions are a significant source of dangerous pollutants, including poisonous gases and particles that are mostly linked to established health risks from inhalation exposures in living things. Water vapor, carbon oxides (CO, CO_2), sulfur oxides (SO_2) and nitrogen oxides (NO, N_2O, NO_2) are common components of such gases (Chow, 2001). Because of the incomplete combustion of the gasoline inside the engines, hydrocarbons are a significant component of vehicle exhausts (Chang & Chen, 2008). Mechanically, the lubricant coating over the cylinder wall divides the hydrocarbons that enter the engine during fuel intake. This portion of the unburned fuel components escapes the engine during the expansion and emission strokes of the burning process (Henein & Tagomori, 1999).

Environmental scientists have been interested in environmental assessment, and extensive study has been done in this field. The implementation of emission limits for the transportation industry is a response to the environmental concerns caused by worsening air pollution and greenhouse gas emissions (Colvile *et al*., 2002). Kenya and other Sub-Saharan nations have rules that reduce air pollutants like greenhouse gases caused by the combustion of petroleum-based fuel in automobile engines, hence increasing vehicle fuel efficiency (Schipper, 2011). The quality of gasoline during delivery is a crucial factor to take into account because these qualities can vary to significantly impact the outcome of combustion (Bergthorson & Thomson, 2015). In order to reduce pollution caused by various petrol characteristics, the Kenyan government has created and enforced standards aimed at reducing fuel usage. Globally, governments are employing these policies as well (Change, 2007). The government authority that sets standards for the caliber of gasoline sold in Kenya is called the Kenya Bureau of Standards (KEBS). The government is considering this to address potential environmental and health impacts that may arise from using "unclean" gasoline exhaust emissions. For instance, the KEBS standard (KS EAS 158: 2019) gives specifications for an ideal automotive gasoline. It states that "Automotive gasoline must have a marketable odor, a clear and brilliant appearance, and be free of dispersed particles during visual inspection" (Mwangoma, 2019).

In this situation, evaluating the quality deviation in finished fuels is the main objective of standard method testing. The availability of diverse analytical techniques is quite helpful in identifying fuel adulteration in the current situation (Vempatapu & Kanaujia, 2017). The following discussion will provide a general overview of the two basic domains in which the characterization is conducted: physico-chemical and chromatographic/spectroscopic approaches.

2.4 Physicochemical methods

Most commonly used materials, including petroleum products, have their physicochemical properties examined using standard American Society of Testing and Materials (ASTM) techniques (Babazadeh Shayan *et al*., 2012). There are numerous published and established ASTM tests for diesel and gasoline. Some of these tests determine the fuel's physical and chemical qualities, while others assess the fuel's acceptability for use in automobiles in terms of engine performance and the amount of air pollution it produces (Babazadeh Shayan *et al*., 2012; Gupta & Sharm, 2010). The most common tests used to identify fuel adulteration are density, distillation, research octane number (RON), motor octane number (MON), and Reid vapor pressure. However, no test is specifically developed to evaluate the adulteration of gasoline by adding diesel or diesel by mixing kerosene (Gupta & Sharm, 2010).

In this instance, fuel density is calculated per volume and tested at 15 °C. Regardless of the methods used to produce gasoline or diesel fuel, density monitoring assures that the hydrocarbon distribution is uniform (Speight, 2015). The ambient distillation of these fuels in a batch distillation system at laboratory scale gives quantitative measurement of boiling range properties. The content and characteristics of the components contained in pure and contaminated samples are revealed by a comparison of the boiling range (Speight, 2015). The primary qualities of gasoline are determined by their octane values (RON, MON), which give a delicate indicator of the fuel's anti-knocking activity. The greater the octane rating, the better the gasoline resists explosion and the smoother the engine performs (Pasadakis *et al*., 2006). If there is any adulteration, the octane number will be lower than what the engine requires due to the chemical makeup of the gasoline. Similar to how variations in the Reid vapor pressure show the presence of comparatively volatile or non-volatile adulterants (Sandu *et al*., 2016; Speight, 2015).

2.4.1 Determination of boiling point range properties using distillation American Society for Testing Materials (ASTM D 86)

The volatility of gasoline, which can be assessed by a distillation experiment, is one of its most significant characteristics. In this procedure, the boiling range properties of fuel products including gasoline and diesel, are quantitatively determined using a laboratory batch distillation apparatus (Balabin *et al*., 2007). The composition, vapor pressure, anticipated initial boiling point, anticipated final end point, as well as combustion of the sample are all taken into consideration during distillation. Equipment that is both automatic and manual can be utilized (Ferris & Rothamer, 2016).

Hydrocarbons' performance and safety are significantly impacted by their distillation properties. Specific aspects of gasoline and diesel performance have been associated with the different ranges of a distillation profile. In order to achieve straightforward cold and hot starting, independence from vapour lock, and little to no evaporation and running-loss emissions, front-end volatility is modified. Additionally, tail-end volatility is modified to ensure better fuel efficiency after engine warm-up, independence from engine deposits, little fuel dilution of crankcase oil, and little volatile organic compound emissions (Drabo, 2011).

2.4.2 Standard test for Density at 20 °C (ASTM D 4052)

Using this test method, the density or relative density of viscous oils and petroleum products that can be treated regularly as liquids at temperatures between 15 and 35 °C is determined. It is only appropriate for use with liquids that have vapor pressures under 600 mm Hg (80 kPa) (Riazi, 2005). In this procedure, a small amount of sample is added to a circulating sample tube, and the calibration data, along with the change in oscillating speed brought on by the change in tube mass, are used to calculate the sample density (Babazadeh Shayan *et al*., 2012). It uses a digital analyzer with a U-shaped revolving sample vial and an electronic excitation, frequency counting, and display system. The analyzer must either allow for an accurate sample temperature measurement during the measure phase or regulate the temperature of the sample (Pandey & Kumar, 2020). Products including waxes, and lubricating oils, gasoline and gasoline-oxygenate blends, diesel, jet, and basestocks, are just a few examples of what can be tested using this method. Grams per milliliter (g/mL) or kilograms per cubic meter (g/cm^3) are the standard units of measurement for density (Pandey & Kumar, 2020; Pradhan *et al*., 2016). Because density is a basic physical characteristic that may be used alone or in combination with other characteristics to describe both the light and heavy components of petroleum and petroleum products, this method has a major use. In order to convert measured quantities to volumes at the standard temperature, it is also necessary to determine the density or relative density of petrol and its constituents (Riazi, 2005).

