



**EVALUATION OF LIQUID BIOFUELS, JATROPHA OIL, AND ITS BLENDS WITH
KEROSENE AS ALTERNATIVE FUEL FOR LIGHTING AND COOKING**

By
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DECLARATION

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

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ABSTRACT

Many economies in the world depend on non-renewable fossil fuels for their energy supply, whose economic benefit is in question. Kenya currently depends on imported petroleum to meet 75% of her commercial energy. The prices of the product are regulated by the market forces which is beyond the control of the country. Kerosene for instance is still being advocated as an alternative fuel for cooking, and as cheaper lighting source in lamps in slum areas and where electricity is not provided especially in urban towns. Further, the continual use of kerosene exacerbates both the environmental and human health through the emission of greenhouse gases contributing to global warming hence the need for an alternative cheap clean renewable source. This was achieved by determining the oil yield from *Jatropha Curcas* seeds from Tana River, Lamu county, preparing Kerosene *Jatropha* blends, evaluating the physiochemical properties of the blends, evaluating the burning and lighting performance of the best blends while testing for the emissions. The physiochemical and thermal properties were determined using standard methods as per the Institute of Petroleum's standards for petroleum and its products, this included kinematic viscosity, specific gravity, acid value, flash point, calorific value. The water boiling test was also performed and from this test the amount the energy output of the fuel blends was determined. While the water boiling test was ongoing the amount of emissions from the fuel being used was also determined, these emissions were the particulate matter (P.M2.5) and the amount of carbon monoxide. *Jatropha Curcus* oil was extracted from its seeds, it was blended with kerosene which was bought at an identified petrol station, the blends were made at different ratios and the best blends were found to be Blend 5, Blend 10 and Blend 20. A one wick kerosene lamp was used to determine the lighting effectiveness of the fuel blends, while a normal wick stove found in Kenya was used to perform the water boiling test. There was a significance difference among all the three oil blend samples tested and the results obtained emphasized the use of optimum oil blends on normal stoves and the importance of using the stoves in well ventilated areas to decrease the amount of exposure from emissions.

DEDICATION

To my father, William Ndombi Kundu, who no matter how hard the going got, encouraged me to get to the end, to my children Seanice, Tamara and Tyler and to everyone else who has been there to support me through this journey.

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ABBREVIATIONS AND ACRONYMS

ASTM	American Society for testing and Materials
BS	British standards
CCT	Controlled Cook Stove
CO	Carbon Monoxide
CO ₂	Carbon dioxide
COPD	Chronic Obstructive Pulmonary Disease
EIA	Energy Information Administration
FAME	Fatty Acid Methyl Esters
FAO	Food and agricultural organization
GDP	Gross domestic Product
GHG	Green House Gas
GRFA	Global Renewable Fuels Alliance
HC	Hydrocarbons
h _c	Thermal transfer efficiency
ISO	International Organization for Standards
ITDG	Intermediate Technology Development Group
KIRDI	Kenya Industrial Research Institute
KEBS	Kenya bureau of standards
KSH	Kenyan shillings
LPG	Liquefied petroleum gas
M ₁	Mass of water in Sufuria
MTBE	Methyl tert- butyl Ether
OECD	Organization of Economic Cooperation and Development
OPEC	Organization of Petroleum Exporting Countries
OSHA	Occupational Health and Safety Administration

PM	Particulate matter
PPM	Parts Per Million
SFA	Saturated Fatty Acids
SVO	Straight vegetable oils
UFA	Unsaturated Fatty Acids
US	United States
USDoE	United states department of Education
USA	United States of America
WBT	Water Boiling Test
NEMA	National Environment Management Authority
NO _x	Nitrogen Organic Compounds
WHO	World Health Organization
WSG	Wood Burning Stove Groups
LPG	Liquefied Petroleum Gas
VITA	Fighting hunger and climate change in Africa
VOC's	Volatile organic compounds

LIST OF CHEMICAL SYMBOLS

CO	Carbon monoxide
CO ₂	Carbon dioxide
SO _x	Sulfur organic compounds
SO ₂	Sulfur dioxide
NO _x	Nitrogen organic compounds
C = C	carbon carbon double bond

CHAPTER ONE

1 INTRODUCTION

1.1 Background

Energy is a critical component of livelihoods in communities worldwide whose use affects all facets of life. The source, whether renewable or non-renewable, dictates the supply, availability, cost, environmental and human health effects. Many economies depend on non-renewable fossil fuels for their energy supply, whose economic benefit is in question. The price of petroleum products has continued to fluctuate with notable effects to the global economy, with factors such as shrinking supply and political unrest (causing security concerns in the petroleum mining countries), playing a major role. Further, environmental health, to be specific the changes in climate globally, is linked to emissions from fossil fuels, a major concern to the global warming is carbon dioxide (CO₂) emissions that are projected to increase by 52% by the year 2030.

In Kenya, the major concern on the petroleum products is the total product consumption, which is increasing per year. In a case example the quantity of petroleum product imported in Kenya increased from 4,409.0 thousand tonnes in 2014 to 4,431.7 thousand tonnes in 2015. The total import bill for petroleum products however decreased by 32.6 per cent to Ksh. 226.1 million during the same period. Overall demand for petroleum products rose to 4,742.7 thousand tonnes in 2015, mainly due to growth in domestic demand for illuminating kerosene, motor gasoline and light diesel oil which rose by 29.9, 22.5 and 20.9 per cent, respectively. Light diesel oil, (bulk of fuel sold in the country) accounted for 43.9 per cent of the total domestic demand in 2015 (Central Bureau of statistics Kenya, 2017).

Kenya is hoping to commercially exploit its oil reserves which it recently discovered through exploration efforts, where an estimated one billion barrels were found in south of Loki char (Kuo, 2016). However, it has been stated that these amounts cannot sustain the Kenyan demand for fossil fuel. Other challenges to Kenya commercializing its oil find are setbacks in the construction of ports and transport systems in the North West part of the country as well as meeting the demands of local communities. In most countries, liquefied Petroleum Gas (LPG) and natural gas are considered the cooking fuels of choice in urban towns as they have high calorific value and yield less emissions. Biogas made from anaerobic digestion of animal dung is used where the raw

material is abundant and conditions are suitable. This alternative is expensive and out of reach for the larger population and therefore kerosene is sometimes advocated as an alternative fuel for cooking and is often used for lighting where electricity is not available (Nicholas and Kirk, 2016). The devices used with kerosene for cooking and lighting emit substantive amounts of carbon monoxide (CO), nitric oxides (NO_x), particulate matter and sulfur dioxide (SO₂). There is no documented data on amounts of kerosene used for lighting as it's very hard to distinguish the utility of kerosene at purchasing points as it can be used for cooking or lighting. In highly populated African nations over and above 60% of people rely on kerosene as the main source of illumination (Apple, 2010; Uganda Bureau of Statistics, 2010; International Finance Corporation and the World Bank, 2008).

Generally, the reliance on fossil fuels as a single commodity to supply the country and the world's energy needs thus poses much risk, and use of vegetable oils as fuel alternatives is being explored. One such vegetable oil source is *Jatropha Carcus*, which is increasingly receiving interest although its sustainability system has not been thoroughly assessed (Wouter and Achten, 2010).

In an investigation conducted by (Mogaka, 2014), it was concluded that *Jatropha* plants in Kenya were promoted and adopted without the presence of an established and reliable market and without tried processes for its local use. Consequently, many adopters were unable to use their product for their own energy supply; this further justifies the need for more study on the energy potentials of oil from *Jatropha*. Work has been done on small scale initiatives where *Jatropha* oil is produced in local decentralized areas; the oil is extracted using oil mills producing cold pressed *Jatropha* oil which require no additional conventional refinery processes such as degumming, de-acidification and bleaching (Ashwani and Satyawati, 2008).

This project entailed the following tasks that were carried; Task 1: Oil extraction and blending

The task here entailed purchasing the seeds, drying the seeds and pressing the oil using a mechanical extractor, filtering the oil and storing the oil. It also involves purchasing the Kerosene fuel from an identified petrol station and further blending of the *Jatropha* oil with the Kerosene purchased in volumetric percentages.

Task 2; Characterization of the neat oils and the fuel blends

The task entailed taking the fuel blends in a chemical laboratory for the oil and fuel properties testing. The oil and fuel properties relevant to combustion of the fuel blend were performed.

Task 3: Measuring the lighting effect of the blends.

In this task the blends were placed in a kerosene wick stove lamp and tested if they could light.

Task 4: Measuring the efficiency of the fuel blends and the emissions

This task utilized the water boiling test to determine the efficiency of the fuel blend prepared. During the water boiling test emissions were also tested.

1.2 Problem statement

Kenya currently depends on imported petroleum to meet 75% of her commercial energy needs and the prices of these products are controlled by the market forces that are beyond the control of the country, thereby increasing the cost of the products (Central Bureau of statistics, 2016). The statistics from the Economy survey of Kenya, a government press document, reports that the amounts of the imported petroleum products have been increasing on yearly basis and data from the economic survey of Kenya shows that from the period 2014 to 2015 there has been an increased from 4,409.0 thousand tonnes in 2014 to 4,431.7 thousand tonnes in 2015 the period 2015 to 2016 had an increase in the volume of petroleum imports from 4,417 thousand tonnes to 4,852 tonnes in 2016 and so on and so on (Central Bureau of statistics Kenya, 2015).

These forces that are beyond the country's control makes the product to have high prices which trickle down to the local people. Most local people rely on Kerosene for cooking and lighting in semi urban areas and for cooking in urban areas. There has been ongoing research on biofuels which has dealt with a number of issues like production of biodiesel to run engines to production of bioethanol for cooking and as a result a research need a rose of blending Kerosene with straight vegetable oil from *Jatropha* which has been encouraged in arid areas as fences and finding out the best blends and efficiency of these blends while analyzing the emissions from these blends with an aim that the introduction of this type of fuel will help in the reducing the cost of the new fuel blend and lower the emissions.

Kerosene is advocated for as an alternative to biomass fuels for cooking in urban regions, and as cheaper lighting source in lamps where electricity is not provided. In rural homes, however it is still being widely used as a lighting source and for cooking; this makes the cost very expensive for these people hence the need for research on cheaper alternatives.

Kerosene is used on wick stoves and on pressurized stoves, and finding a cheaper fuel that can be blended and used without altering the normal stoves would be an added advantage to the local people. The use of Kerosene as a fuel on these stoves emits substantial amounts of carbon

monoxide (CO), sulfur (SO_x), carbon dioxide (CO₂), fine particulates matter and nitric oxides (NO_x). These emissions result to depletion of the ozone layer leading to global warming and an increase in infection on respiratory diseases.

Studies conducted by FAO in the year 2005 concluded that about 90% of the sources of energy consumed in the world especially in developing countries are gotten from Biofuels (FAO, 2005) Kenya is endowed with abundant biodiversity that can be used to extract vegetable oils from non-conventional feedstock such as *Calodendrum capense*, *Jatropha curcas* and many more. The presence of this biodiversity should encourage the use of idle and unproductive land for more cultivation of new biofuel crops so that there is no competition with food crops in the fertile agricultural land (Singh, 2009) The oils from these plants can be used by blending them with kerosene and investigating the effectiveness of the various blends and the emissions during the use of these fuels.

This study aimed at investigating the effect of blending kerosene with direct vegetable oils on normal wick cook stoves and the emissions emitted with the same blends. Previous studies have been done on the use of processed vegetable oils on stoves but there is a gap on the direct use of vegetable oils on the existing stoves and a gap on the effect on emissions from the fuel blends.

1.3 Justification

The Kyoto- based policies all over the world looks at ways of reducing greenhouse gases and one such approach is by reducing the earth's emissions (Prasad et al, 2011). Biofuels have been considered as one of the key fuel sources of new energy resources (Delfort et al, 2008). Jatropha oil is considered as a biofuel because it is derived from biomass in a liquid form. (Granda et al, 2007; Prasad et al ,2007). In this study the use of Kerosene Jatropha blend is expected to ideally help in the reduction of emissions because biofuels should be carbon neutral therefore reducing the total accumulation of carbon in the environment (Oliveira et al, 2005)

Kerosene in Kenya is widely used in the semi urban areas where electricity is not available and usually as a source of lighting when used as a source of cooking because of lack of biomass material such as firewood, the tenants will not have the laxity to use them because of rules from the owners of the houses. The price of kerosene in the Kenyan market has been increasing due to unavoidable circumstances such as geo-political dependence on one source of energy; it is economically driven leading to insecurities. As a result of the above reasons there is need to try

and find a fuel that besides it reducing the total amounts of emissions when used as an oil blend the fuel blend should be fairly affordable to the people who will use it. Affordability of the fuel in Kenya will increase energy security since full reliance on fossil fuel will be reduced.

There have been several biofuel policies in different countries and to help in support of these policies, a study on kerosene *Jatropha* blend on cook wick stove in Kenya will be borrowing the support of the European commission policy, that is committed to support the usage and production of biofuels to higher than 5% blends of biofuel (Lechon, 2009; FAO, 2008). Research and findings from the early 1990's shows that there is a gap on data on emissions from cook stoves during the daily use of cooking and the current research will help in adding data to the little data on types of fuels in specific regions. The data and information available gives a generalized data over a large geographical region, narrowed down data on specific fuel and specific cook stove in use in a specific environment would give better results on what type of emissions are affecting the climatic changes in a specific region hence the need to work on a specific fuel on a common wick stove and the emissions during its use (WHO, 2006)

1.4 Objectives

1.4.1 Broad objectives

The overall objective of the study was to establish the utility of liquid biofuels and their kerosene blends for cooking on existing stoves.

1.4.2 Specific objectives

1. To extract *Jatropha curcas* oil from Kenya, Mpeketoni, Lamu County for blending with kerosene.
2. To determine the physiochemical properties of the blends and compare their lighting and burning effectiveness with a view to determine the optimum ratio of the blends.
3. To determine the emissions of carbon monoxide (CO) and particulate matter (PM) from wick cook stoves using the optimum blends.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Introduction

Energy usage in the world was estimated to be growing at the rate of 2.3% yearly (Prasad and Dhanya, 2011). The energy information Administration report (EIA, 2010) had estimates of the primary energy being 36% petroleum, 27.4% coal and 23.0% natural gas all this totalling to 86.4% of fossil fuels being consumed in the world as primary energy. Kenya's current energy sources comprises of biomass at 69%, petroleum at 22% and electricity at 9% (Central Bureau of statistics Kenya, 2017).

Kenya has envisioned itself to be a growing economy by the year 2030 this translates to the country being able to offer stable jobs to its citizens as well as offering them high quality life. In order to have this in place rural towns have to be urbanized. Urbanization comes about with a few changes like reliance on kerosene for cooking since the citizens will move to the urban part of the town to work therefore having most of them renting houses and not being in apposition to quickly and effectively access biomass materials for cooking. All the above will result to a purported increase in petroleum imports in Kenya hence need to find alternative affordable cleaner fuel for use.

