

POTENTIAL OF SOUR PLUM (*Ximenia americana L.*) SEED OIL AS A BIOFUEL

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**A Thesis submitted to the Graduate School in partial fulfilment for the requirements of
the Master of Science Degree in Engineering Systems and Management of Egerton
University**

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DECLARATION

I declare that this Thesis is my own original work and that it has not been presented before to any other University known to me for similar or any other degree award.

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DEDICATION

I dedicate this work to my Family. May God bless you all.

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ABSTRACT

Energy systems based on fossil oil products have witnessed increased demand all over the world with prices reaching new peaks, and continue to further weaken African economies. Potential biofuel oil sources, production and their optimization in standard to fossil equivalent should be sought. Sour plum (*Ximenia americana L.*) seed oil as one potential biofuel was extracted from plant seeds using screw press then tests were carried out to evaluate its properties as substitute for kerosene. Fuel properties of the sour plum (*Ximenia americana L.*) seed oil that had less than 10% difference and therefore had insignificant difference from kerosene and *Jatropha* seed oil properties were: calorific value, specific gravity, pour point, sulfur content and acid value, while Density, kinematic viscosity, fire point, carbon residue, and ash content had difference above 10% from those of kerosene. The latter properties: Density, kinematic viscosity, fire point, carbon residue, and ash content were analyzed further to determine their effect on mass burned and flame height burning parameters when sour plum seed oil was unblended and blended with kerosene in ratio 50%, 40%, 30%, 20% and 10%. Pearson's product correlation coefficient $r = 0.975$ between these parameters was obtained. Further, regression analysis done indicated that parameter values were influenced by the fuel properties: viscosity, density, fire point, carbon residue and ash content which were used as predictor variables. Analysis of burning the blended seed oils in modified wick stove showed Pearson's product correlation coefficient $r = 0.855$ between the fuel energy and power produced and transferred. However, energy produced by the fuels differed significantly probably due to effect of the fuel properties. In conclusion, sour plum (*Ximenia americana L.*) seed oil when blended with kerosene in ratio above 10% had better burning characteristics and can supplement kerosene as biofuel.

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LIST OF ABBREVIATIONS, SYMBOLS AND DEFINITIONS

ABBREVIATIONS

ASTM	- American Society for Testing and Materials
KIRDI	- Kenya Industrial Research and Development Institute
USDOE	- United States Department of Energy
API	- American Petroleum Institute
NRET	- New and Renewable Energy Technologies
VO	- Vegetable oil
EPA	- Environment Protection Agency
CBS	- Central Bureau of Statistics
UNEP	- United Nations Environment Program
UNESCAP	- United Nations Conference on Climate Change in Bali
APCAEM	- Asian and Pacific Centre for Agriculture and Engineering Machinery
FAO	- Food Agriculture Organization
IPCC	- Interparty Committe on Climate Change
LPG	- Liquified Petroleum Gas
GHG	- Green House Gases
ANOVA	- Analysis of variance
OECD	- Organization for Economic Cooperation and Development
IEA	- International Energy Association
KIPRA	- Kenya Institute for Policy Research and Analysis

SYMBOLS

C_e	- effective heat capacity of calorimeter (J/K)
m_{ba}	- mass of benzoic acid (kg)
Q_{ba}	- calorific value of benzoic acid (J/kg)
$\Delta\theta_{ba}$	- temperature rise during the determination (K)
T	- Temperature ($^{\circ}\text{C}$)
γ	- kinematic viscosity (mm^2/s)
μ	- Dynamic viscosity (mm^2/s)
θ	- temperature (K)
θ_F	- Flash point (K)
θ_{Fr}	- Fire point (K)
θ_p	- Pour point (K)

- Q_g - gross calorific value (J/kg)
 Q_{net} - net calorific value (J/kg)
 Q_s - heat liberated from miscellaneous sources (J/Kg)
 m_s - mass of sample (g)
 V_o - volume of oil at temperature θ (m^3)
 $\rho_{15.5 (o)}$ - density of oil (kg / m^3)
 $\rho_{15.5 (w)}$ - density of water (kg / m^3)
 θ_1 - measured temperature (K)
 θ - required temperature (K)
 θ_2 - temperature of the determination (K)
 ρ_o - density of oil (kg/m^3)
 ρ_w - density of water at temperature of determination (kg/m^3)
 $\Delta\theta$ - Temperature rise (K)
 m_a - mass of ash (g)
 C_1 - viscometer constant $\approx 0.254 \times 10^{-6}$
 C_2 - coefficient of kinematic viscosity $\approx 17.93 \times 10^{-6}$
 t - time (s)
 ρ - density (kg/m^3)