2.4.3 Research Octane Number determination (ASTM D 2699)

In this laboratory test process, the knock rating of fuel for liquid spark ignition engines is quantitatively assessed using the Research Octane Number. Usually, in conventional method single-cylinder stationary laboratory engines run under precise conditions of standardized test procedures D2699, the Research and Motor Octane Number, or generally the Antiknock rating, of a spark-ignition engine fuel is measured (Da Silva *et al*., 2019). The primary reference fuel (PRF) blends' volumetric content (typically mixtures of 2,2,4-trimethyl pentane and *n*-heptane) determines the octane number scale, and the sample fuel's knock strength is contrasted with that of one or more PRF blends (Mehl *et al*., 2006). The Research Octane Number is determined by finding the PRF blend's octane number that corresponds to the sample fuel's knock intensity (Ranzi, 2006). The test method's functional range is between 40 and 120 octane number. The Research Octane Number range for normal commercial fuels generated for spark-ignition engines is between 88 to 101. Ratings at different levels across the Research Octane Number range can be produced by testing gasoline blend stocks or other process flow components (Vom Lehn *et al*., 2021).

The Eralytics spectral (ERASPEC) multi-fuel analyzer (Figure 3.3) was used in the current study to measure RON (Section 3.3.3). For gasoline, diesel, jet fuel, and even specialist fuels like ethanol fuels, it provides measurements of fuel component concentrations, intricate attributes like RON and density (Kurczyński & Łagowski, 2019). Results of the measurement are displayed after it is complete, and with a single click, they can be printed or saved to a library (Insausti & Fernández Band, 2016).

2.4.4 Determination of Unwashed Gum (ASTM D-381)

The purpose of this test technique is to determine the gum content of aviation fuels and the gum content of finished motor gasolines or other volatile distillates at the time of the test (Kalghatgi *et al*., 2000). Under controlled temperature and steam or air flow, a specific amount of fuel is evaporated. The remnant is weighed and recorded in milligrams per 100 mL for jet fuel and aviation turbine fuel. For motor gasoline, the residual is measured both before and after heptane extraction, with the findings given in milligrams per 100 mL (Dabbagh *et al*., 2013). The determination of the oxidation products created in the sample before or during the relatively benign conditions of the test procedure is the main goal of the test method when it comes to motor gasoline. The heptane extraction process is essential to separate nonvolatile oils or additives from the evaporation remnant in order to identify the harmful substance, gum. This is because many motor gasolines are intentionally combined with nonvolatile oils or additives (Crompton, 1993).

2.5 Chromatographic methods

High Performance Liquid Chromatography (HPLC) plays a minimal role in identifying adulterated gasoline due to its restricted applicability. Reversed-phase chromatography has been used in HPLC procedures to detect kerosene as an adulterant in gasoline using ultraviolet (UV) detection (Dhole & Ghosal, 1995). Due to its versatility, simplicity, effectiveness, and power, gas chromatography (GC) has been widely applied for this purpose. Particularly for gasoline, the approach provides unmistakable results that provide information at the molecular level. For thorough gasoline analysis, detailed hydrocarbon analyzers (DHA) are frequently utilized. The most common detector used for this purpose is the flame ionization detector (FID), which is both versatile and very sensitive for hydrocarbons (Rudnev *et al*., 2011). Due to the likelihood of its earlier presence, it is difficult to detect solvent adulteration in gasoline; nonetheless, GC-FID makes it simple to monitor their disproportionate presence (Moreira *et al*., 2003).