Kerosene is a petroleum product that is light, clear and highly flammable characterized by a strong pungent smell, in terms of volatility it's considered to be less volatile than gasoline or petrol. In a country like India, the government in the year 2007 decided to subsidize the price of kerosene to discourage deforestation, forests were being destroyed and used as sources for fire wood for cooking (Bradsher, 2008). In Kenya households that rely on kerosene have been mostly hit with the price of kerosene being increased, this makes it even harder for them to access the product but the reason for its price increase is to deter the traders from adulterating diesel and making large profits from the adulterated petroleum fuel.

Kenya is a country that is a signatory to the Kyoto protocol and therefore it tries to play a major role in trying to reduce the emissions. A percentage of the emission contribution in Kenya is associated from the normal cooking process that has to be practiced in almost all Kenyan homes. The homes that use kerosene stoves are the highest contributors to these emissions and hence the

need to open up research areas that would reduce the use of this petroleum product without adding more emissions to the environment.

Over three hundred tree species exist that produce oil producing seeds as reported by Subramanian et al in the year 2005, this report makes the research on oil blending to make fuel blends for cooking more viable. These seeds have enabled more research on biodiesel and currently the researches are still ongoing. Biodiesel production involves a chemical reaction on the oil from the seeds to produce a fuel molecule. An oil molecule is broken down through a process known as Trans esterification, a catalyst and an alcohol usually methanol is used during this process. The oil molecule is broken down and its glycerine part is replaced by the alcohol molecule. During this process the glycerine is separated and drained off while the remaining biodiesel is washed to remove any remaining impurities and it is later used directly on engines as fuel.

Ethanol fuel was first used approximately around the 20th century in the United States where it was used to power engines (Hausmann et al, 2009). In 1970 the supply of fossil fuel became very scarce and an alternative fuel had to be sourced hence it made the state go back to the use of ethanol as a fuel. This situation however did not last long and the state reverted to the use of fossil fuel. An issue arose on environmental concern and the world's energy demands increased too prompting the state to do more research on the alternative fuel ethanol.

Currently Ethanol is being considered the fuel of the future as it can almost comfortably substitute the fossil fuel especially as a substitute fuel in cook stoves. Hedon 2005's study in Malawi, Lilongwe showed that ethanol can be mixed with a thickening agent to make a gel fuel that was used on cook stoves in household sectors. The thickening agents increased the viscosity of the fuel making it safer to handle, the project had a capacity of 1000 L per day.

Another study in Ethiopia by Debebe in the year 2005 showed that a new type of stove was made that could use ethanol fuel or methanol fuel and it gave a fire power of 1.5 kW per burn. The use of pure ethanol in stoves for household cooking is however dangerous and as a result ethanol and water mixture were tested at Nimbkar Agricultural Research Institute and a suitable mixture found as that of 50% w/w ethanol to water (NARI, 2006) With all this study ongoing then there is more need to further explore alternative fuels besides ethanol and biodiesel.

Kerosene lamps and stoves have been widely used for sources of lighting and cooking and the most common ones are the wick stoves and lamps. These stoves and lamps emit some smoke when

used and the emission from them has not been widely investigated (Smith, 1995). It would therefore be an added advantage when a study is being done on fuel blends the emission from the stoves are also investigated. The typical stove found in Kenya that was used for the above study is as shown in the diagram below



Figure 2-1: Normal wick cook stove (left) and small wick lamp (right) found in Kenya.

This type of stove has eight wicks, with a fuel tank capacity of one litre, it is made of metallic material and weighs approximately one kilogram. It's average price from one shop to another is between 800 to 1200 Kenyan shillings.

2.2 Previous work done

Jatropha Curcas has been studied for different uses such as its cultivation in a small-scale farm the oil yields obtained using the screw press, the quality of the oil obtained using this cold press method in comparison to other feed stocks such as sunflower and rape seed oil. (Baldini et al., 2014) and almost similar study done by Wanjala, K. 2010. In this study the oil was further processed to biodiesel for engine use. The study will not concentrate on this work that was done but will borrow the skill of the use of a mechanical extractor to expel oil from *Jatropha* seeds.

Some other work done by Teoh et al 2014 which showed that Kerosene is an immiscible fuel that can be mixed by other fuels to improve on its performance and this was borrowed to blend it with Jatropha oil to improve the ignition of Jatropha oil.

Lastly Tafadzwa et al 2012 studied on emission from different kerosene cook stoves and concluded that the diameter of the pot in use during the heterogeneous stove testing protocol done at SeTAR centre, University of Johannesburg had little effect on the performance of the stoves in regards to the emissions.

2.3 Climate change

Climate change is a major concern for all humans in the world (Tingem et al, 2009). Currently the situation of the climate change affects all humanities with the highest population being the people with a low income. Some of the adverse effects caused by climate change are high heat intensities, increased floods, droughts which bring in malnutrition, deaths due to increased cold and increased distribution of vector borne diseases (Haines et al., 2006).

During combustion several products are made, the first products in a process called complete combustion are water and carbon dioxide. Then there is a second class of products which are commonly produced in a process known as incomplete combustion and here a wide range of products are created such as carbon monoxide with a mixture of thousand complex compounds which mostly exist in particulate phase which we refer to as soot, these products are highly produced due to the type of device being used to enable the combustion examples here include the different cook stoves in the market. There is a third product called the nitrogen oxides which are created at very high burning temperatures where the nitrogen in the air is fixed. The fourth and last products are the contaminants from the fuel being used and such examples include fuel ashes Sulphur, mineral fibers and such like compounds

Global warming and greenhouse gas effects are also some of the contributors of climate change. They are caused by the release of emissions that are from combustion of fossil fuel, such emissions include carbon dioxide, nitrogen dioxides, sulphur dioxides and particulate matter. The accumulation of these gases traps a hot air blanket from the earth's surface which makes the temperatures of the earth raise too.

A schematic diagram of how greenhouse gases are formed is as illustrated below

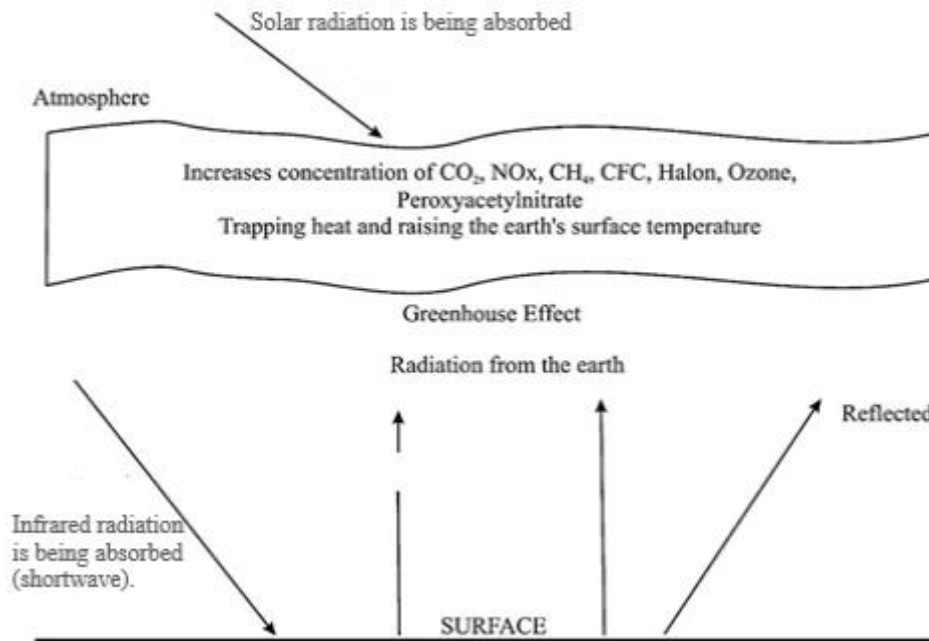


Figure 2-2: A schematic illustration of greenhouse effect

2.4 Biofuels

Biofuels can be defined as fuels made from biomass that can supplement fossil fuels; they are also known as renewable energies. Renewable energy in this sense is a fuel which when burned give minimum amounts of emission as well as when grown they supplement the amount of carbon dioxide being emitted in combustion during photosynthesis.

Biofuels can be divided into two groups, the first-generation biofuels and the second-generation biofuels. First generation biofuels are those produced from vegetable oils and corn sugar. This group of biofuels has brought concern because its sources of raw material are a great competitor with food products when the oil is processed and also it makes the prices of food very expensive (Laursen, 2006).

This challenges lead to the look of the second-generation biofuels which are biofuels produced from biomass material, mostly the lignocellulosic material as it makes up the larger part of the plant and oils from non-edible plants that cannot bring competition to food products. The second-generation biofuels try to utilise all the parts of the plant such as leaves, barks, seeds and fruits.

The production of this biofuels is however facing challenges because it is not cost effective due to a number of technical barriers that need to be overcome so that their potentials are all explored (Naik et al., 2009).

Below in figure 2-3 is a schematic diagram to show the comparison of fossil fuels, first generation and second-generation biofuels.

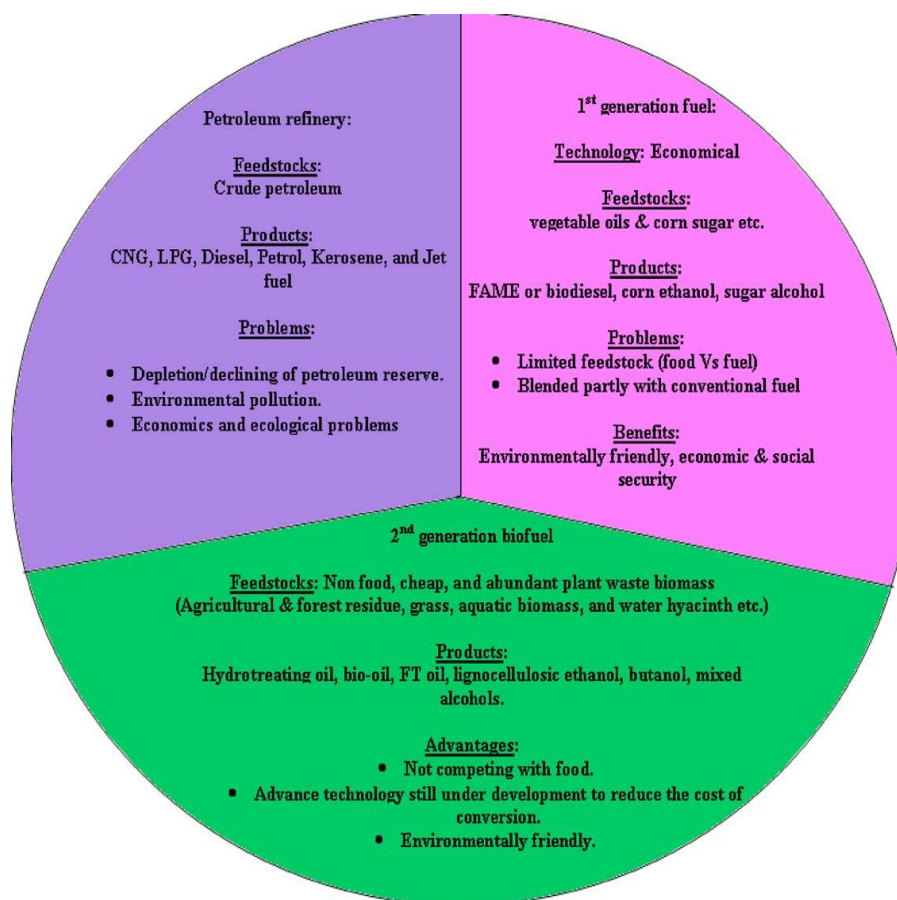


Figure 2-3: Comparison of first, second generation biofuel and petroleum fuel

2.5 Vegetable oils

Vegetable oil is an extract from seeds or fruits of plants and might be utilized directly as fuels in some diesel engines. The unprecedented rise in fuel prices world -wide at some point made the research on vegetable oils become more economically attractive (Diamente and Lan 2014). The utilization of these oils for energy is not new and has been used for lighting and heating purposes in the world over. Vegetable oils can be easily sourced and the glycerides present in the oils makes

it a viable alternative for diesel fuel. The oils have good heating power and provide emission gas with trace amounts of Sulphur and aromatic polycyclic compounds. Their combustion yields complete recyclable carbon dioxide (zero emissions). CO₂ is normally associated with solar energy, as the solar energy falls on the earth; it gets converted into the feedstock through photosynthesis. In East Africa feed stocks that receive particular attention as a source of straight vegetable oil (SVO) use or biodiesel production are maize and sunflower which are considered a threat to food security, another available non-edible feedstock is *Jatropha Curcus*, *Croton sp.* and *Castor sp.* (ODI, 2011). Straight vegetable oils have potential for rural energy supply since the people in the rural areas can produce the oil without sophisticated equipment (GTZ, 2009: ODI, 2011: Wahl et al., 2009). Examples of vegetable oils and their oil content as researched on by Munavu and Odhiambo in 1984 is as shown in the table below

Table 2-1: Percentage oil content of vegetable oils

Oil Seed	Oil Content %	Oil Seed	Oil Content %
<i>Afzelia Cuanzensis</i>	14.4 _b	<i>Craibbia ellioti</i>	32.2 _b
<i>Annona Squamosa</i>	29.0 _b	<i>Croton Megalocarpus</i>	49.°C
<i>Areasstrum Romanzofianum</i>	57.°C	<i>Cucumsus spp</i>	24.0 _b
<i>Azadirachta Indica</i>	56.°C	<i>Cupressus lusitanica</i>	18.0 _b
<i>Balanites Aegyptiaca</i>	44.°C	<i>Erythrina abyssinnica</i>	15.3 _b
<i>Bauhinia purpurea</i>	22.°C	<i>Passiflora edulis</i>	36.0 _b
<i>Caesalpenia Decapetala</i>	24.2 _b	<i>Sesamum indica</i>	45.0 _b
<i>Calodendrum Capense</i>	60.°C	<i>Stereulia Africana</i>	21.1 _b
<i>Citrullus Vulgaris</i>	26.8 _b	<i>Jatropha curcas</i>	50.°C

b, percentage of whole seed; c, percentage of Kernel

The table 2-1 shows several vegetable oil crops and the oil contents, it can be seen that *Calodendrum Capense* and *Jatropha Curcas* have the highest amount of oil content of 60.0 % and 50.0 % respectively allowing further research on it as it was being promoted as a plant that has to be planted on the hedge for fences.

2.6 Jatropha Curcas

Jatropha Curcas is a tree species of flowering plant in the spurge family, Euphorbiaceae, it is known to be a native in the American tropics, mostly in Mexico and Central America.