DEFINITION

Bioenergy	Energy derived from biomass
Biofuels	Liquid, gaseous or solid hydro-carbon fuels/ Energy carrier derived from biomass
Fuel	Any substance burned as a source of heat or power.
Energy	Capacity to do work (SI Units Joules)
Power	Rate of doing work (SI Units Joules/second)

CHAPTER ONE

INTRODUCTION

1.0 Background Information

Global energy consumption has been estimated at over 400 Exajoules and is projected to grow 50 percent by the year 2025 (FAO, 2007; IEA/OECD, 2010). Most of this demand for energy is currently met by fossil fuel whose natural endowment is unevenly distributed among countries in the world. In addition, there has been rapid growth in demand for this oil whose source is finite, increasing and volatile prices due to political instability in regions and oil producing countries; a situation that seem to be continuing. By the year 2007, 1.6 billion people worldwide did not have access to electricity; in the year 2010, over 2.7 billion people in developing countries relied on biomass fuel such as wood, charcoal, leaves, animal dung and crop residue for cooking with most using these fuel in inefficient burners. Further, this number has been rising due to growing population, increasing cost of liquid fuel and economic recession that has driven more people to revert to biomass. Worldwide, about 82 percent of these people who use biomass live in rural areas. However, in sub-sahara Africa, 60 percent of urban residents use biomass (wood and charcoal) for heating and cooking. With the rapidly growing urban population, meeting this high and growing demand for energy is a challenge (IEA/OECD, 2010; Karlson, 2007).

The IEA (2009) noted that tackling climate change and enhancing energy security requires massive decarbonization of the global energy system. Further, latest IPCC and the Copenhagen Accord have indicated that limiting atmospheric carbon dioxide concentration to 450 parts per million (ppm) will limit global temperature rise to 2°C. This requires big Green House Gas (GHG) reduction in all regions without which temperature rise will be in the range of 6 °C with rising energy cost. It has also been found that cleaner energy development is key to effort to combating climate change and poverty reduction. These two: combating climate change and poverty reduction are processes that need to reinforce one another without which progress made in sustainable Development is reversed (Mainhardt-Gibbs, 2011).

The global energy map depicts Africa as net energy exporter because of large exports of crude oil made by the leading oil producing countries. Their percentage exports are indeed large with Nigeria exporting 89 % and Angola 86 % of their production in 2005 (OECD/IEA, 2005) yet about 75 % or over 550 million people in Africa use biomass, because they do not have access to electricity or liquified petroleum gas. This scenerio has therefore created what is refered to as energy poverty. A society is said to be energy poor if there is no access to at least the equivalent of 35 kg LPG for cooking per capita per year from liquid and / or gas or from improved supply of solid fuel sources and 120kWh electricity per capita for lighting; energy-dependent basic services such as access to drinking water, communication plus some added value to local production (Tennakoon, 2008). Based on this criterion, approximately 92 % of rural populations in Africa are energy poor (Ejigu, 2008). Since fuel products contribute significantly to give impetus to any country's Industrial, Commercial and Economic Development; for many African countries characterized by this energy poverty, the problem of access to fuel for domestic, commercial and industrial consumption should therefore be a focal area for creating the basis of development. In this context, increased access to fuel products to meet commercial, manufacturing and residential needs requires increased exploitation of renewable energy resources to minimize the negative impacts of petroleum fuel use.

The potential of renewable energy sources to meet the present world energy demand is enormous in terms of enhancing energy supply markets, securing long term sustainable energy supplies and reducing local and global atmospheric emissions among other benefits. However, most of the renewable energy technologies such as Solar, Biomass, Hydro, Wind, and Fuel Cell and related technologies are still in nascent stages of development and are therefore not technically mature. In addition, few of these technologies can compete with conventional fuels in terms of cost, except in some niche markets (Turkenberg, 1998). Renewable energy therefore demand; continuing research, development and demonstration efforts in order to overcome the challenges and enable realization of renewable energy potential.

Meeting energy needs for Kenya, which is one of the developing countries, in a manner that fosters commercial, industrial and economic development while avoiding environmental degradation, is one of the foremost challenges (UNESCAP-APCAEM, 2008; FAO, 2007; and Belser and Hedland, 2004).