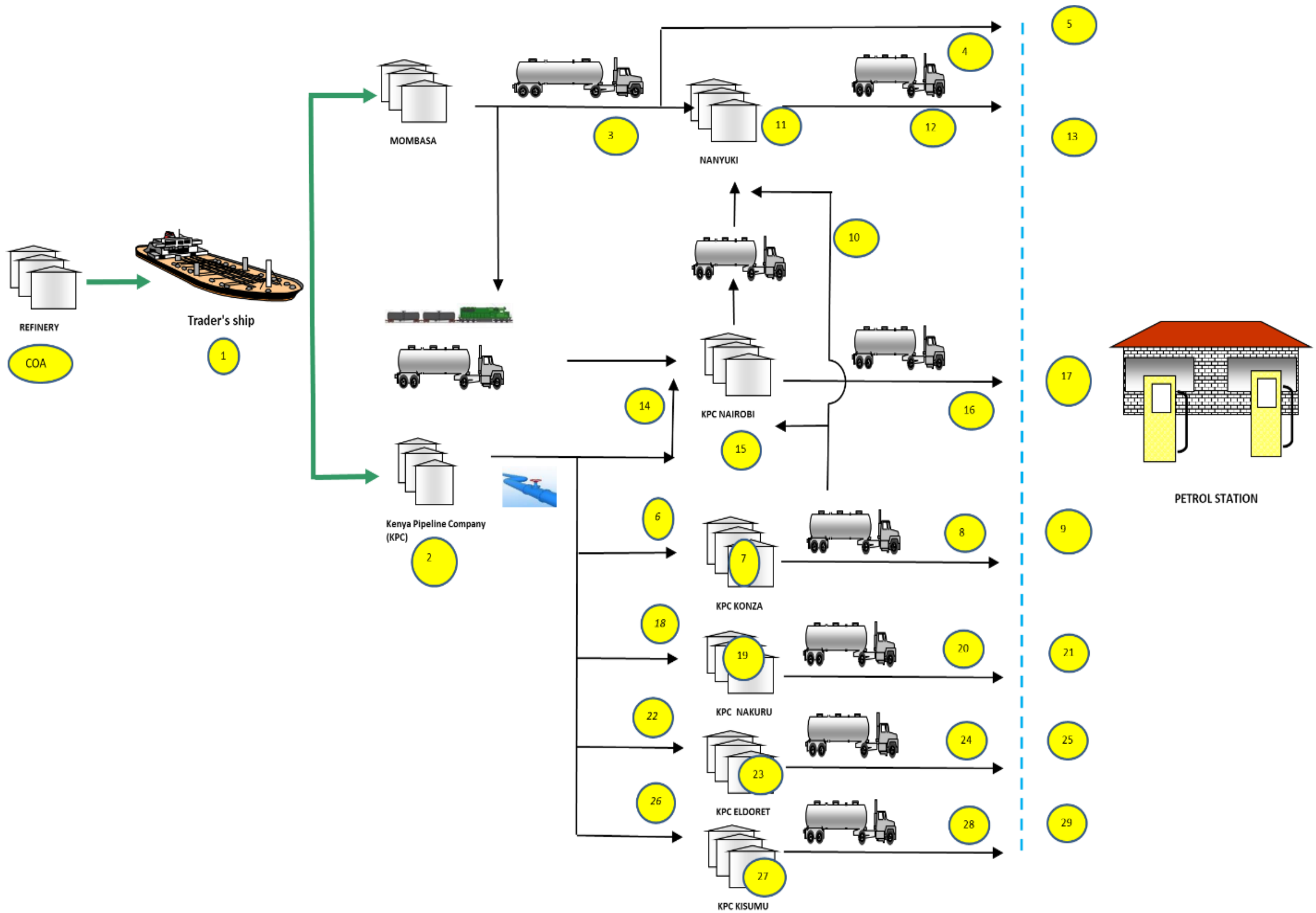
CHAPTER 3: MATERIALS AND METHODS

3.1 General procedures

The combustible samples, which readily reach their flash points, were stored in a refrigerator. Petroleum distillation equipment (OptiDist Herzog by PAC, Canada - USA) for fractionating oil into various hydrocarbon lengths while assuring the quality of the fraction under test. This procedure also included the use of thermometers and distillation flasks. In the distillation process, boiling chips are used to guarantee smooth boiling and to remove entrapped air in the fuel. The flashpoints of the samples were measured using ERASPEC Fuel Analyzer (eralytics GmbH, Austria) with a touchable user interface, and the data was converted into readable CSV excel files using RCS software, which is integrated with the Eralytics equipment. Beakers for measuring fixed-point gasoline in tanks (BQKD, 300 mL, 500 mL, 1000 mL). GUM content tester (Anton Paar GmbH) was used to determine volatile composition and fuel gum content. To handle gum samples for further investigation, GUM glass tongs (106362) were used. Quincy Air Compressor (USA) was utilized for onshore and offshore tasks such as sustaining reservoir pressures that gradually decrease over time during transit. The density was measured using a digital density meter (Anton Paar DMA HPM).

3.2 Sample collection

The sampling locations used to collect samples for the chosen parameters are shown in Scheme 3.1, Figure 3.2 and Table 3.1, respectively. With tap water and detergent, every glassware used in this study, including measuring cylinders, distillation flasks, beakers, boiling tubes, and glass bottles, was thoroughly cleaned. Following that, they were rinsed with deionized water and acetone. Since light deteriorates samples, dark glass bottles were utilized to collect the samples. Samples were taken from the top, middle, and bottom of the tanks as well as the pump nozzles, and they were tightly corked to stop the loss of light hydrocarbons that might have an impact on the test results. After collecting the sample, the glass bottle was labeled right away. The gasoline samples were then transported to a Vivo Energy specialized fuels testing laboratory in Nairobi where they were kept in a cool, dry environment while awaiting analysis.



Scheme 3.1: Kenya Gasoline Supply Chain and Sampling Plan

Figure 3.1: Geographic representation of the key interior Kenyan deports along the pipeline gasoline delivery system from the Mombasa depot.

Table 3.1: Selected Gasoline Sampling Points

Sample No.	Sampling Point
1	Ship – Pre-discharge
2	PS-14 KPC Mombasa
3	Ex-Mombasa truck to station sampled at destination
4	Ex- Mombasa truck to Nanyuki sampled at destination
5	Station loaded from Mombasa
6	Line into Konza - before tank
7	Konza tank - post receipt
8	Ex-Konza truck to station sampled after loading.
9	Ex-Konza truck to station sampled at destination
10	Ex-Konza truck to Nanyuki sampled at destination
11	Nanyuki receiving tank - post discharge
12	Ex-Nanyuki truck to station sampled at destination
13	Station loaded from Nanyuki
14	Nairobi line before receiving tank
15	Nairobi tank - post receipt
16	Ex-Nairobi truck to station sampled at destination
17	Station loaded from Nairobi
18	Line into KPC Nakuru -before tank
19	KPC Nakuru tank - post receipt
20	EX- KPC Nakuru truck to station sampled after loading.
21	EX- KPC Nakuru truck to station sampled at destination
22	Line into KPC Eldoret -before tank
23	KPC Eldoret tank - post receipt

24	EX- KPC Eldoret truck to station sampled after loading.
25	EX- KPC Eldoret truck to station sampled at destination
26	Line into KPC Kisumu -before tank
27	KPC Kisumu tank - post receipt
28	EX- KPC Kisumu truck to station sampled after loading.
29	EX- KPC Kisumu truck to station sampled at destination

3.2 Experimental

In order to provide a general indication of the status of gasoline, the physical-chemical properties examined were based on the following standard analytical methodologies; American Standards for Test and Materials (ASTM) procedures for measuring density (ASTM D 4052), distillation (ASTM D 86), research octane number (ASTM D 2699), and unwashed gum (ASTM D 381) were used in the testing.

3.2.1 Density at 20 °C (ASTM D 4052)

Density measurements were performed according to ASTM D 4052 (American Society for Testing and Materials, 2013) using a digital calibrated density meter (DMA 4500 M/Anton Paar, Figure 3.1). Briefly, a 10 mL homogeneous sample of petrol was drawn into 50 mL beaker. The sample details; product and source in a digital screen of the equipment was recorded and a 20 °C equilibrium temperature was set. In order to make sure the cell was fully filled and free of gas bubbles, the sample injection tube was first placed into the sample before clicking the start button on the screen. After temperature equilibrium had been reached, the density was recorded to four decimal places and g/cm ^{3} units in triplicates.

Figure 3.2: A Digital Density Meter

3.3.2 Distillation in °C (ASTM D 86)

Using atmospheric distillation equipment (Automated Distillation Analyzer, OptiDist Herzog by PAC, Figure 3.2), the distillation analysis was performed in line with the established test procedure (ASTM D 86) (Ferris & Rothamer, 2016). The prevailing temperature and barometric pressure were first noted. Then, a precisely measured amount of conditioned petrol sample at a temperature below 10 °C was poured into the receiving cylinder up to 100 mL mark. After that, it was totally transferred into a 125 mL distillation flask, and three boiling chips were then added. The probe was well cleaned, mounted in the distillation flask, and set in the apparatus with a base plate of 38 mm. The sample was properly set in the distillation apparatus. The equipment was set up properly for the receiving cylinder before the test. Each test took 45 minutes to complete after which the results were printed out.

Figure 3.3: Atmospheric Distillation Instrument

3.3.3 Research Octane Number (ASTM D 2699)

The Research Octane Number (RON) values were determined using the ERASPEC equipment (Figure 3.3), in accordance with ASTM D 2699 standards (Chaloulos, 2014). The equipment sample container was filled with 50 mL of petrol sample. The sample was then placed inside an intake pipe. To clean the Pyro sensor stabilization IR and reference scans, the empty button was then selected. After the scan was finished, the samples were tested (in triplicate) by pressing the start button. Each test was allowed to run for 10 minutes, before results were recorded.