Jatropha Curcas is a semi-evergreen, poisonous shrub mostly reaching a height of 6m (20ft.) (Van der Vossen and Mkamilo, 2007) it is an arid plant thus, can be grown in arid and semi-arid areas. A study done in India (Kumar, 2007) showed that the seeds were found to contain approximately 28% - 38% (W/W) oil (average: 34.4%), which can be processed producing biodiesel of high quality that can be used to run a standard diesel engine. (Van der Vossen and Mkamilo, 2007)

In Kenya, a *Jatropha* project was examined by Areval et al., in the year 2014 where 64,000 ha of *Jatropha* plantation were to be established in a 160,000-ha leased land in Tana Delta County at Garsen division (Tana Delta district).

The project was funded and undertaken by Bedford fuels a Canadian company and was incorporated locally through its affiliate Bedford Biofuels Tana Delta 1 limited, this project commenced in May 2011, where 10,000 ha was given conditional licence by the National Environment Management Authority (NEMA, 2011) as a “pilot” project and its first harvest of oily fruits was realized in March 2012 after which a cease trade order was issued in May 2012, stopping the company from further sourcing funds from the company’s home province after a fault of offering memorandum (Alberta securities Commission, 2012).

An article quoted the likelihood of project being abandoned due to “political instigations” (Edmonton Journal, 2012). Despite this project ending and if all the bioenergy plantation conflicts and policies are addressed then the plantation of *Jatropha* can then be revisited for further energy production.

Uses and environmental importance of *Jatropha Curcas*

The *Jatropha* tree in Kenya is known as Physic nut in English however in the native languages in Kenya it is known as Kyaiki Kyakyeni in Kamba or as Kya Muunyi. In Luo the same tree is referred to as Jok. The tree was used for ornamental purposes or as live fences or as boundary markers. In Kenya the tree grows along the river beds in western, coastal and central Kenya (Maundu, P. and Tengnas, B. 2005)

The tree was characterized with a bark which when peeled was thin and yellow grey in colour. When cut it produced a milky substance. This plant has many unique parts that were used for different purposes in the older days. for example, it has a latex that contains a component known as Jatrophine. This Jatrophine contains anti-bacterial and anti-microbial properties therefore was used to prevent skin diseases when applied and also it was used to treat sores on animals such as cows. The twigs were cut and used as tooth brushes. The milky substance produced when cut was used as an anti-dote for snake bites.



Figure 2-4: Jatropha plant (left) and Jatropha green fruits (right)

2.6.1 Cultivation

Jatropha Curcas is usually propagated by cuttings, which matures faster results than multiplication by seeds (Van der Vossen and Mkamilo, 2007). Complete germination is achieved within 9 days. The addition of manure during the germination time has negative effects at that phase but is favourable if applied after germination is achieved.

Jatropha Curcas thrives on a mere 250mm (10inches) of rain a year and needs the water mostly in its dry season. Regular ploughing and planting are not needed as the plant has a life expectancy of approximately forty years. The plant has fungicidal and pesticides properties thus it is resistant from attack from a variety of pests.

2.6.2 Handling after harvest

The harvested seeds are dried under shade to achieve moisture content of a range 6% – 9% and stored in an airtight container. Conventional oil extraction methods involve boiling of roasted and ground seeds until the floating oil can be skimmed off the surface. However, this method is very

inefficient and other methods like based on extrusion by hand-operated or mechanized screw presses are used. The efficiency of the pressing method increases when the seeds are milled prior to cold pressing. The residue seed cake can be used as organic fertilizer as it has potassium, phosphorus and nitrogen. In addition, the residue can be utilized as biomass feedstock in steam power plants. Oil produced can further be refined in continuous trans-esterification reactor producing bio-fuel (92% yields) which has diesel-oil quality and yields glycerol by-product which can be used in cosmetic industries.

Environmental importance during the crushing of *Jatropha* seed, the oil collected can be used as a straight vegetable oil or processed to get biodiesel that can be used in a standard diesel car or further processed into a jet fuel.

According to a 2013 study published by the European Geosciences Union (Becker, 2013) the *Jatropha* tree also have applications in the absorption of carbon dioxide, thus helps slow down climate change.

2.6.3 Mechanical extraction of vegetable oils

Vegetable oils can be extracted using mechanically extraction then followed by the chemical extraction process. The second method is applied to remove the remaining oil components in the cake that cannot be removed by the press using a solvent however the chemical extraction process is slightly expensive.

Mechanical extraction is a process where force that is sufficient enough is exerted on seeds that breaks its cells and allow the oil to oose out. Different seeds have different ways of being treated before being pressed like de-hulling and kernel treatment. a schematic diagram of how extraction is carried out is as follows

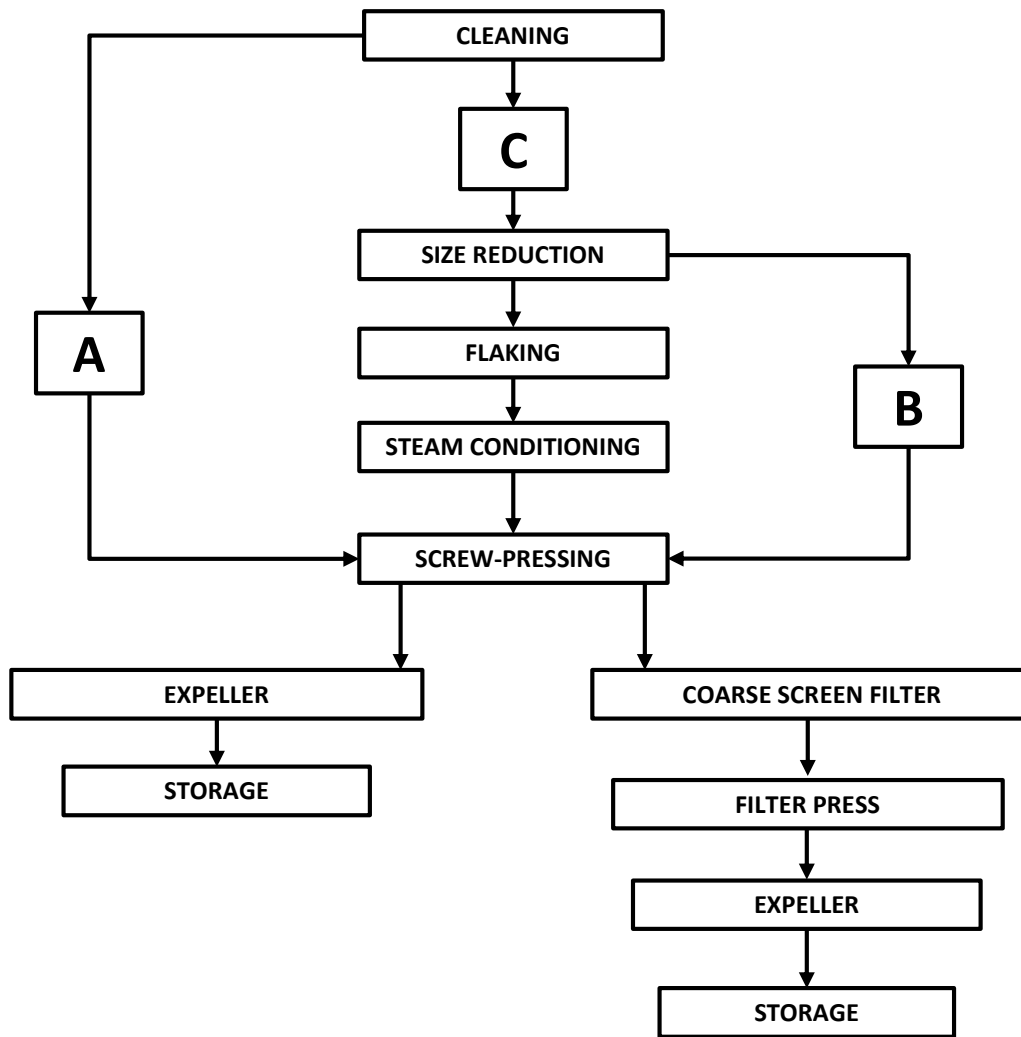


Figure 2-5: Mechanical extraction of kernel oil

2.6.4 Composition of Jatropha oil

Jatropha oil contains saturated fatty acids (SFA) and unsaturated fatty acids (UFA) at 21% and 79% concentration respectively. The main fatty acids are Oleic acid ($C_{18}H_{34}O_2$) at 43.1%, Linoleic acid ($C_{18}H_{32}O_2$) at 34.3% and Palmitic acid ($C_{16}H_{32}O_2$) at 14.2%. The concentration of free fatty acids in the oil varies depending on species 0.06% up to 6.7%. Sulfur and Nitrogen are present in amounts of 0.13% and 0.11% respectively (Bouffaron et al., 2011), (Belot, G. T. 2009).

2.7 Kerosene

Kerosene also known as paraffin is a combustible hydrocarbon in liquid form in the C_{12} to C_{15} range, followed by diesel fuel and heavier fuel oils in the refinery industry. It is a thin, clear liquid with density of 0.78 g/cm^3 - 0.81 g/cm^3 . It is obtained from the fractional distillation of petroleum between 150°C and 275°C , resulting in a mixture of carbon chains that typically contain between

6 and 16 carbon atoms per molecule. The heat of combustion of Kerosene is similar to that of diesel: with a lower heating value of 43.1MJ/kg, a higher heating value of 46.2MJ/kg. The flash point of kerosene is between 37°C and 65°C (100°F–150°F) and its auto ignition temperature is 220°C (428°F). Kerosene is insoluble in water (cold or hot), but miscible in petroleum solvents. Kerosene is commonly used as an alternative in countries where solid fuels biomass such as wood, agricultural residues, animal dung and coal are the major household energy sources but its preferred in developing towns where solid fuel biomass is not readily available; Due to increased population growth the housing structures are also put under pressure thus most lack chimneys or smoke hoods. Kerosene is often burned indoors and exposure to exhaust combustion gases have great health risks, including lung cancer, cataracts, chronic obstructive pulmonary disease (COPD), low birth weight, pneumonia, and tuberculosis (Fullerton, 2008). Fluctuating pump prices of Kerosene have been witnessed (table on appendix 1,2,3,4 and 5 on pump prices of fuels 2017, 2016, 2015, 2014, 2013, 2012, 2010, 2009.) and may contribute to the sustainability debate of this product.

Kerosene is produced from processing of crude oil through distillation or by catalytic cracking of heavier petroleum streams. Raw kerosene has ideal properties making it suitable for blending with performance additives for use in a variety of commercial applications, including transportation fuel therefore the study borrowed the properties to do a study on a mix of Jatropha oil and kerosene, finding its best blends and using it for cooking and lighting on the normal wick stove and hurricane lamp found in Kenya.

2.7.1 The kerosene wick stove study

Work previously done on kerosene wick stoves was intensely done in 1983 at the wood burning stove group (WSG) at the energy department of world bank. The main purpose of the work was to provide reliable information and data on kerosene stoves of diverse designs to aid policy planners for selection of designer. The results obtained proved that none of the existing commercially available kerosene stoves at that moment had a maximum power output above 2kW (World Bank, India, 2002). The following specifications were found to be suitable for Sahelian countries (Bussman, 1987): maximum power 4.0kW, minimum power 0.7kW, thermal efficiency 50%, preparation use of a spherical pot and its low cost.

Direct results of this work done found that there was need to develop and build a high-power kerosene stove which was called the Pet stove. In the commercial market a newer and high-power

kerosene stove was discovered at the moment called the Thomas Cup 36. In Burkina Faso (Verhoeven, 1989) and in Cape Verde (Bussman, 1987) during the test in the field studies both stoves were found to be having disappointing results with respect to the efficiency and to the power output. Another weakness found during the study of the kerosene wick stoves was that they wear out very easily even if they were protected as suggested by the research and development team (Bussmann, Sangen, Sulilatu and Visser international communication WSG 1988). All in all, the kerosene wick stove was found to be a promising stove for the developing countries because they are easy to maintain, they have a low purchase price and there is a possibility of the local manufacturing of the stove by small scale artisan and industries (Verhoeven, 1989).

2.8 Emissions

When fossil fuel is burned there is a release of Volatile Organic Compounds, particulate matter, nitrogen oxides (NO_x) and carbon Monoxide (CO). The main component of smog is usually a combination of nitrogen oxides and volatile organic compounds in the presence of sunlight which leads to the formation of a zone in the atmosphere known as the troposphere zone (Prasad et al 2011). Results of the United States Department of Education(USDoE) research paper in the year 2007 showed that the results of fossil fuel combustion released approximately 21.3 billion tonnes (21.3 giga tonnes) of carbon dioxide (CO_2) annually while natural osmosis process absorbs approximately half of this amount produced leaving a net balance of 10.65 billion tonnes of carbon dioxide in the atmosphere

It is estimated by the World Health Organization (WHO) that over 1.6 million deaths globally are caused by indoor air pollution from use of biomass fuel (Akinori and Pena, 2000).

Carbon dioxide a greenhouse gas is produced during the combustion of fossil fuels. By the year 2005 the CO_2 concentration had almost doubled from the preindustrial value of about 280ppm (IPCC, 2007)

Climate change is a threat to our planet and livelihood; it has been brought about by greenhouse gases. In the recent years the world has observed high frequencies of drought, floods, violent storms which are all associated with climate change.

When kerosene is combusted by the use of inefficient and badly designed stoves, they become a major source of poor indoor air quality and can also result to plenty of household fires (McGlone, 2010) this is common in informal modes of settlement that are usually poorly constructed and poorly ventilated.

2.8.1 Principle of Carbon monoxide meter and particulate matter meter

Particulate matter meters (UCB Particle and Temperature Sensor (UCB-PATs) and CO meters (TSI IAQ-CALC 7545 (TSI Inc.) use the principle of spectroscopic chemistry. The principle of absorption of light by the gases under test are analyzed, the analyzers are of two type's non – dispersive infrared analyzers (NDIR) and non-dispersive Ultra violet analyzers (NDUV). As a gas passes through the instrument and is exposed to the Infrared light source, light energy absorption occurs which is subsequently detected in comparison with a reference gas.

2.9 Tests

The tests that were performed in this research are as follows

2.9.1 Lighting Test

It was done on the lamp using the fuel blends. A one wick stove that has a volume of 200ml tank was filled with kerosene, then the lamp was made to light while the timing was taking place, until all the fuel was consumed. This process was repeated for all the three fuel blends that were made and the time it took to light until all the fuel was consumed was recorded. These results gave a typical picture of how long the fuel will take to light. An image of the wick lamp is as shown in the figure 2-7 below



Figure 2-7: small wick stove found in Kenya

2.9.2 Calorific value

This can be defined as the amount of heat generated when a sample of is burned under oxygen in an enclosed system at a constant pressure and temperature. This process is done using an apparatus called a bomb calorimeter that measures calorific values of combustible samples that could either be in solid or liquid state.

The calorific value measured using a bomb calorimeter gives the gross heat generated during combustion of a sample where the carbon, sulfur and hydrogen are converted to carbon dioxide and water. The result of the calorific value includes the heat of vaporization emitted which is converted to steam and condensed to temperatures of the equipment being used. To compensate for the steam being lost in the calculations the heat of combustion is calculated by removing the latent heat of vaporization from the gross value attained.