As Kenya pursues Vision 2030, with the aim of being a middle income economy by the year 2030, it is faced by challenges of meeting energy needs due to the high expectations in growth to power the economy. The major sources of energy in Kenya are wood fuel, Petroleum and Electricity accounting for 70%, 21% and 9% respectively (UNEP, 2006 b). However, Potential sub-sectors of energy identified to secure sustainable supply of energy to meet the growing demand are Electricity, Petroleum and Renewable energy (KIPRA, 2010). Electricity sources in Kenya by 2011 are hydro providing 3217.2 GWh, Geothermal 1443.7 GWh, Wind 17.6 GWh and Thermal power 2800.5 GWh (KNBS, 2012). The overall installed Electricity capacity in Kenya was 1150MW and effective capacity of 1066.9MW by the year 2005 (UNEP, 2006 b) against consumption that has been rising from 5,252.2 KWh in 2008 to 6,273.6KWh in 2011 (KNBS, 2012).

In Kenya, most fuel supply for commercial sector is based on petroleum oil products. The major energy consuming sectors are transport, manufacturing and residential sectors with transport sector leading in consumption of petroleum products (KIPRA, 2010). All fossil fuels in Kenya are imported including kerosene illuminating oil and jet fuel . In the last few years, there has been increased demand for fossil fuels rising from 3133.2 thousand tonnes in 2008 to over 3857.9 thousand tonnes in in 2011 (KNBS, 2012). Further, import of petroleum fuel accounted for over 26% of import bill in 2012 and used 44.3 % of the country's foreign exchange earnings from domestic export of principal commodity (KNBS, 2012). There has been rising petroleum prices all over the world. As prices reach new peaks for instance in the year 2000, crude oil price per barrel was US \$ 28.5 rising to US \$ 96.91 in the year 2008 (<http://chartsbin.com/view/oau>). Such sharp increase further continue to weaken the economy. The cost of such oil product imports are significant; for instance in Kenya in the year 2008, it cost over Kshs.197,245 million rising to over Kshs. 330,714 million in 2011 representing over 25% of imports of principal commodity (KNBS, 2012). Therefore foreign exchange earning continue to be committed to importing petroleum fuel in increasing amount. In addition to that are the perverse environmental pollution impacts owing to the use of fossil fuel (Mbarawa, 2007; EPA, 2002) besides negative health impacts. For instance kerosene as a lighting and cooking fuel is important for the poor in the rural and urban areas; though it has served as substitute for wood fuel, key emerging concerns are the identified impacts of its use on level of indoor air pollution and the consequent health impacts on the poor (UNEP, 2006 b).

Kenya is well endowed with the renewable energy resources. Hence, this predisposes the country to take another path towards meeting energy demand through research on renewable energy sources. These sources of energy and technologies are environmentally sustainable; since harmful fuel-generated gases such as carbon dioxide are recycled without an overall net increase in the atmospheric carbon dioxide inventory, while sulfur dioxide and nitrogen dioxide produced are negligible (UNEP, 2006 b; Batey, 2004; and Connemann, 1998). It was predicted in 1980's that large amounts of liquid and gaseous fuels would be produced economically from biomass, but there is still a lot of work to be done in research to make biofuel sufficiently and economically feasible (US Department of Energy, 2005).

There are a varied range of driving issues that spearhead the wide introduction of renewable energy especially biofuel as alternative fuel throughout the world, these include land-use, energy security given that oil is finite, economics such as rising prices for fossil fuels, environment, climate change concerns and rural development (FAO, 2007). It has been identified by the World Energy Council (2010) that, the main challenge for the future is to develop biofuels which do not compete with food chain; are sustainable and efficient both in terms of cost and energy, and for which the carbon footprint is a net gain. Further, biofuel promise to bring on board more countries into liquid fuel business production, therefore diversifying supplies and reducing volatility in supply and therefore prices. This volatility in supply and prices has been known to be caused by among others high demand, especially by developed countries, the rapidly industrialising countries such as the so called (BRICS): Brazil, India, China and South Africa (World Energy Council, 2010) while the suppliers have continued to be few.