Figure 3.4: ERASPEC Fuel Analyzer

3.3.4 Unwashed Gum Determination (ASTM D-381)

According to the established protocol (ASTM D-381) (Dabbagh *et al*., 2013), unwashed gum (UWG) was quantified. Briefly, 100 mL beakers were properly cleaned, then soaked and rinsed with gum solvent (SBP 80/110), cleaned with a moderate alkaline detergent, and rinsed with distilled water. The beakers were taken out of the cleaning solution using stainless steel forceps and dried for an hour in an oven set at 150 °C. After drying, they were placed in a vacuum desiccator to cool for two hours then their weights were taken. The sample was then measured and transferred into 4 separate beakers each holding 50 ± 0.5 mL. Placing the first and last beaker in the evaporation bath (Gum Content Tester, Figure 3.4) at the same time, all filled beakers as well as another empty weighed beaker were placed in the bath at 160 ± 5 °C. The air jet was set, time recorded and allowed test to proceed for 30 min ± 0.5min. After the test, beakers were transferred with forceps to the vacuum desiccator and allowed to cool for two hours. After cooling, the beakers were weighed, their masses were noted, and the amount of unwashed gum was estimated.

Figure 3.5: Gum Content Tester

CHAPTER 4: RESULT AND DISCUSSION

4.1 Density

The density is a very important parameter, since the injection systems, pumps and injectors must deliver the amount of petrol precisely adjusted to provide proper combustion (Payri *et al.*, 2011). The density is related to the type of raw material and the purification steps (Predojević, 2008). The density results for various gasoline samples (at 20 °C) obtained using ASTM: D4052 procedure are presented in Table 4.1 below. The sampled gasoline had a density between 0.7498 and 0.7521 g/cm^3, falling within the permitted range of 0.716 – 0.771 g/cm^3. The density of the sampled petrol along the supply chain was between 0.7498 and 0.7521 g/cm^3 showing that the density was within the allowed and recommended level.

Table 4.1: Density of petrol at different sampling points along the supply chain in 2021 and 2022 (mean ± SD, n = 3)

Sample No.	Density at 20 °C 2021 g/cm^3	Density at 20 °C 2022 g/cm^3
1	0.7521 ± 0.021	0.7447 ± 0.0021
2	0.7509 ± 0.019	0.7461 ± 0.0233
3	0.751 ± 0.002	0.7469 ± 0.2139
4	0.7521 ± 0.021	0.7456 ± 0.0035
5	0.7515 ± 0.004	0.7448 ± 0.0213
6	0.7512 ± 0.345	0.7451 ± 0.2672
7	0.7511 ± 0.026	0.7447 ± 0.2271
8	0.7499 ± 0.037	0.7464 ± 0.2378
9	0.7502 ± 0.002	0.7451 ± 0.2411
10	0.7511 ± 0.232	0.7447 ± 0.0239
11	0.7523 ± 0.023	0.7441 ± 0.3671
12	0.7518 ± 0.041	0.7441 ± 0.2571
13	0.7517 ± 0.056	0.7443 ± 0.0035
14	0.7515 ± 0.0152	0.7457 ± 0.2271
15	0.751 ± 0.011	0.7469 ± 0.2134

16	0.7504 ± 0.019	0.7451 ± 0.2367
17	0.7519 ± 0.0237	0.7461 ± 0.036
18	0.7511 ± 0.3454	0.7441 ± 0.2341
19	0.751 ± 0.241	0.7463 ± 0.2565
20	0.7513 ± 0.2621	0.7469 ± 0.0244
21	0.7509 ± 0.3454	0.7457 ± 0.0031
22	0.7507 ± 0.0112	0.7441 ± 0.0378
23	0.7501 ± 0.2171	0.7465 ± 0.5672
24	0.7498 ± 0.0117	0.7451 ± 0.3951
25	0.7504 ± 0.221	0.746 ± 0.2245
26	0.7499 ± 0.0132	0.7441 ± 0.2129
27	0.7521 ± 0.022	0.7459 ± 0.2971
28	0.7519 ± 0.132	0.7452 ± 0.3271
29	0.7504 ± 0.410	0.7461 ± 0.2128

Possible factor affecting density of petrol along the supply chain are; introduction of unwashed gum to the petrol by the walls of the tanks and walls of the trucks and evaporation that may be taking place along the supply chain. The results of this experiment confirmed those of earlier research. For instance, Kumar and Pillai (2020) found that there was no appreciable variation in the fuels' density observed at different levels. Even with the addition of more adulterant substance, they observed that density was still well within the permitted range. On the other hand, it has been demonstrated that even at low levels of adulteration, kinematic viscosity and the percent opacity rate significantly decrease. Consequently, these two factors in particular may be highly helpful classifiers for petrol adulteration tests.

4.2 Distillation

Table 4.2 and Figures 4.1 and 4.2, respectively display the boiling points (FBP) of samples taken at various sites along the fuel supply chain, from the pre-discharge to the final consumption points, as well as the trend over time. From the pre-discharge to the last outlet stations, the ultimate boiling point kept rising in the supply chain. The KPC Kisumu depot's final boiling point is observed to rise to 210.5 °C, which is higher than the lowest final boiling point at the pre-discharge of 186.9 °C. For fuel pipelined from KPC Mombasa to various inland depots, the FBP margin was calculated and compared. For 2021 sampling, between KPC Mombasa and Konza, the pipeline's final boiling point of gasoline varied by 8.1 before the tank and 8.6 after receipt. Additionally, the disparity between Mombasa and Kisumu was 21.7 before delivery and 22.1 after receipt, while the margin between Mombasa and Eldoret was 18.1 before tank and 19.3 after receiving. The deviation margin of the gasoline's ultimate boiling point between Mombasa and Konza through the pipeline before tank was 6.1 and 6.2 before and after receipt, respectively, during the sampling and analysis in 2022. Mombasa and Nakuru had a margin of 11.4 before tank and 12.4 after tank, Mombasa and Eldoret had a margin of 16.8 before tank and 17.6 after receiving, while Mombasa and Kisumu had a margin of 17.8 before delivery and 18.0 after receipt. Mombasa to Kisumu recorded the biggest deviation of 21.7 (2021), followed by Mombasa to Eldoret at 18.1; 17.8; and 16.8 correspondingly. The deviation margin is seen to grow with distance traveled. This illustrates that the longer gasoline remains in contact with pipeline walls, the more impure it becomes, resulting in fuel contamination and an increase in boiling point. When compared to those seen during pipeline transmission, the deviation margins before tank and after receiving are not as noticeable. There is a chance that the tank walls at each KPC introduced cross - contaminants that raised the final boiling points, albeit little. In comparison to 2022, the deviation margins found in 2021 were larger. The different weather conditions at the time of sampling may have contributed to this. While sampling in 2022 was done during a cooler season of the year, sampling in 2021 was done during a warmer season of the year. The quantity of cross - contaminants or reactions that would have jeopardized the integrity of gasoline may have been impacted by the variation in meteorological circumstances.