2.9.3 Flash point

Flash point determines the flammability of fuels; this can be described as the heat of combustion of a fuel. The standard method used to do this test is ASTM D93. A sample of fuel is put in an enclosed container (Pensky-Martens closed-cup flash point tester) and stirred while heating, a flame is passed on the surface of the fuel, ignition will take place once there is accumulated vapours, a detectable continuous flash shall be observed too and this is referred to as the flash point of the fuel (Van Gerpen, 2004).

2.9.4 Kinematic viscosity

Viscosity can be described as a measure of fluid friction or further thought as its internal resistance to flow.

2.9.5 Iodine value

This can be described as the amount of iodine needed to saturate olefinic bonds in a given sample, it also indicates how the fuel is unsaturated and this relates to problems related to storage of a fuel since the stability of a fuel increases with reduction in C=C bonds that have a tendency of undergoing oxidation.

2.9.6 Acid value

This can be described as taking one gram of oil and finding the amount of potassium hydroxide in mg that can neutralize the fatty acids in the oil; this decomposes by an action known as the lipase action. The units used to express the results found are usually expressed as mg fatty acids

per g or as mmoles per Kg. This test is done to usually give general information on the condition and edibility of oils. The test was done using the standard method (ASTM D664-11)

Oxidation stability causes fuels to thicken and form gums and sediments. Oxidation alters the physical and chemical properties of oils and fuels. It can cause acidity and increase in viscosity due to formation of insoluble gums.

Factors that affect the rate of oxidation are the amount of oxygen, the degree of unsaturation and the presence of antioxidants, the presence of metals, temperature and light. For every one double bond in a chain there is an active center for an oxidation reaction. Examples are as follows soy bean has between 19-30% oleic acid (one double bond), between 44-62% linoleic acid (two double bonds). For olive oil it had 55-83% Oleic acid, 10% linoleic acid. The high amounts of oleic acid in olive oil makes it more resistant to oxidation Jatropha has oleic acid values of 43.32% and linoleic acid of 36.70%. Studies done show that Jatropha Curcas seeds oil have the highest amount of polysaturated fatty acids (linoleic acid) (Mudhaffar et al, 2013).

2.9.7 Specific Gravity

This can be defined as the comparison of the density of a substance to that of water; this measure is unit less as water has a density of 1 gram/cm³ and all the units cancel out. This test gave us results that showed the effect of temperature on the density of biofuel.

2.9.8 Water boiling test

This is a laboratory test that was originally designed to test stoves that use fire wood but was later adopted to test other types of stoves and fuels. This is a test done in a controlled environment, it usually is a rough imitation of the exact cooking process (the boiling and simmering of water), where a specific amount of water is heated and timing is done to find out how long it will take for the water to boil. This test usually gives the results that describes the technical performance of a stove unlike the real cooking as it would happen in households

Some of the parameters that are usually tested in this process are efficiency, time to boil and emissions.

2.9.9 Thermal efficiency

Burning in stoves requires three components air (oxygen), fuel and heat, an efficient stove is one that uses little amount of fuel and gives high amounts of energy. To ensure efficient burning some stoves introduce air vents to ensure good supply of oxygen. To measure the efficiency of a stove

three methods were developed by VITA which is a non-governmental organization that focuses on developing situations in third world country.

The water boiling test is one among the three tests, this test mimics normal cooking where the fuel used to boil a specific amount of water under controlled conditions are measured. The kitchen performance test is tested to determine how much fuel is used in a normal cooking in a home stead for a number of days. The last test is the controlled cooking test which serves as a bridge between the water boiling test and the kitchen performance test, during the performance of this test trained personnel cook a specific food in a controlled setting and the amount of fuel per standard meal consumed is weighed, the results from this test are used to compare all the other stoves.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Sample collection

Jatropha seeds that were harvested from Mpeketoni- Lamu County, the seeds collected weighed 20kgs, they were dried under the sun to minimum moisture content (10- 11%).

The seeds were extracted using an oil press and the extraction yield was determined after extraction. The oil was blended at different ratios with kerosene and the following parameters were measured the lighting test, boiling water test, kinematic viscosity, calorific value, flash point, CO emission and particulate matter.

3.2 Oil extraction

The seeds were collected and dried to minimum moisture of between 10 to 11 % the oil was extracted using the oil pressing machine or mechanical extraction method: Oil was mechanically extracted using the mechanical oil extractor at Kenya Industrial and Development Institute (KIRDI) as shown below. The obtained oil was filtered to remove solid impurities and packed in dry clean air tight containers.



Figure 3-1: The Mechanical oil extractor.

3.3 Blends

The obtained *Jatropha* oil was referred to as the pure blend (Blend 100). From the pure blend other blends of kerosene and *Jatropha* were made ranging from 0 to 100%. To prepare a 2-liter Blend 5 blend, 100 ml (5%) of pure *Jatropha* oil was measured and mixed thoroughly with 1900 ml (95%) of Kerosene, For Blend 10, 20 ml (10%) of the pure *Jatropha* oil was well mixed with 1800 ml (90%) of the kerosene The Blend 20 was also prepared by mixing 400ml (20%) of the pure *Jatropha* oil with 1600 ml (80%) of kerosene. The following physical parameters were measured from the blends (Kerosene/*Jatropha*): Lighting test, Water boiling test, Kinematic viscosity, Calorific value, Flash point, CO emission, particulate matter, Acid value and Specific gravity

3.4 Kinematic Viscosity

The test was done using the Ostwald viscometer size D BS/U 790. The viscometer was thoroughly cleaned using chromic acid solution and rinsed using distilled water. It was then clumped in a temperature-controlled water bath in a vertical position such that the marks 'a' and 'c' were below the water level and that it was clearly visible through the water bath.

A pipette was used such that 10ml of distilled water was put in the wider arm, which could fill the upper bulb 'b' between the two marks and at the same time leaving the lower bulb 'B' about 1/3 full. The temperature of the bath was adjusted to 15°C using ice cubes and the use of a thermostat thermometer and left for 15 minutes - 20 minutes to reach thermal equilibrium. The water was then sucked through tube 'T' to a level above 'a' and given time to flow down. The time taken for the meniscus to pass from 'a' to 'c' was determined as shown in the diagram below. This was repeated three times and then averaged.

The procedure was done repetitively for the temperature 15°C to 60°C at increments of 5°C. The viscosities were determined using the equation shown below:

$$\frac{V_w}{V_s} = \frac{P_w t_w}{P_s t_s} \quad \text{Equation (1)}$$

Where V_w is the viscosity of water at the given temperature
 V_s is the viscosity of the sample at the given temperature
 P_w is the density of water at the given temperature
 P_s is the density of the sample at a given temperature

t_w is the time taken for water to run between 'a' and 'b'

t_s is the time taken for fuel sample to run between 'a' and 'b'

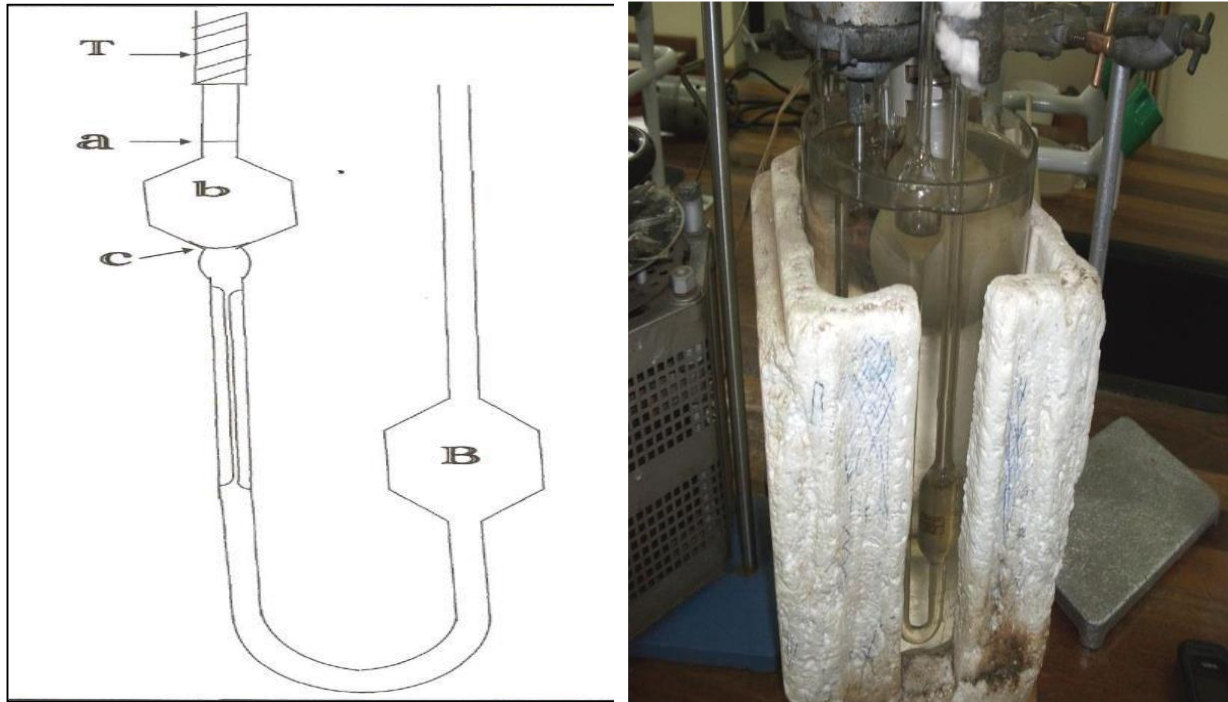


Figure 3-2: Drawing (left) and Picture (right) of an Ostwald Viscometer.

3.4 Calorific value (heating value)

The calorific value procedure was determined in a bomb calorimeter shown in figure below in the university of Nairobi laboratories as follows. The empty capsule was weighed using optical beam balance and its mass recorded. The capsule was filled with oil then reweighed and the mass of the oil determined by subtracting the mass of the empty capsule. Into the cooling jacket of the calorimeter 1.7litres of water was measured. The capsule with the oil was put on the crucible and placed in the firing apparatus of the calorimeter. The bomb stirrer turned on. The temperature readings were taken at intervals of one minute for five minutes to make sure that the temperatures of the bomb were stable and then the bomb was fired. Temperatures were taken at intervals of half a minute for the entire range of the temperature rise and at one-minute interval for five minutes after temperatures started to drop.



Figure 3-3: Constant –volume bomb calorimeter

3.5 Flash point

This was carried out in the laboratories of KIRDI. The test cup was carefully cleaned and dried. Toluene and acetone were used to clean and dry the test cup and its cover. Taking into consideration the volume capacity of the test cup, the cup was filled with a sample fuel to the mark. Excess fuel added to the cup was gotten rid of by the use of a syringe. The cover was used to cover the sample cup and the apparatus assembled. The locking device was ensured to be properly engaged and a thermometer was inserted to its holder.

Adjustments on the intensity of electrical igniter were done according to the instructions on the manufactures manual after the electric igniter was switched on. In case of lighting test flame the diameter had to be adjusted to about 3.2mm to 4.8mm. Safety measures were practiced to prevent abnormally strong flashes during the first applied ignition, these situations normally occur with low flash like fuels. The heat applied was such that the temperature increase rate was in a range of 5 to 6 degree per minute, as shown by the thermometer; the stirrer was then turned occasionally, stirring in a circular manner. The fuel in the testing cup was brought to a temperature of $15 \pm 5^{\circ}\text{C}$ to ensure that the flashing point was accurately determined. The temperature at the time at which the fuel ignited or produced a flash in the test cup was recorded the test was repeated three times each time with fresh fuel being put in the cup and an average for the results attained. The above experiment was repeated for all the test fuels samples with all safety precautions being followed.

3.6 Iodine value

The weight of 0.5ml of the oil sample was weighed accurately into a 250ml Erlenmeyer flask and 20ml of carbon tetrachloride was added into the flask. To the mixture 25ml of Wijs reagent was pipetted into it. The flask was stoppered, the contents mixed by swirling and placed in a dark room temperature for a period of thirty minutes. After the 30minutes, 10ml of the solution of 30% potassium iodide was added to the sample solution followed by 100ml of purified water. The contents were immediately titrated with standard 0.1M sodium thiosulfate solution until the yellow color almost disappeared. To continue the titration 1ml of 1% starch indicator was added and swirling was done until the blue color vanished. This was repeated for the blank where the flask contained all the chemicals except the oil sample.

The Iodine value was calculated using the expression below;

$$\text{Iodine value} = \frac{\text{Blank titre (ml)} - \text{Sample titre(ml)} \times 1.269}{\text{Weight of sample(g)}} \quad \text{Equation 2}$$

3.7 Acid number / value

A dry conical flask was weighed and 1ml of the oil sample was measured into it. The weight of sample oil and the conical flask was recorded. To the oil in the flask 10ml of isopropyl alcohol was added and the mixture warmed. Using 2 drops of 1% phenolphthalein solution, the mixture was carefully titrated using 0.1M potassium hydroxide solution while shaking constantly until a persistent pink colour was obtained for 15 seconds. The acid value was calculated using the following equation

$$AN = (V_{eq} - b_{eq})N \frac{56.1}{W_{oil}} \quad \text{Equation (3)}$$

Where

V_{eq} = amount of KOH (ml) consumed by the oil sample at the equivalent point

b_{eq} = amount of KOH consumed by the blank sample

N = concentration of KOH

W_{oil} = mass of the oil sample used

The molecular mass of KOH is 56.1gm

3.8 Specific Gravity

A 10ml capacity empty density bottle was cleaned and dried in the oven and weighed using an optical beam balance and its mass recorded. The bottle was filled with distilled water to brim over and corked, the excess water escaped through the hole in the cork and what remained was exactly 10ml. The bottle was immersed in the water bath and remained in the bath for 15-20 minutes to attain uniform temperature. The test temperatures investigated were from 15 to 60°C at an increment of 5°C. It was then removed and dried of any water on its surface and reweighed, from which the mass of water was determined by subtracting the mass of the empty bottle. This process was done for all temperatures. The fuels under study were tested using the same method as the distilled water and their masses at different temperatures were determined and recorded.

The relative density was calculated from the relation;

$$\rho = \frac{M_{oil}}{M_{water}} \quad \text{Equation (4)}$$

Where

ρ = Density

M_{oil} = Mass of oil

M_{water} = Mass of Water

3.9 Water boiling test

The Water Boiling Tests (WBT) with ambient emissions were carried out at the Kenya Industrial Research and Development Institute (KIRDI) Stoves Center Laboratories and were conducted on the cooking Stoves running on pure kerosene or kerosene blends with Jatropha oil. These tests were done according to WBT version 4.2.4 Methodology. The reported values were average for each phase which were the cold start phase, hot start phase and simmering phase

3.10 Emission testing

The emissions were carried out in a typical kitchen environment. The kitchen dimensions were as follows: -

Height-8.3ft -Width-9.5ft -Length -11.3ft

Windows: - W1-Height-2.2ft; -Width-2.8ft; W2-Height-2.8ft -Width-2.1ft

Doors: - D1-Height-6.6ft -Width-2.92ft; D2-Height-6.6ft-Width-4.8ft.

This test was performed using a CO meter and a PM meter. A hobo logger was launched for 14 days of monitoring taking a reading every hour.

A set up of how the hobo meter is as shown in the photos below;



Figure 3-4: Pictures of a CO hobo meter (left) and of a particulate matter meter (right).

3.11 Carbon monoxide (CO)

Ambient concentrations of Carbon monoxide emissions were measured 1 meter away and 1 meter above the stove. Real-time measurements of CO were taken using a TSI IAQ-CALC 7545 as shown in (figure 3-4 left), The TSI IAQ-CALCs were calibrated immediately before deployment with NIST traceable zero and span gases, and again following deployment to check for any potential changes in response. The reported values were average for each phase.

3.12 Particulate Matter P.M_{2.5}

The Particulate Matter (P.M_{2.5}) are particles suspended in the air and with an aerodynamic diameter of less than 2.5 micrometers, were monitored with UCB Particle and Temperature Sensor (UCB-PATs) as shown in fig 3-4 (right). UCB data logger has a detection limit of between 30 $\mu\text{g}/\text{m}^3$ - 25,000 $\mu\text{g}/\text{m}^3$, a logging interval of between 1minute -240 minutes and a storage capacity of 32768 records.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

4.1 Oil Yield

Then oil extracted the seeds from Mpeketoni, Lamu County gave 8.5 liters of fuel. This translated to 42.5% (v/w) oil yield per total weight of the seeds. An oil press was used because no conventional refinery process was needed (degumming, deacidification, bleaching and deodorisation).

In studies done before other vegetable oils such as rape seed and sunflower are also considered as straight vegetable oils had yields of 40.6 and 42.8 respectively with the seeds having a moisture content of 6.2 and 6.7%, Jatropha seeds in a study done at Nhacra Oio region of Guinea- Bissau had a 35.2 % oil yield with a moisture content of 8.6. This region usually has an annual rainfall of about 430mm (Baldini et al. 2014). The difference in yield could be attributed to different ecological zones receiving different annual rainfall amounts. Tana delta region receives and approximate amount of 370mm. Post handling of the seeds after harvest could also contribute to the difference in percentage yield of the oil.

4.2 Physicochemical Properties of Fuel blends

The oil blends that were prepared had different proportions of oils and were given different names depending on the content in the blend as shown on table 4-1 below.

Table 4-1: Types of blend names of fuel used.

Types of blend names used	Content of the blend type
Blend 5	5% Jatropha+ 95% Kerosene fuel
Blend 10	10% Jatropha + 90% Kerosene fuel
Blend 20	20% Jatropha + 80% Kerosene fuel
Blend 100	Pure Jatropha
K100	Pure Kerosene

4.3 Iodine value

The following table shows the values obtained for the fuel. The iodine value of oils shows the stability of the oils, presence of instability causes formation of gums and sediments. From research done the accepted iodine values for standard biodiesel should be less than 115 mg/Kg (Annon, 2003)

Table 4-2: The iodine value of different oils and oil blends

Fuel type	Iodine average value
Jatropha oil	112.69mg/Kg
Kerosene	0.1238mg/Kg
Blend 5	0.7901mg/Kg
Blend 10	0.9867mg/Kg
Blend 20	1.3466mg/Kg

Neat Jatropha oil has an average iodine value of 112.69mg/kg which is almost similar to the accepted biodiesel iodine value this just says that Jatropha oil is a fairly stable oil and therefore making a fuel blend can be made out of it.

4.4 Specific gravity

The specific gravity of the test fuels at each temperature was determined as the ratio of the mass to that of water at the same temperature. The results are presented in table below.

Table 4-1: Specific gravity for pure Jatropha oil, Kerosene and their resultant blends

Temp. °C	Jatropha	Kerosene	Blend 5	Blend 10	Blend 20
15	27.6770	2.4563	10.7895	12.8964	14.8710
20	24.6780	2.0097	9.8790	11.7642	13.2234
25	20.5670	1.7863	7.7890	9.8566	12.3475
30	18.6547	1.65432	7.4563	8.4555	10.9985
35	16.3456	1.45321	6.8945	7.4533	9.3442
40	14.3546	0.8673	5.4332	6.3330	8.2310
45	11.0987	0.8633	3.8973	6.2310	7.4532
50	9.4537	0.8605	3.0020	5.9342	6.7844
55	6.8970	0.8589	2.8976	3.9877	4.9876
60	5.5678	0.8572	2.7653	3.5670	3.4675

From the results in table above graph of specific gravity against temperature for pure *Jatropha* oils, pure Kerosene and blends was obtained as shown on figure below

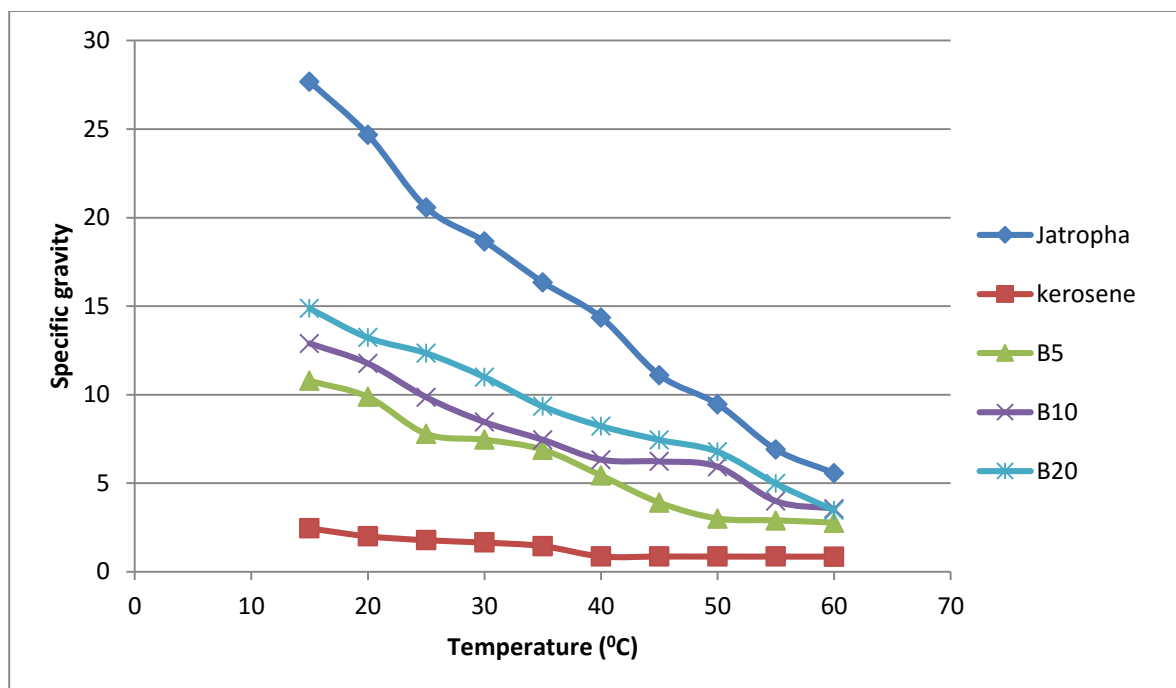


Figure 4-1: Variation of specific gravity with temperature of blends, *Jatropha* and Kerosene

From figure 4-1 above, it can be observed that the specific gravity for both blends, *Jatropha* and Kerosene decreased as the temperatures increased from 15°C to 60°C. At 15°C the specific gravity of *Jatropha* and Kerosene was 27.6770 and 2.4563 respectively. Since *Jatropha* is very viscous it can be observed that at the same temperature of 15°C the specific gravity of *Jatropha* was higher than that of kerosene. During blending the specific gravity of the blends decreased significantly with an increase in the amount of *Jatropha* in the blend.

At 15°C the Blend 5, Blend 10 and Blend 20 had a specific gravity of 10.7895, 12.8964 and 14.8710 respectively, these results are tending towards *Jatropha*'s specific gravity than those of Kerosene.

From this results it can be seen that it averagely took a long time for water to boil when the fuel blends were used unlike when Kerosene was used alone as it took a longer time for the fuel blend to go up the weak stoves due to its reduced specific gravity unlike that of kerosene. (Mogire, 2013) noted that the specific gravities of the blends increased with percentage of *Jatropha* methyl esters (biodiesel) in the blend at all temperatures and decreased with increase in temperature for all the tested fuels.

4.5 Kinematic Viscosity

Viscosity can best be explained as the measure of resistance of a fluid which is being deformed by either shear stress or tensile stress. In table 4-3 and Figure 4-2 below, is data and plot of viscosities of kerosene Jatropa blends; These plots were used as a calibration curve to find out the extent of adulteration in kerosene on the basis of viscosity. The kinematic viscosities of the different oils attained were tabulated below.

Table 4-2: Kinematic Viscosities of Jatropa Curcas, Kerosene and Kerosene blends

Temp. °C	Jatropa	Kerosene	Blend 5	Blend 10	Blend 20
15	90.4567	8.7109	30.0000	65.7824	70.4320
20	70.5670	7.5779	28.4560	51.4076	57.2255
25	60.2345	6.1085	24.5433	38.9413	44.0275
30	57.8940	5.6871	21.5670	30.0174	34.9027
35	46.7893	4.9047	20.9876	25.5966	27.8424
40	42.7685	4.5711	18.4560	20.4544	23.9447
45	40.6789	3.9579	16.8790	17.1073	19.7247
50	38.2345	2.8544	12.6750	13.9177	16.0490
55	32.6784	2.5921	9.3567	9.57860	11.9372
60	28.4594	2.2863	7.8923	8.3983	10.1339

From figure 4-2 below, the viscosity of the fuel blends showed a decrease with an increase in temperature from 15°C to 60°C. From table 4-3 at 15°C the Kinematic viscosity of Jatropa oil and Kerosene were 90.4567 and 8.7109 respectively. In comparison with Jatropa oil the Kinematic viscosity decreased significantly after blending. At 15°C the Blend 5, Blend 10 and Blend 20 had a Kinematic viscosity of 30.0000, 65.7824 and 70.432 respectively.

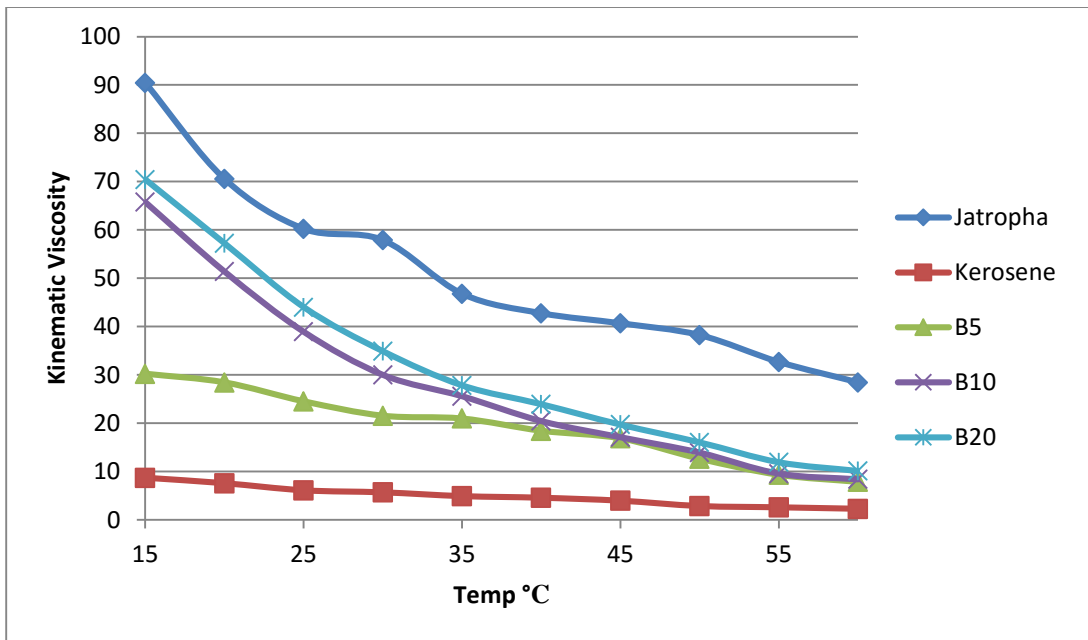


Figure 4-2: Variation of Kinematic viscosity with temperature of blends and Kerosene

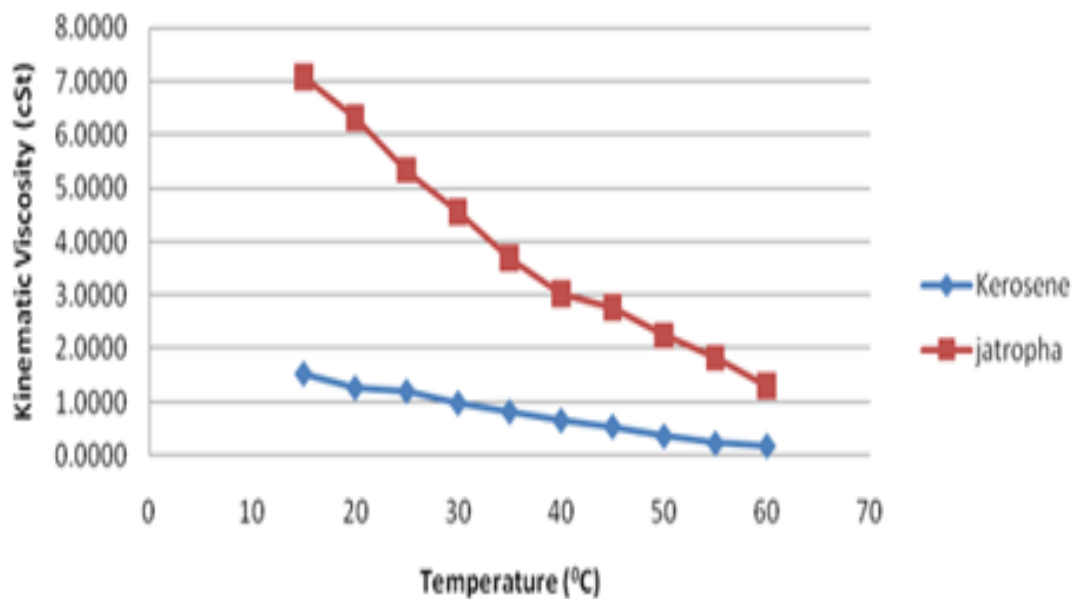


Figure 4-3: Variation of kinematic viscosity with temperature of Jatropha and Kerosene

Kinematic viscosity shows the ability of the fuel to flow, in figure 4-3 the rate of flowing of kerosene and Jatropha oil increases with increase in temperature despite the fact that Kerosene and Jatropha oils have different calorific values. This explains the short time it took for cooking

during the hot stage phase as the temperature of the fuel in the tank of the stove had changed from room temperature due to continuous cooking.