Table 4.2: Final boiling points (°C) of petrol along the supply chain for sampling in 2021 and 2022

Sample No.	Sampling Point	FBP 2021	FBP 2022
1	Ship – Pre-discharge	186.9	189.8
2	PS-14 KPC Mombasa	187.2	190.1
3	Ex-Mombasa truck to station sampled at destination	192.3	194.9
4	Ex- Mombasa truck to Nanyuki sampled at destination	193.5	195.8
5	Station loaded from Mombasa	194.2	195.9
6	Line into Konza - before tank	195.3	196.2
7	Konza tank - post receipt	195.8	196.3
8	Ex-Konza truck to station sampled after loading.	195.9	196.5
9	Ex-Konza truck to station sampled at destination	196.2	196.6
10	Ex-Konza truck to Nanyuki sampled at destination	196.5	196.9
11	Nanyuki receiving tank - post discharge	196.9	196.9
12	Ex-Nanyuki truck to station sampled at destination	197.1	197.3
13	Station loaded from Nanyuki	197.4	197.4
14	Nairobi line before receiving tank	197.7	198.5
15	Nairobi tank - post receipt	198.2	198.7
16	Ex-Nairobi truck to station sampled at destination	198.4	198.8
17	Station loaded from Nairobi	198.9	198.9
18	Line into KPC Nakuru -before tank	199.5	201.5
19	KPC Nakuru tank - post receipt	199.9	202.5
20	EX- KPC Nakuru truck to station sampled after loading.	200.7	202.7
21	EX- KPC Nakuru truck to station sampled at destination	201.6	203.5
22	Line into KPC Eldoret -before tank	205.3	206.9
23	KPC Eldoret tank - post receipt	206.5	207.7
24	EX- KPC Eldoret truck to station sampled after loading.	207.5	207.9

25	EX- KPC Eldoret truck to station sampled at destination	208.7	208.9
26	Line into KPC Kisumu -before tank	208.9	207.9
27	KPC Kisumu tank - post receipt	209.3	208.1
28	EX- KPC Kisumu truck to station sampled after loading.	209.6	209.0
29	EX- KPC Kisumu truck to station sampled at destination	210.5	210.2

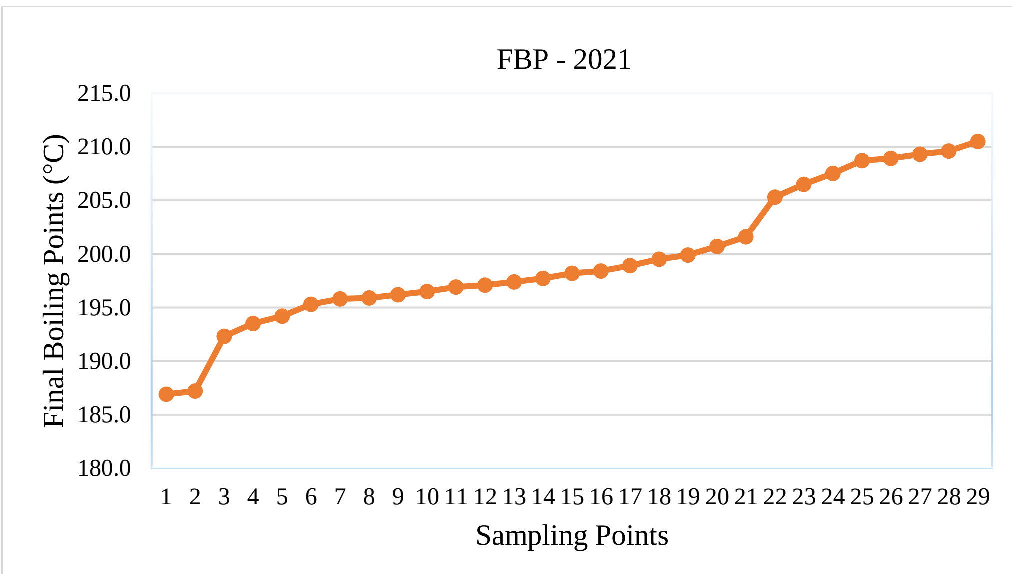


Figure 4.1: Trend of the final boiling point of petrol along the supply chain (2021)

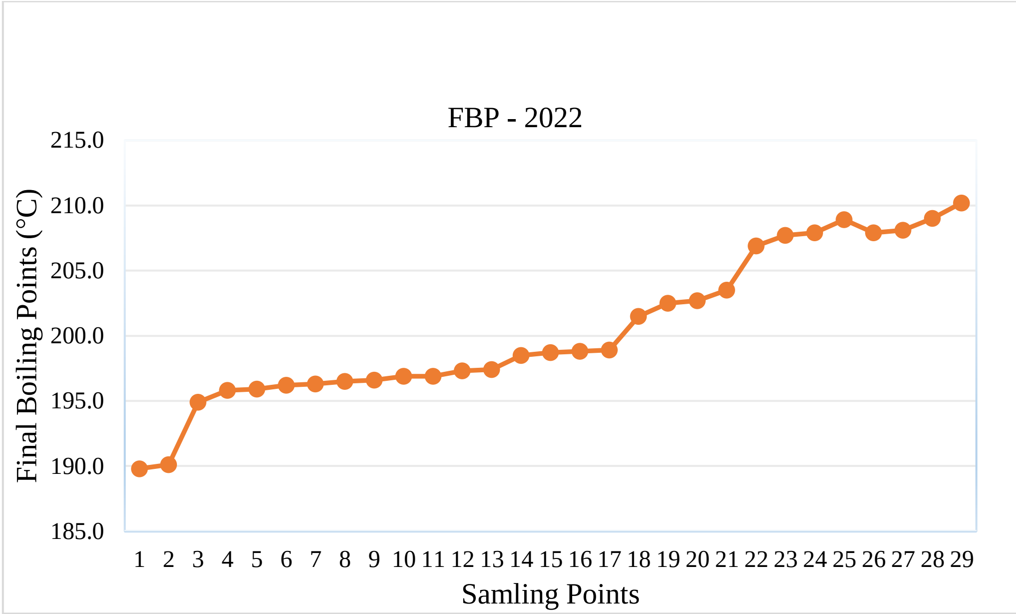


Figure 4.2: Trend of the final boiling point of petrol along the supply chain (2022)

The boiling point of gasoline can change when foreign solvents, solutes, or other particles are added (Aikawa *et al.*, 2010). Maintaining gasoline temperatures is critical because higher temperatures alter with the combustion energy owing to shifts in fuel properties such as density and heat energy. Numerous factors, including the presence of complex microbiological diversity in gasoline, contribute to microbial diesel contamination, which may be responsible for the rising trend in gasoline's ultimate boiling point observed throughout the supply chain. First, petroleum products are transported from the port of Mombasa to interior depots upcountry via a pipeline that is operated by Kenya Pipeline Company. Since petrol and diesel are transported over the same pipeline, even though not simultaneously, it is conceivable for petrol to come into contact with very minute amounts of diesel and become contaminated. Seasonal contaminations arise due to fast microbial growth in warm and humid conditions, regardless of fuel factors such as carbon or energy sources (Christensen & McCormick, 2014). Further, the increased level of unwashed gum in the supply chain may have also led to an increase in the fuel's final boiling point.

4.3 Research Octane Number (RON)

According to Table 1.1, the lowest permitted limit for Research Octane Number (RON) is 93 as per the KPC Regulations. Based on the study's findings, all links in the supply chain had an octane number that was within the acceptable ranges. The level from the pre-discharge to the final outlet station ranged between 93.2 and 94.9. From the pre-discharge point down the supply chain, the number continued to drop, but it stayed within the recommended limit (Table 4.3 and Figures 4.3 and 4.4, respectively). In both 2021 and 2022, the Research Octane Number (RON) trend was similar and both years saw a decline in RON along the supply chain. From KPC Mombasa to various depots, the margin of gasoline's RON was computed and compared. Mombasa to Kisumu recorded the largest deviation of -1.0, followed by Mombasa to Eldoret at -0.9 for 2021; -1.5 and -1.3, respectively, for 2022. The deviation margin is noted to grow with the distance covered. This demonstrates that fuel may become contaminated along the route, possibly due to unclean truck tanks and a shared pipeline contaminating the fuel with foreign substances and reducing its purity.

Table 4.3: Research octane number of petrol from different sampling points along the supply chain in 2021 and 2022 (mean ± SD, n = 3)

Sample Number	Research octane number 2021	Research octane number 2022
1	94.5 ± 4.5	94.9 ± 4.3
2	94.5 ± 4.5	94.9 ± 4.5
3	94.4 ± 5.1	94.3 ± 4.5
4	94.3 ± 4.3	94.1 ± 3.9
5	94.3 ± 6.7	94.1 ± 4.5
6	94.3 ± 4.3	94.1 ± 4.3
7	94.3 ± 4.4	94.0 ± 4.5
8	94.3 ± 4.4	93.9 ± 3.7
9	94.3 ± 4.4	93.9 ± 4.3
10	94.2 ± 4.9	93.9 ± 6.1
11	94.2 ± 7.1	93.9 ± 4.3
12	94.2 ± 6.3	93.9 ± 4.3
13	94.2 ± 4.1	93.9 ± 4.5
14	94 ± 4.7	93.9 ± 3.9
15	94 ± 5.2	93.8 ± 4.2
16	93.9 ± 3.9	93.8 ± 4.3
17	93.9 ± 4.3	93.8 ± 4.5
18	93.8 ± 5.2	93.7 ± 4.1

19	93.8 ± 4.1	93.7 ± 3.8
20	93.8 ± 4.1	93.7 ± 4.5
21	93.7 ± 4.1	93.6 ± 4.5
22	93.6 ± 4.5	93.6 ± 9.3
23	93.6 ± 4.1	93.5 ± 6.7
24	93.6 ± 3.8	93.5 ± 4.5
25	93.5 ± 2.6	93.5 ± 4.5
26	93.5 ± 3.8	93.4 ± 4.3
27	93.5 ± 4.5	93.4 ± 4.3
28	93.5 ± 4.5	93.4 ± 4.5
29	93.4 ± 4.5	93.2 ± 4.5

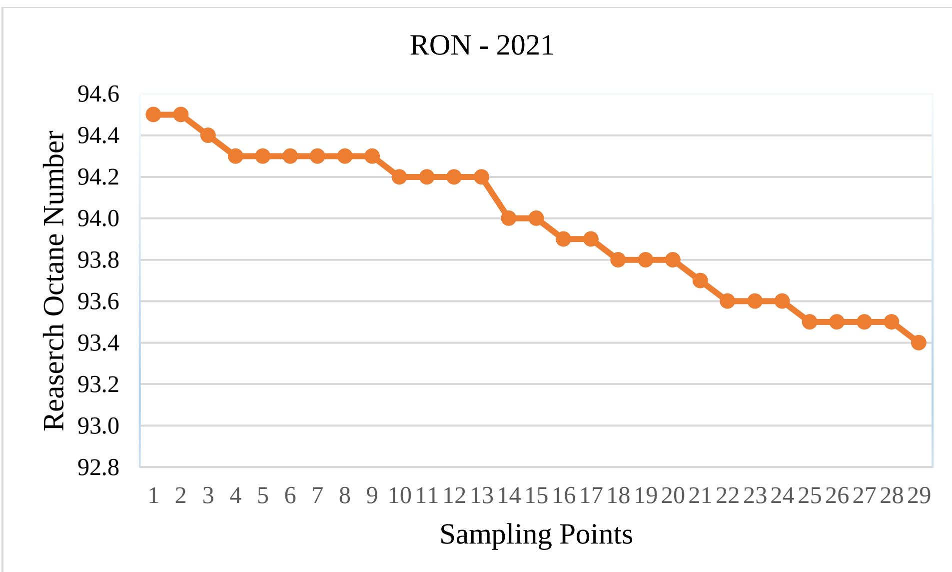


Figure 4.3: Trend of research octane number of petrol along the supply chain (2021)