4.6 lighting time, calorific values, acid value and flash point.

These results were found after different test were performed, during the set up a number of parameters are measured the time it took for the lamp to light until the fuel was consumed, the amount of heat that was produced during the cooking process in the water boiling test, the safety of the oil in terms of its acidity and the safety of the oil in terms of its ability to explored.

Table 4-3: Comparison of lighting time, Calorific value, acid value and flash point

	Lighting time(minutes)	Calorific value (MJ/KG)	Flash point (°C)	Acid value mgKOH/g
B5	31.7±0.37 c	41.8±0.26 d	49.7±0.17 b	0.314±0.006b
B10	25.8±0.32 b	39.5±0.42 c	51.8±0.17 c	0.725±0.011c
B20	21.1±0.26 a	37.4±0.03 b	55.1±0.06 d	0.966±0.038d
Kerosene	72.1±0.85 d	46.2±0.15 e	37±0 a	0.095±0.008a
Jatropha		36.2±0.13 a	145.2±0.62 e	2.904±0.029e
LSD	1.5	0.75	0.94	0.0701
p value	<.001	<.001	<.001	<.001
CV%	4	1	0.8	3.9

There was a significant variation in duration, the fuel kept lighting among the four fuel types that lit ($p < 0.001$) except for Jatropha, which did not light. All the four fuel types that lit had a significant variation among each other in the time they sustained lighting with Kerosene lighting the longest, followed by B5 and B10 respectively with B20 lighting for the shortest time.

There was also a significant variation in calorific value among the 5 fuels ($p < 0.001$). Kerosene recorded the highest calorific value (46.2MJ/kg), followed by B5 (41.8MJ/kg), B10 (39.5MJ/kg) and B20 (37.4MJ/kg) respectively. Jatropha recorded the lowest calorific value (36.2MJ/kg). The calorific value of biodiesel made from Jatropha oil is 37.27MJ/Kg as found by Elsayed et al 2003. The calorific value of Jatropha found in the current study compares to the one in the previous study and the slight variation could be due to the processing of the oil to biodiesel. This explains the varied time it took to boil the same amount of water during the water boiling test.

Flash point temperature was significantly different among the fuel types ($p < 0.001$). In general Blend 5, Blend 10 and Blend 20 had flash points that had a range between diesel and gasoline. Studies done showed that bioethanol had a significant flashing point that was between diesel and gasoline (Battelle, 1998). Mean separations revealed that this variation in flash point temperature was significantly among all the 5 fuel types. Kerosene had the lowest flash point temperature (37°C) followed by Blend 5, Blend 10 and Blend 20; Jatropha oil had the highest flash point temperature (145.2°C) however previous studies done on biodiesel from Jatropha showed a flash point of (> 130) From these results it can be explained why Jatropha oil cannot light on its own.

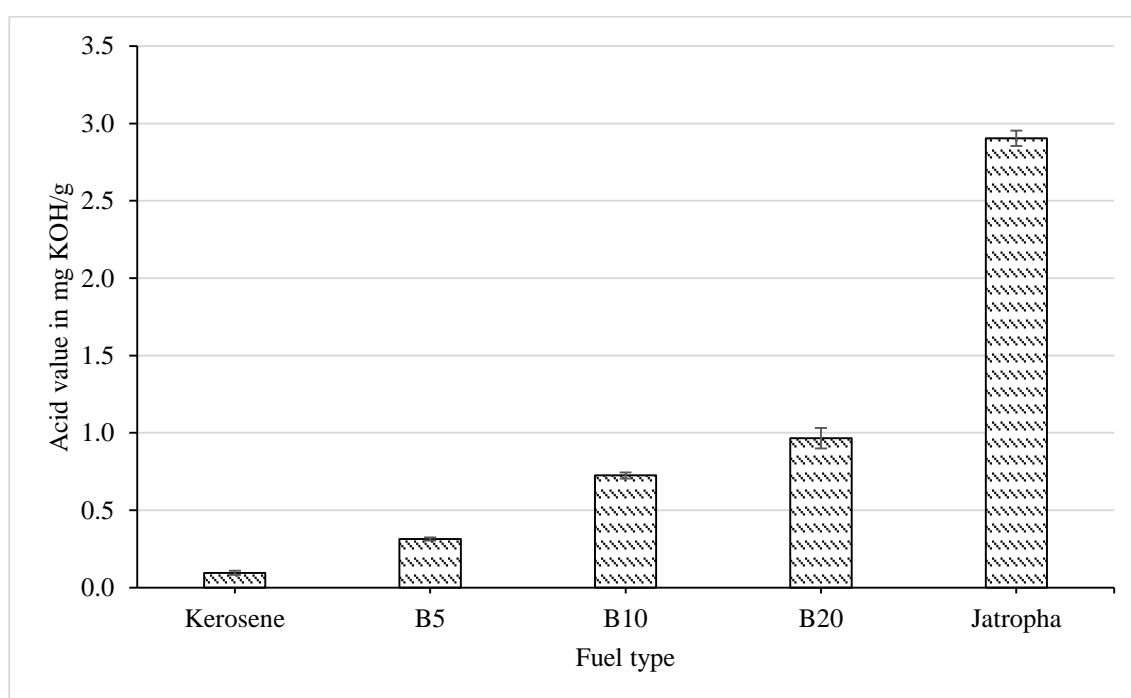


Figure 4-4: Graph of acid value for all the five fuels

Variation in acid value was significantly different among the fuels ($p < 0.001$). Like other parameters this variation was significantly different between all the fuel types. Kerosene recorded the lowest acid value while B5, B10 and B20 followed in that order. Jatropha had the least acid value and it was within the literature limits for Jatropha of a range of $0.92 - 6.16\text{mgKOH/g}$, this translates to the fuel blends being safe for use in the ordinary stoves and lamps since no corrosion is expected from the fuel. The flash point for Jatropha oil was found to be the highest at 145.2°C but this is slightly lower than the ASTM standard value of 150°C , the Kerosene flash point was found to be 37°C which fall within the range of $40-60^{\circ}\text{C}$.

4.7 Boiling water test

Generally, to demonstrate the suitability and potential of fuel blends for cooking with an aim of targeting the liquid fuel stoves in the market, the water boiling test was conducted. The results showed the fuel blends initially started with a yellow flame and soot that was black in color deposited (carbon deposits) at the bottom of the Sufuria then the flame became blue burning without smoke.

However, when Kerosene was used it burnt with a strong pungent smell while depositing black soot (carbon deposits) on the bottom surface of the Sufuria. The mean results on different stove parameters attained at the end of the three water boiling test phases were tabulated below.

4.7.1 Cold start phase

The performance of the stoves varied depending on the fuel properties: The capillary action which draws fuel through the wick fibers was quicker (more efficient) than those from less viscous fuels. Kerosene had an average viscosity of 8.7109; the time to boil for Kerosene was 18 ± 0 min. The time to boil water for blend 5 and blend 10 boil was 25.6 ± 0.5 min and 34.3 ± 0.5 min respectively. The rates of burning for the Blend 5 and Blend 20 fuels were 1.6 ± 0.1 and 1.3 ± 0.1 respectively. The calorific values for Kerosene, Blend 5, Blend 10 and Blend 20 are as follows 42.31 ± 0.8 MJ/Kg, 39.04 ± 0.09 MJ /Kg and 37.32 MJ/Kg ± 0.72 and respectively and hence they took a longer time respectively to boil an equal volume of water. (Table 4-1)

Table 4-4: Mean indicators for the stove's performance for cold start phase (Cook and light stove)

Cold start (used high power)	Unit	Jatropha	Kerosene	Blend 5	Blend 10	Blend 20
Time to boil.	Min	Could not light.	18.0 ± 0.0	25.6 ± 0.5	34.3 ± 0.5	48.6 ± 0.5
Fuel consumed	g	None	23.6 ± 0.5	42.0 ± 0.5	45.3 ± 0.5	53.0 ± 0.1
Burning rate	g/min	N/A	2.1 ± 0.1	1.6 ± 0.1	1.3 ± 0.1	1.2 ± 0.1
Thermal efficiency	%	N/A	$48.0\% \pm 0.6$	$46.0\% \pm 0.6$	$45.0\% \pm 0.6$	$43.0\% \pm 0.6$
Specific fuel consumption	g/liter	N/A	47 ± 0.5	45.6 ± 0.5	44.6 ± 0.5	42 ± 0.5
Evaporation rate	g/min	N/A	18.6 ± 0.5	14.3 ± 0.5	11.3 ± 0.5	9.4 ± 0.1
Fire power	Watt	N/A	1373.6 ± 1.2	1313.6 ± 0.5	1263.3 ± 0.5	1213.6 ± 2.1

The specific fuel consumed and fire powers were affected by the fuel's heating value and viscosity. When Kerosene was used in the stove, its fuel consumption was less and a shorter time was used to bring the water to boil this was attributed by kerosene's low viscosity and high energy content. The heat transfer efficiency of all the three blends was found to be in the same range (43% to 46%) which is similar to that of kerosene that is 48%

Kerosene fuel took the least time to boil the water 18 ± 0 minutes, consuming almost 50% and this gave the highest power output of 1.4kW during this phase. The fire power for the fuel blends were in the range (1.0 -1.3kW). The fire power from the blend in comparison to that of ethanol studied by Debebe 2005 which was 1.5kW are almost similar with a difference of 0.2 kW.

4.7.2 Stove performance during hot start phase

From table 4-6 below the mean results of different parameters obtained during the hot start for kerosene and the fuel blend had less time ranging between 2 to 3minutes to boil the same amount of water in comparison to the cold start and as a result there was an increase in power output of between 4 to 6 % .The increase in power output and reduced time to boil can be said to have been attributed by the slightly higher temperatures of the fuel in the tank than the room temperature as a result of the previous cooking process

Table 4-5: Mean stove performance during hot start phase

Low power test (hot start)	Units	Jatropha	Kerosene	Blend 5	Blend 10	Blend 20
Time to boil.	Min	None	22.7 ± 0.6	45.0 ± 0	43.6 ± 0.5	45.3 ± 0.5
Fuel consumed	G	None	11.3 ± 1	57.16 ± 0.6	60.6 ± 1.15	62.3 ± 0.5
Burning rate	g/min	None	1.6 ± 1.7	1.52 ± 0.07	2.0 ± 0.5	2.4 ± 1.7
Thermal efficiency	%	N/A	$41.0\% \pm 0.5$	$44.0\% \pm 1.0$	$43.6\% \pm 0.5$	$44.6\% \pm 0.5$
Specific fuel consumption	g/liter	N/A	112.0 ± 0.5	124.0 ± 1.0	125.0 ± 0.5	128.0 ± 0.5
Evaporation rate	g/min	N/A	21.6 ± 0.5	16.0 ± 0.5	15.0 ± 0.5	13.0 ± 0.5
Fire power	Watt	N/A	911.3 ± 3.2	905.3 ± 0.5	905.0 ± 0.0	904.0 ± 0.0

The slight heat from the previous cooking that warms up the fuels increases the flash point and lowers its viscosity therefore increasing the capillary action on the wicks thereby increasing the ease of burning. The heat transfer efficiency remained more or less the same as in cold start.

4.7.3 Stove performance during Simmering phase

The goal of this cooking phase is to maintain the boiling water at boiling point temperatures while using the least power output from the stove. The amount of energy required to maintain the water at simmering phase that is 3 to 4 degrees below its boiling temperature seemed to remain the same for all the fuels used. The efficiency for all the fuels remained relatively the same within the range of 41 to 43 %, meaning the more the amount of Jatropha in the fuel the lower the flow ability of the blend hence for tasks that require to be cooked in low heat then the fuel blends perform the task well just like in kerosene

The time to boil for the three blends was ranging between 22.7 ± 0.6 min and 45 ± 0.5 min respectively with their calorific value being 46.2 ± 0.15 MJ/Kg for kerosene which was the highest, 41.81 ± 0.26 MJ/Kg for blend 5. Other fuel blends (blend 10 and blend 20) had calorific ranges of 39.5 ± 0.42 MJ /Kg and 37.4 ± 0.03 MJ/kg respectively and hence they took a longer time of (34.3 ± 0.5 and 48.6 ± 0.5 minutes) respectively to boil an equal volume of water. Jatropha recorded the lowest calorific value (36.2 ± 0.13 MJ/kg) and it could not burn on its own.

Low viscosity and high energy content for kerosene fuel resulted in less fuel consumption and a shorter time to boil.

4.8 Emissions

The emissions produced during the cooking process was measured during the water boiling test, the emissions were carbon monoxide and particulate matter (P.M_{2.5}) were measured using a carbon monoxide meter (CO hobo meter) and a particulate matter meter. The results of carbon monoxide emission from the four fuel blends are as shown on table 4-7 below.

4.8.1 Carbon monoxide emission

Table 4-6: Carbon monoxide emission rate from 4 biofuels across time

Time in minutes	Cumulative CO concentration in ppm			
	5%	10%	20%	Kerosene
0	0	23.5	23.5	0
10	0	144.5	144.5	0
20	0	219.0	219.0	0
30	3.5	266.0	266.0	10.5
40	3.5	313.0	313.0	10.5
50	8.0	365.0	364.0	22.6
60	8.0	383.0	382.0	22.6
70	101.5	396.0	395.0	118.1
80	300.5	405.5	404.5	318.1
90	463.5	405.5	404.5	482.1
100	583.0	405.5	404.5	603.1
110	659.5	405.5	404.5	682.6
120	713.0	405.5	404.5	740.1
128	719.0	405.5	404.5	750.1

The minimum amounts of Carbon monoxide concentration within the first one hour for blend 5 and Kerosene were in the range of between 3ppm to 22.6ppm respectively, these results agree with the laboratory results of (Hanoune, 2014) although his results for the highest range was 13ppm slightly lower than the attained of 22.6ppm.