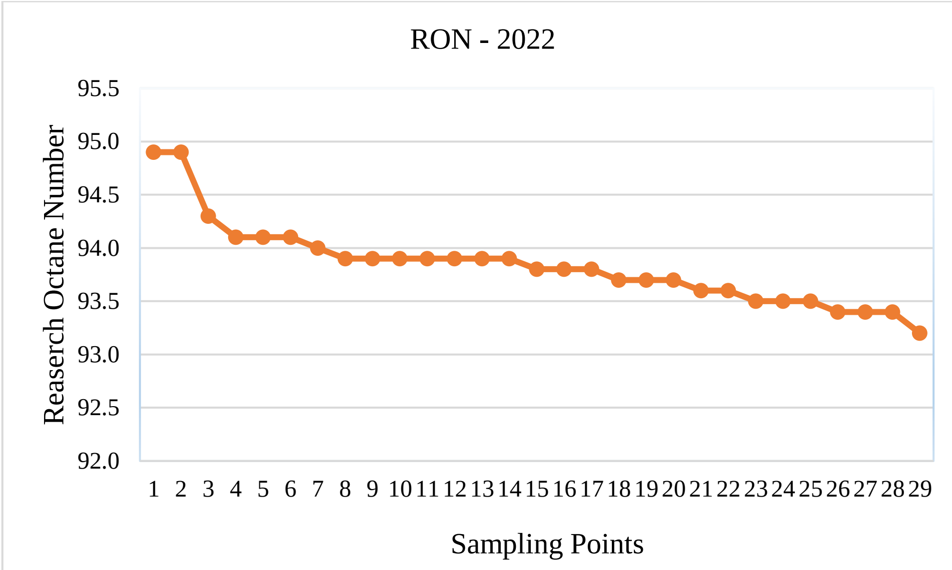


Figure 4.4: Trend of research octane number of petrol along the supply chain (2022)

RON property defines petrol's resistance to anomalous or uncontrolled combustion and higher the RON, the greater petrol's resistance to engine knocking. The research octane number serves as a measure of an engine fuel's combustibility at low speeds and temperatures. The purpose of Research Octane Number is to depict how fuel behaves in storage or while in use in an engine (Simons & Gbadam, 2010). The change in the level of RON in the supply chain may also have been influenced by increase in the number of straight run gasolines as compared to reformate gasoline and also by changes in the mid-boiling point. At relatively higher temperatures than room, petrol exhibits high kinetic energy which is associated with high reactivity. This can make petrol to form compounds with pollutants lowering its combustibility (Al-haj Ibrahim & Al-Kassmi, 1997). Non-compliant gasoline products containing lower RON values harm engines and pollute the environment as a result of increased exhaust emissions brought on by incomplete combustion.

4.4 Unwashed Gum

The current study's findings showed that the amount of unwashed gum in the fuel sample taken from the pre-discharge was within the permitted range of 5.0 mg/100 mL. Up to the last outlet point, the level kept rising along the supply chain. The amount of unwashed gum in the gasoline at the pre-discharge in Mombasa was 4.0 mg/100 mL (2021) and 5.0 mg/100 mL (2022), respectively, which was within the permitted range (Table 4.4). The concentration of unwashed gum was found to have increased to 7.0 mg/100 mL in samples taken from a petroleum truck delivering gasoline from KPC Mombasa to various stations. In addition, it is seen that the deviation margin for gasoline delivered by pipeline widens with increasing distance, with Mombasa to Kisumu recording the largest deviation of 32, followed by Mombasa to Eldoret at 26 for 2021 and 12 and 10 for 2022, respectively. The highest concentration observed was 41.0 mg/100 mL, which was far beyond the permitted upper limit of 7.0 mg/100 mL for aviation engines. Another important finding worth mentioning is that samples taken in 2022 often contained less unwashed gum than samples taken in 2021 (Table 4.4). This might be as a result of the different sampling times and seasons. The sampling for 2021 was carried out in January, which is typically a warm month, whereas the sampling for 2022 was conducted during the typically chilly months of July and August. The melting of the gums due to the high temperatures may have led to the high level of unwashed gum in 2021.

It's possible that contamination of the shipping containers, pipes, and truck walls contributed to the rise in unwashed gum along the supply chain. Petrol, for instance, is held in storage tanks while being transported from the Kipevu port to inland depots before being distributed. This may cause the walls of these storage tanks to corrode, which could result in the development of products that could change the fuel's integrity. Additionally, the fuel's chemical features, such as the rapid oxidation of its hydrocarbon components, may cause greater acid levels as well as the formation of gum and sludge in the fuel. There may also be other processes, like polymerization and condensation. Storage tanks are a breeding ground for impurities that may be found after gasoline has been stored for a long time. Such impurities include leaking water and microbial growth. For the sampling conducted in 2021 and 2022, the quantity of unwashed gum and the trend along the supply chain are shown in Table 4.4, Figures 4.5, and Figures 4.6, respectively.

Table 4.4: Amount (mg/100 mL) and trend of unwashed gum in petrol along the supply chain for sampling in 2021 and 2022

Sample Number	Unwashed gum (2021)	Unwashed gum (2022)
1	4.0	5.0
2	6.0	5.0
3	7.0	7.0
4	9.0	9.0
5	10.0	12.0
6	13.0	12.0

7	14.0	14.0
8	13.0	13.0
9	15.0	15.0
10	16.0	14.0
11	17.0	12.0
12	17.0	16.0
13	20.0	16.0
14	21.0	15.0
15	21.0	17.0
16	23.0	18.0
17	24.0	15.0
18	25.0	15.0
19	27.0	14.0
20	29.0	16.0
21	31.0	14.0
22	32.0	15.0
23	35.0	16.0
24	36.0	14.0
25	38.0	16.0
26	38.0	17.0
27	39.0	19.0
28	40	21
29	41	23

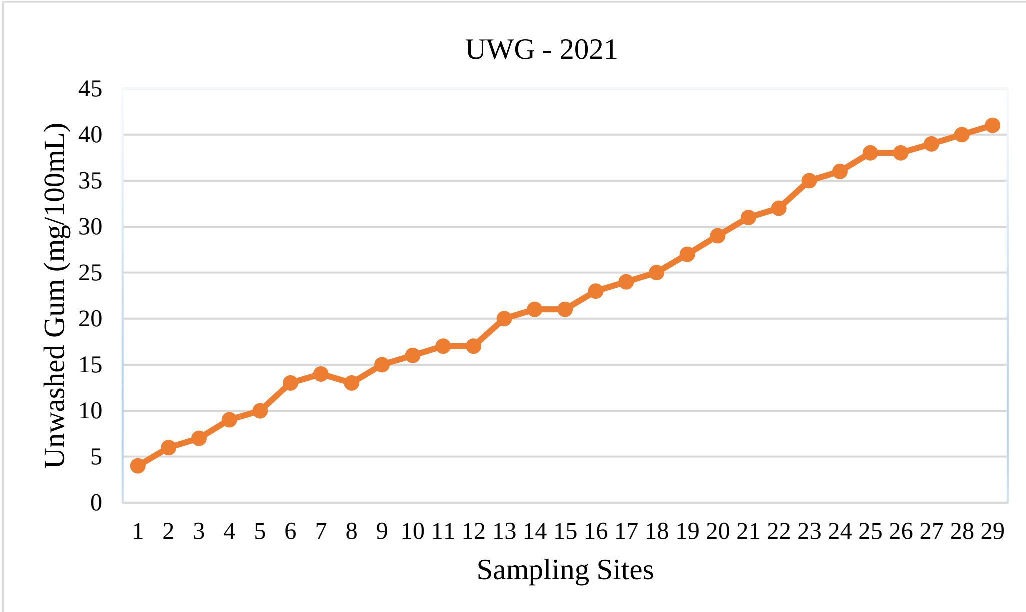


Figure 4.5: Trend of unwashed gum in petrol along the supply chain (2021)