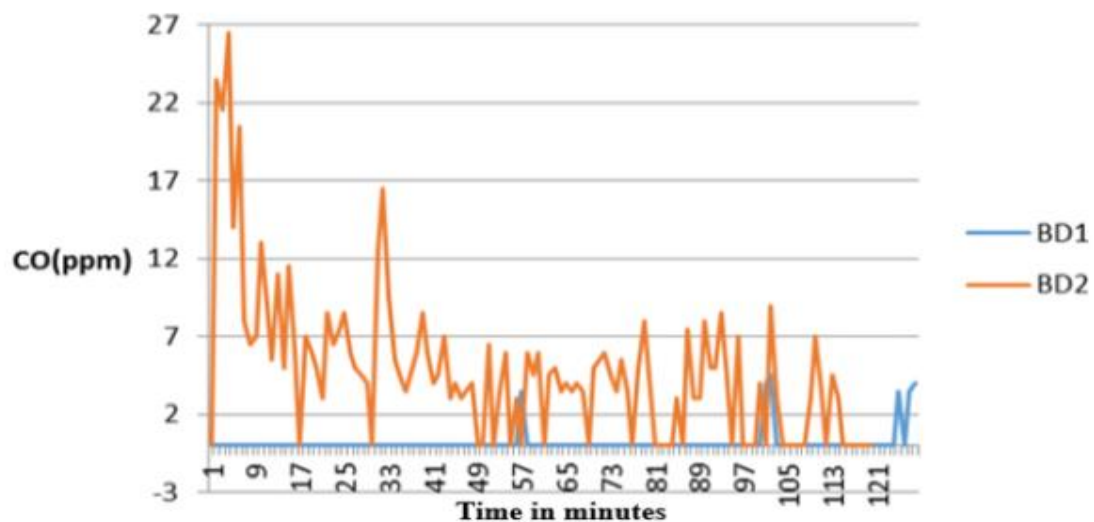


Figure 4-5: Average concentration of amount of Carbon monoxide during cold start versus time

From the figure 4-5 above BD1 is Carbon monoxide emission for Blend 5 for the cold start process of the water boiling test while BD2 is the Carbon monoxide emissions for blend 10 for the cold start phase. The slightly higher amounts of Carbon monoxide in this study can be attributed to the incomplete combustion and this is due to deposit of gum on the wick stove however these range of results obtained for Blend 5 and Kerosene falls within the short-term range value stipulated by WHO indoor air guide line value of 30ppm (WHO, 2010). After an hour the concentration of Carbon monoxide for Blend 5 and kerosene increased with time.

Blend 10 had a minimum Carbon monoxide concentration of 23.5ppm however the concentrations increased with time to a maximum level within an hour of 383 ppm. The increase in the amount of Carbon monoxide is attributed to the increase in Jatropha oil volume concentration increasing the amount of gum deposits which causes incomplete combustion that forms soot on the surface of the cooking pot.

Studies reported previously in dwellings using Kerosene for cooking showed a Carbon monoxide concentration of 100ppm (Amitai et al., 1998). This amount is expected to be lower for blend 10 with an assumption that the higher the concentration of Jatropha oil in the blend the cleaner it would burn but with presence of gum deposits on the wicks then a film is formed on the wicks causing incomplete combustion resulting to high amounts of Carbon monoxide during combustion. The same result is also duplicated in the blend 20 fuel with the same reasoning only that this time the Carbon monoxide is even higher because of the increase in concentration of the Jatropha oil in the blend.

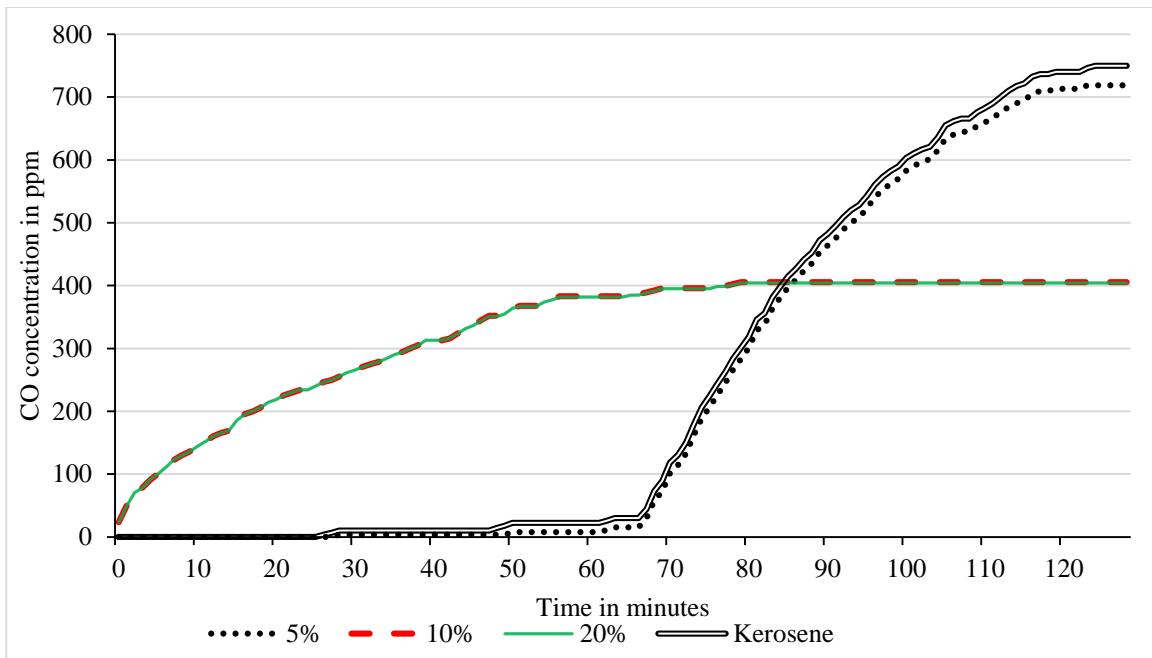


Figure 4-6: Carbon monoxide emission rate from three biofuels in comparison with kerosene across time

Figure 4-6 shows the Carbon monoxide emissions during a given time period of cooking and from the graph it can well be seen that Blend 5 and kerosene almost had a similar pattern of emission where the amounts were little in the first 50 minutes and it later increased to very high levels from the 65-minute level and above. Those for Blend 10 and Blend 20 were almost similar too, they recorded very high concentrations during the first 50 minutes and started being constant at high levels from the 65 minutes.

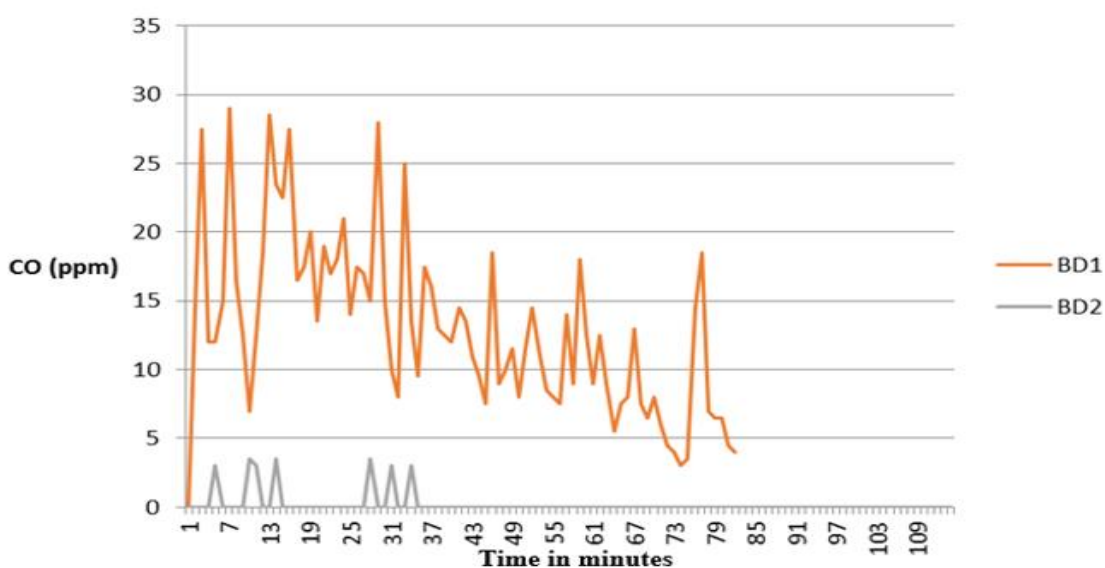


Figure 4-7: Average concentration of Carbon monoxide during hot start versus time.

Figure 4-7 shows the graph of amounts of Carbon monoxide generated during the hot start testing, from the figure the processing of cooking had already started for 30 minutes, the cooking stopped and new cold water was weighed and put on the already hot stove. Here the amount of Carbon monoxide remained high during the hot start process for Blend 5 fuel while it was relatively low for the Blend 10 fuel and the reason for this was because of gum deposits on the wick and the stove was about to go off.

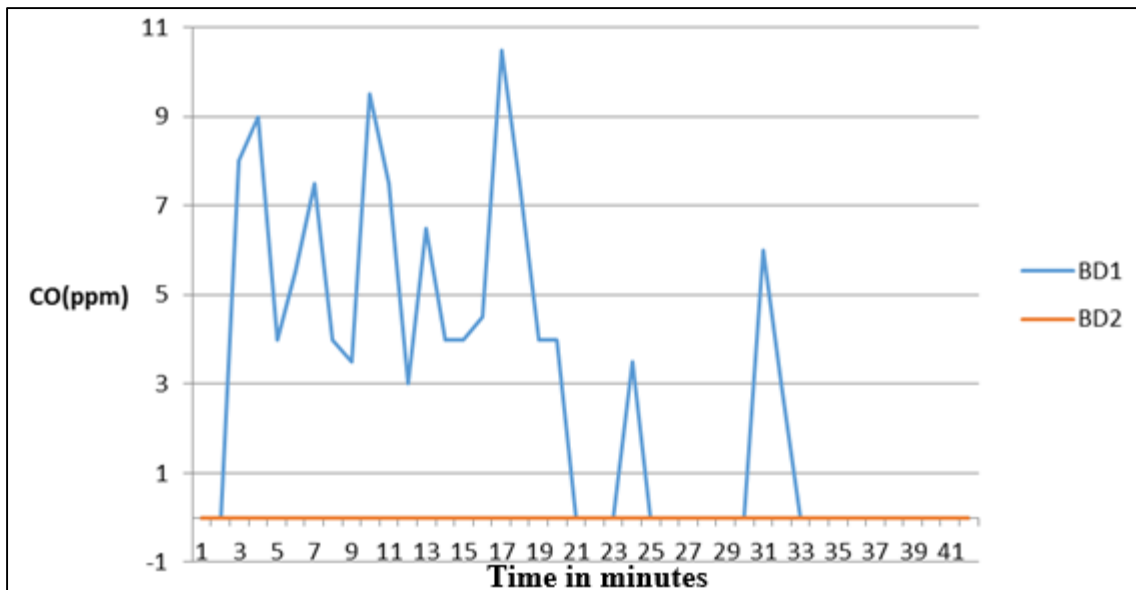


Figure 4-8: Average concentration of Carbon monoxide during simmer phase versus time

Figure 4-8 are graphs of the amount of Carbon monoxide emitted during the simmering stage, in the simmering stage the water in the hot stage is allowed to boil for a period of thirty minutes as the amount of emissions are measured. Blend 5 fuel shows random records of high and low amounts of Carbon monoxide emission with high picks being more than the low peaks. Blend 10 shows a standard amount of Carbon monoxide emission and this is because the stove was burning with very little fire output as the wicks looked like they were going off.

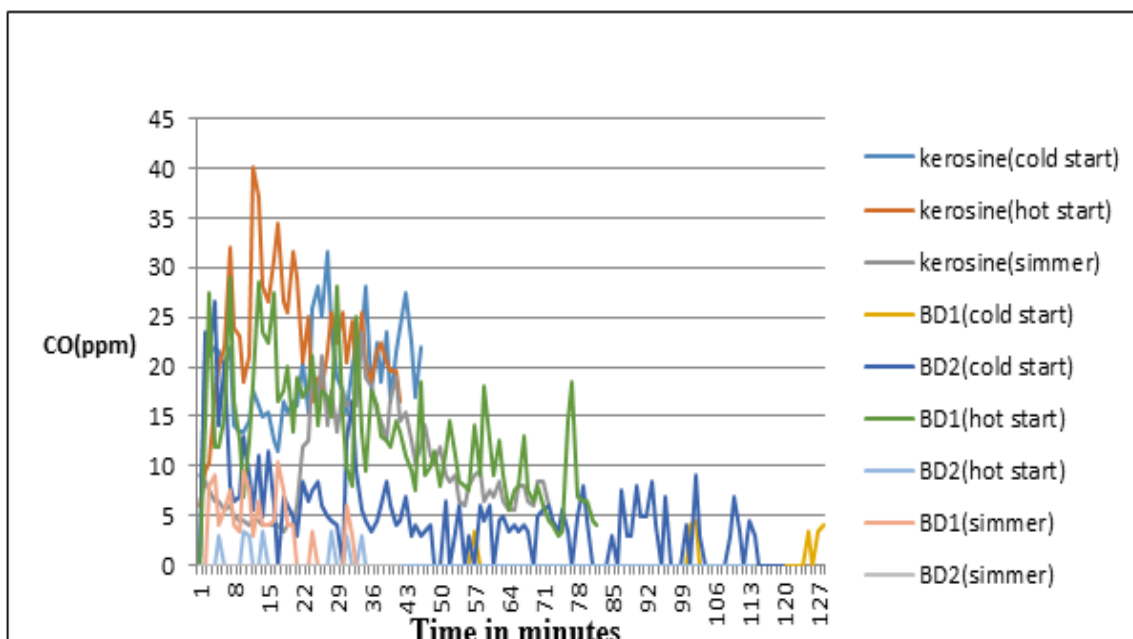


Figure 4-9: Concentration of Carbon monoxide in kerosene and the blends during the three phases.

4.8.2 Particulate matter P.M_{2.5}

Particulate matter are particles that are released during the cooking process and they have a diameter of 2.5 micrometers or smaller, some have bigger sizes but of interest are those of a diameter of 2.5 micrometer because this size affects the bronchial system of human beings. The amount of particulate matter that was measured during the cooking process are tabulated as shown on table 4-8 below.

Table 4-7: Comparison of average particulate matter in $\mu\text{g m}^{-3}$

Fuel type	Cold start	Hot start	Simmering stage
Blend 5	10.825	8.423	8.424
Blend 10	9.454	8.475	8.424
Blend 20	10.878	8.428	8.422
Kerosene	71.821	63.780	62.811

Particulate matter P.M_{2.5} main source is believed to be produced by lamps and stoves that use Kerosene; other sources of particles within a range of between 0.3 μm to 0.5 μm are also produced by other sources and could appear as black carbon deposits on surfaces. The maximum

permissible value for a one-hour exposure time level is $29.3\mu\text{g m}^{-3}$ with an average of $7.3\mu\text{g m}^{-3}$. The WHO chronic guide lines permit low exposure levels of below $10\mu\text{g m}^{-3}$

From the study the amount of average particulate matter during the cold start, hot start and simmering stage of Blend 5, Blend 10 and blend 20 were found to be below the accepted amounts of $7.3\mu\text{g m}^{-3}$. Kerosene on the other had high levels ranging between $62.81\mu\text{g m}^{-3}$ and $71.82\mu\text{g m}^{-3}$

This study can therefore be compared to previous studies (Mumford et al., 1991; Leaderer et al., 1999; Ruiz et al., 2010; Hanoune and Carteret, 2014) and any differences noticed can be due to the different sizes of kitchen in the world, that have different ventilations, the studies showed the use of kerosene devices increased the indoor P.M_{2.5} by approximately $40\mu\text{g m}^{-3}$

This result can justify that the use of biofuels can aid in the reduction of global warming because there is a partial reduction of the amount of particulate matter (P.M_{2.5}) being released in the environment when a blend of Jatropha is used in making a fuel to when a fossil fuel that is Kerosene is used in its neat form

5 CONCLUSIONS

The main objective of this project was to establish the utility of liquid biofuels and their kerosene blends for cooking on existing stoves. The biofuel oil used was from the plant *Jatropha Curcas* from Mpeketoni, Lamu county which was extracted mechanically using an oil press and the oil yield determined was found to be 42.5%(v/w), this compared to those of rape seed oil 40.6%(v/w) and sunflower oil 42.8%(v/w) that were extracted using a similar process in other studies. Research done in Guinea – Bissau *Jatropha* seeds had a yield of 35.2 %(v/w) and this difference can be due to different ecological zones receiving different annual rainfall amounts.