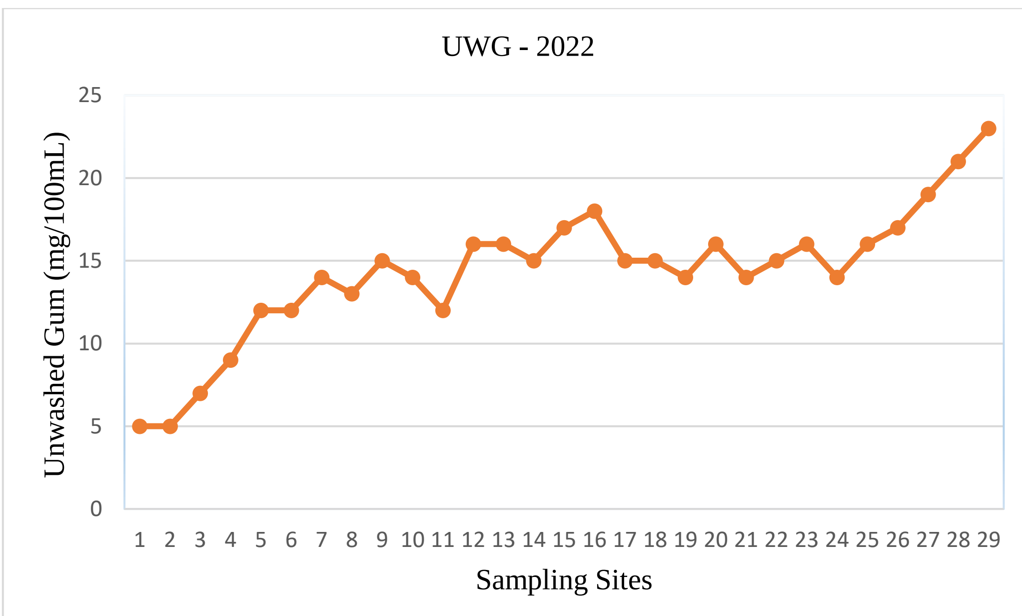


Figure 4.6: Trend of unwashed gum in petrol along the supply chain (2022)

During transit or storage, hydrocarbons (paraffins, naphthenes, aromatics, olefins) in gasoline react with each other or with absorbed ambient oxygen to generate the gum, a polymeric, resinous substance with a high molecular mass concentration. This causes changes in the physiochemical properties of gasoline, such as an increase in fuel density, oxygen concentration, aromatics, distillation temperatures, and a decrease in olefin content (Teixeira *et al*., 2007). As a result, when the gum content grows, the efficiency of the air/fuel combustion process declines, leading to an increase in the emission of noxious compounds in exhaust gases as engine efficacy falls (Pereira & Pasa, 2005). This suggests that when it comes to air pollution, fuel stability is critical.

Various policy regulations regarding unclean gum concentration in gasoline have been suggested. The results found in this investigation for unwashed gum content, particularly at Kisumu deport, were much greater than the suggested value by several regulatory agencies. The ASTM D4814 specifies that the maximum gum content be less than 5.0 mg/100 mL of gasoline at 100 °C induction period be greater than 360 minutes (Pradelle *et al*., 2015). However, since unwashed gum is composed of old fuel products and toluene-acetone washings from the glass sample container, expensive antioxidizers and metal deactivators should be used to postpone the gum forming process. This will aid in limiting the release of noxious gases into the environment, hence lessening the global warming threat impacts that we are now experiencing.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The Kenyan Petroleum supply chain as per the order of movement of Petrol from the point of import goes through Mombasa Port Depot – Konza Inland Depot – Nairobi Inland Depot – Nakuru Inland Depot – Eldoret Inland Depot – Kisumu Inland Depot and Nanyuki Inland Depot plus a station supplied from each of the listed depots all the way to the consumer.

The density of the petrol along the supply chain from the pre-discharge to the final consumer points was between 0.7498 and 0.7521 g/cm^3 and was within the recommended level. The research octane number level ranged from 93.2 to 94.9 from the pre-discharge to the last output station. From the pre-discharge site on up the supply chain, the number kept rising, although it stayed within the advised range. The unwashed gum level in the petrol sample obtained from the pre-discharge was within the allowed level. The level kept increasing along the supply chain to the final outlet station. When the petrol reached KPC Mombasa, the unwashed gum level was 5.0 mg/100 mL which was within the allowed limit. The level started increasing from the transportation from KPC Mombasa and it was between 7.0 – 41.0 mg/100 mL which were way to high compared to the maximum allowed limit. The KPC Kisumu depot's final boiling point trend was found to climb to 210.5 °C, however it stayed within the permitted norms. The lowest final boiling point at the pre-discharge was 186.9 °C.

The deviation is seen to increase with increasing distance, with Mombasa to Kisumu having the largest deviation of 21.7 for FBP in 2021 and 17.8 in 2022; 32 for UWG in 2021 and 12 in 2022; and -1.0 for RON in 2021 and -1.5 in 2022. This illustrates that the longer gasoline is exposed to the walls of pipelines and delivery trucks, the more polluted it becomes, and minor changes in its chemical composition occur, resulting in changes in its physiochemical characteristics.

5.2 Recommendations

This study's recommendations are based on the findings, and they are as follows:

i. To remove cross-contaminants that could foul gasoline, The walls of storage tanks and transportation tracks need to be thoroughly cleaned on a regular basis.

ii. To remove carryovers that could result in contamination of storage tanks, transportation trucks, and pipelines should be specific for a certain type of petroleum product.

iii. To ensure that the Gasoline purchased by the consumers meet the required quality specifications, standard parameters especially density and cross - contamination with kerosine should be checked at the point of delivery.

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