The kerosene was blended with *Jatropha* oil in volumetric percentages between the ratios of 0 to 100%. The best blends were found to be Blend 5, Blend 10 and Blend 20. These best blend fuels were found to be lighting. Blend 5 gave the optimum value with an approximate average time period (31.7 minutes) which is approximately half the time (72.1 minutes) it took for neat kerosene of a similar amount however neat *Jatropha* oil did not light.

An increase in the percentage of *Jatropha* oil in the blend reduced the kinematic viscosity of the fuel blend hence a reduction in the time it took to light. Another disadvantage that may have been experienced in the fuel blend is the formation of a film of gum deposits on the wick stoves therefore preventing complete combustion or just simple combustion making the lighting time to reduce with an increase in the amount of *Jatropha* in the oil blend.

The caloric values of the three fuel blends were found to be within a range as that of biodiesel in previous work done of (37.27MJ/kg) and Kerosene (47.02MJ/Kg). Blend 5 had a value of 41.8 MJ/Kg this was much closer to that of the kerosene that was being used whose value was 46.2 MJ/Kg on the other had the neat *Jatropha* oil had a calorific value of 36.2 MJ/Kg almost similar to that attained by Elsayed et al., 2003 of 37.27 MJ/Kg

The flash point temperatures of the oil blends were significantly different with Blend 5 having the lowest figure of 49.7°C among the three blends and this can be concluded to the fact that an increase in the amount of *Jatropha* in the oil blend increased the flashing point. This could be an advantage

because it makes the fuel blend safe to use on the normal wick stove as chances of exploding are reduced. Kerosene had the lowest flash point figure of 37°C while Jatropha oil had the highest figure of 145.2°C.

The acid values of the three best blends were found to be high with blend 20 having the highest amount of 0.966mgKOH/g. Kerosene had an acid value of 0.095mgKOH/g with Jatropha having an acid value of 2.904mgKOH/g. A high acid number translates to reduced corrosion on the fuel tank and on other moveable parts of the stove to be used

The method used to test the effectiveness of this fuel blends, was the water boiling test. The burned fuel blends had a characteristic smell emitting an average fire power of 1386 W with specific fuel consumption of 45.5 per liter of water (56% higher than that of kerosene). The heat transfer efficiency of all the three blends was found to be in the same range (43% to 46%) which is much closer to that of kerosene that is 48%. The rates of burning were ranging between 1.6 g/min and 2.1 g/min respectively for kerosene and blend 5

It can therefore be concluded that the Jatropha kerosene blends tested using the standard water boiling test showed that the best fuel blend (Blend 5) had a capacity to generate an average fire power of 1386W which is 20% lower than that of kerosene

The fuel blends showed an average specific fuel consumption of 45.5g per liter of water which was higher by 56 % compared to that of Kerosene.

The findings suggest that the blends have a greater potential as an alternative to provide an alternative source of domestic cooking and heating energy.

The minimum amounts of Carbon monoxide concentration within the first one hour for Blend 5 and Kerosene were in the range of between 3ppm to 22.6ppm respectively, the results further increased after the one-hour period this result are unlike what other studies recorded and this could be as a result of not degumming the Jatropha oil therefore presence of incomplete combustion leading to an increase in the amount of Carbon monoxide. These figures however vary from one study to the other because kitchens in different parts of the world are built with different ventilations. The study however does not a conclusive result on the amount of Carbon monoxide

effects during combustion until the Jatropha oil is degummed and there is no formation of gum deposits on the wicks

Fuel blends (biofuels) are recommended for use because when used less amounts of particulate matter were recorded in comparison to when the kerosene stove was used. The amount of Particulate Matter released during the three stages of cooking in the water boiling test for the three best blends were found to be below the accepted exposure levels of $7.3\mu\text{g m}^{-3}$ unlike that of kerosene which had elevated values within the same time period.

From the results obtained it can therefore be concluded that

The blends have a greater potential as an alternative source of domestic cooking and heating energy

1. The best fuel blends were found to be Blend 5, Blend 10 and Blend 20 with Blend 5 being the optimum blend.
2. The Blend 5 fuel blends had a characteristic smell emitting an average fire power of 1386W with a specific fuel consumption of 45.5 per liter of water. (56% higher than that of Kerosene)
3. The heat transfer efficiency of all the three blends was found to be in the same range (43% to 46%) which is much closer to that of kerosene that is 48%.
4. The rates of burning were ranging between 1.6 g/min and 2.1 g/min respectively for kerosene and blend 5
5. The amount of Carbon monoxide (CO) emitted were below the minimum accepted amounts of 30ppm in eight hours (WHO) but further increased to very high amounts.
6. The total amount of Particulate Matter (P.M_{2.5}) emitted during the cooking process were within the minimum accepted WHO values of $29.9\mu\text{g m}^{-3}$ in eight hours.

6 RECOMMENDATIONS

The following recommendation follows for the work done above

1. The pure Jatropha can further be degummed after pressing to avoid the formation of gum on the wick stoves
2. More non-edible oil seed crops available in Kenya that can be used in their straight vegetable format to be researched on to identify the optimum fuel blend that can be made for cooking.
3. More ecological regions where Jatropha Curcas is planted in Kenya to be identified and the oil yields from the seeds in this region extracted to give a better picture on the percentage yield of the Jatropha oil in arid regions in Kenya.
4. Carbon dioxide and other emissions to be tested after the oil is degummed to conclude whether the fuel blends aid in reduction of emission during cooking.
5. Different types of stoves can be used such as the pressurized stoves to check out if the burning effect will be better.

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8 APPENDICES

Appendix 1: Average retail price of selected petroleum fuels for the years 2013 -2017

Economic Survey 2018

Table 9.6: Average Retail Prices of Selected Petroleum Fuels, 2013- 2017

	Month	KSh per Litre			KSh per 13 Kg cylinder
		Motor Gasoline (Premium)	Light Diesel Oil	Illuminating Kerosene	Liquified Petroleum Gas (LPG)
2013	January	112.35	104.83	84.71	2,630.73
	March	118.41	108.21	89.39	2,662.61
	June	108.93	100.01	82.38	2,573.75
	September	114.69	106.47	86.47	2,836.67
	December	110.11	105.44	83.99	2,876.00
	Annual Average¹	113.89	105.38	83.92	2,769.24
2014	January	111.41	105.65	85.98	2,995.22
	March	114.43	105.79	84.82	3,094.16
	June	115.43	105.73	84.04	3,074.57
	September	112.46	103.28	82.55	3,111.74
	December	102.86	91.79	72.30	3,018.45
	Annual Average¹	112.75	102.99	82.46	3,062.40
2015	January	93.75	84.3	66.53	2,954.36
	March	90.34	77.16	56.71	2,629.56
	June	98.14	84.26	62.73	2,387.04
	September	103.49	80.94	53.52	2,393.85
	December	90.94	79.47	54.23	2,369.46
	Annual Average¹	94.63	80.99	57.67	2,465.44
2016	January	89.52	77.66	47.11	2,343.86
	March	86.46	66.68	43.13	2,277.48
	June	87.07	74.69	59.1	2,231.38
	September	92.28	83.42	60.08	2,029.12
	December	95.08	88.18	64.52	1,983.06
	Annual Average¹	90.22	77.83	54.68	2,154.81
2017	January	96.88	85.2	64.41	1,989.50
	February	101.14	90.22	68.15	1,976.38
	March	101.91	91.39	68.93	1,998.70
	April	99.01	89.7	65.44	2,063.95
	May	100.48	89.02	66.26	2,104.29
	June	99.68	87.95	66.04	2,112.19
	July	98.00	85.45	63.55	2,073.62
	August	96.98	86.84	64.41	2,080.10
	September	98.62	87.4	65.33	2,094.22
	October	101.09	88.43	67.12	2,140.47
	November	103.58	93.37	72.2	2,128.59
	December	105.04	93.41	72.39	2,141.46
Annual Average¹	100.20	89.03	67.02	2,075.29	

¹ Twelve months average

Source 8-1: Adopted from Economic Survey 2018, Kenya National Bureau of statistics

Appendix 2: Kerosene pump prices for 2017 from three towns Mombasa, Nairobi and Kisumu.

2017 Kerosene Pump prices			
	Mombasa	Nairobi	Kisumu
15th Jan - 14th Feb	60.60	63.44	65.39
15th Feb - 14th March	64.34	67.19	69.12
15th march- 14th April	65.11	67.96	69.89
15 th April - 14th May	61.63	64.38	66.42
15 th May - 14 th June	62.52	65.28	67.02
15 th June - 14 th July	62.29	65.05	66.98
15 th July -14 th Aug	59.83	62.56	64.51
15 th Aug - 14 th Sept	60.69	63.42	65.37
15 th Sep -14 th Oct	61.63	64.36	66.30
15 th Oct - 14 th Nov	63.42	66.18	68.11
15 th Nov -14 th Dec	68.46	71.23	73.15

Source 8-2: Adopted from Energy regulatory commision, Kenya.

Appendix 3: Kerosene pump prices for 2016 from three towns Mombasa, Nairobi and Kisumu.

2016 Kerosene pump prices			
	Mombasa	Nairobi	Kisumu
15 th Jan - 14 th Feb	43.44	46.13	48.03
15 th Feb - 14 th March	36.94	39.62	41.54
15 th March- 14 th April	43.44	46.13	48.03
15 th April - 14 th May	41.27	43.96	45.86
15 th May - 14 th June	44.28	46.98	48.88
15 th June - 14 th July	47.98	50.80	52.77
15 th July -14 th Aug	58.61	61.45	63.40
15 th August - 14 th Sept	59.64	62.48	64.43
15 th Sept -14 th Oct	56.27	59.10	61.06
15 th Oct - 14 th Nov	55.87	58.71	60.67
15 th Nov -14 th Dec	60.71	63.56	65.50

Source 8-3: Adopted from Energy regulatory commission, Kenya

Appendix 4: Kerosene pump prices for 2015 from three towns Mombasa, Nairobi and Kisumu.

2015 Kerosene pump prices			
	Mombasa	Nairobi	Kisumu
15 th Jan - 14 th Feb	62.84	65.59	67.43
15 th Feb - 14 th March	49.69	52.4	54.28
15 th March- 14 th April	53.03	55.75	57.62
15 th April - 14 th May	54.49	57.21	59.08
15 th May - 14 th June	56.51	59.24	61.10
15 th June - 14 th July	59.04	61.78	63.63
15 th July -14 th Aug	60.00	62.74	64.59
15 th Aug - 14 th Sept	55.25	57.98	59.84
15 th Sept -14 th Oct	49.84	52.55	54.44
15 th Oct - 14 th Nov	78.10	80.88	82.68
15 th Nov -14 th Dec	52.10	54.81	56.69

Source 8-4: Adopted from Energy regulatory commission, Kenya.

Appendix 5: Kerosene pump prices for 2014 from three towns Mombasa, Nairobi and Kisumu.

2014 Kerosene pump prices			
	Mombasa	Nairobi	Kisumu
15 th Jan - 14 th Feb	82.28	85.07	86.85
15 th Feb - 14 th march	80.28	83.07	84.86
15 th march- 14 th April	81.12	83.91	85.69
15 th April - 14 th May	80.37	83.16	84.95
15 th May - 14 th June	80.30	82.81	84.60
15 th June - 14 th July	80.34	83.13	84.92
15 th July -14 th August	81.33	84.12	85.90
15 th Aug - 14 th Sept	80.26	83.05	84.84
15 th Sept -14 th Oct	78.84	81.63	83.42
15 th Oct - 14 th Nov	78.10	80.88	82.68
15 th Nov -14 th Dec	73.54	76.31	78.12

Source 8-5: Adopted from Energy regulatory commission, Kenya.

Appendix 6: Requirements of oils according to the Kenya Bureau of Standards

Serial No. characteristics	Requirements
Kinematic viscosity @40°C	Min 1.6; Max 5.5
Density @ 20 °C,g/ml	Min 0.820; Max 0.870
Total acid number; mg KOH/g	0.5
Water (v/v) max	0.05
Sediments % (m/m) max	0.01
Ash % (m/m) max	0.01
Cetane index (calculated)min	48
Flash point, Pensky Martens closed cup, °C Min	60

Source 8-6: Kenya Bureau of standards (KEBS) DF2 Requirements

Appendix 7: Different water density values and viscosity values at different temperatures

Water viscosity and density		
Temp. °C	Density (g/ml)	Viscosity (cSt)
15	0.99919	1.1390
20	0.99823	1.0087
25	0.99713	0.8910
30	0.99567	0.8004
35	0.99408	0.7200
40	0.99224	0.6536
45	0.99022	0.5960
50	0.98807	0.5492
55	0.98565	0.5040
60	0.98324	0.4699

Source 8-7: Hand book of Chemistry by Lange N. A. Handbook Publishers, INC. Sandusky Ohio (1941)

Appendix 8: Oil content for non-conventional oil seeds and their heating values (Calorific values)

oil seed	Heating Value (Kj/g)	Ratio (Relative to Diesel)
Afzelia cuanzensis	42.10	93.70
Annona squamosal	40.80	90.80
Areasstrum romanzofianum	39.60	88.10
Azadirachta indica	40.10	89.20
Balmmites aegyptiaca	40.80	90.70
Bauhinia purpulea	39.90	88.70
Caesalpenia decapetala	41.50	92.40
Calodendrum capense	40.80	90.80
Citrullus vulgaris	39.40	87.50
Craibbia ellioti	39.60	88.10
Croton megalocarpus	37.60	83.60
Cucumis spp	40.30	89.70
Cupressus lusitanica	39.30	88.80
Erythrina abyssinnica	39.20	87.30
Passiflora edulis	40.70	90.60
Sesamum indica	40.80	90.70
Sterulia Africana	40.00	88.90
Jatropha curcas	31.50	91.35

Source 8-8: Munavu and Odhiambo 1984