With the challenge of global climate change concerns, the need to cut down carbon emissions (Mainhardt-Gibbs, 2011) as laid down in the Kyoto Protocol is inevitable. Bioenergy as an alternative energy source that will contribute to the desired reduction in carbon emission is attractive. With biofuel, there is less change in the way energy is used because biofuel can be used in engines and power plants. Bioenergy can be grown locally in form of biomass by all countries thereby reducing dependence on the imported oil. Bioenergy already account for 10 percent of world energy and the potential to grow more bioenergy crops is enormous with tropical countries better placed for this production and export (Hazell and Pachauri, 2006).

African countries have comparatively better biophysical potential to join the category that can export bioenergy given that it can support some of the most competitive current and potential biofuel feedstock such as palm oil and *Jatropha* respectively. There are approaches that have been thought of as capable of providing access to modern energy at household levels. These include reliance on renewable energy in rural applications and the use of locally-produced bioenergy to produce electricity (IEA/OECD, 2010). Biofuels and biodiesel being derived from plants and agricultural crops represent modern forms of bioenergy and the more efficient use of biomass energy (Ejigu, 2008). It has been said that this efficiency would further be enhanced by international trade in biofuel by directing production to the cost-effective locations and use of highest yielding and lowest cost feedstock (IEA/OECD, 2010).

Tropical seed oils from crops have been considered in this study and harnessed for biofuel use by blending with fossil fuel. These seed oils are considered as second class biofuel feedstock and consist of both annual oil crops such as soybeans, rapeseed, cotton seed, sunflower; and perennial oil crops: palm, *Jatropha* and other tropical oils (Braun, 2007). Use of seed oils that are inedible would reduce cost of biofuel as it would not be competing with edible vegetable oil yet demand for both has been rising (Akbar and Yaakob, 2009). The use of straight vegetable oil (SVO) as potential fuel for engines depend on its characteristics. These depend on type of plant as different plant oils affect engine performance differently (FAO, 2007).

In the process of burning of biofuel to get energy, carbon dioxide that the plants had absorbed from the atmosphere is released back to the ecology becoming available for recycling during uptake by plants for photosynthesis. It has been found that perennial biofuel crops can give better green housegases balance than annual crops (German Advisory Council WBGU, 2008). Therefore biomass energy derived from perennial crops should be sought in order to optimize these environmental benefits. Besides, energy crops such as *Jatropha* and Sour plum require few inputs and can be grown on marginal land that may not support food crops thereby extending landbase for agricultural use and increasing income to farmers. Although cooking and lighting are the main fuel consuming activities in households, fuel substitution is possible depending on cost of the fuel. A low cost fuel is the more likely to be used as the main fuel (Bacon et. al., 2010).

Since use of kerosene in Kenya dominates in low income households residing both in rural and urban areas (KIPRA, 2010), use of supplement renewable energy fuel would contribute to reduced expenditure on import of petroleum, reduced environmental and indoor air pollution among other benefits. Therefore developing substitute biofuels at household level is key to increasing choice of affordable clean fuels. This Thesis shows findings of one way of developing substitute to fossil fuel from renewable sources.

1.2 Statement of the Problem

Recent findings in Kenya indicate massive fossil oil deposits; however, economic exploitation is yet to begin. Therefore, a large amount of capital is spent in importing petroleum products. Few countries worldwide are endowed with fossil fuel, yet its demand as energy source by all countries world wide is without exception. Therefore, petroleum fuel prices have been soaring thereby threatening livelihoods and hurting national economy since large and increasing proportion of income is spent on petroleum fuel. The use of petroleum fuel results in combustion by-products among them, green house gases that pollute and damage the environment. In Kenya, there has been few substitute, supplement and environmnetally mild renewable sources of oil that can be widely used in domestic and commercial sub sectors; in addition, there are few biofuel oil crops that avoid competitive land use with food crops while utilizing the vast arid and wastelands. There is little information on fuel characteristics of seed oil from Sour plum (*Ximenia americana L.*) plant as a potential source of biofuel yet the plant is found growing in naturally in many parts of Kenya. In addition, its potential use as susbtitute to kerosene in comparison to other known biofuel sources such as *Jatropha* seed oil needs to be explored.

1.3 Objectives

The main objective of this research was to determine fuel properties and burning characteristics of the Sour plum (*Ximenia americana L.*) seed oil compared to *Jatropha curcas* seed when unblended and blended with kerosene.

The specific objectives were:

1. To determine fuel properties of *Ximenia americana L.* seed oil and its burning characteristics when unblended.
2. To compare burning characteristics of blended *Ximenia americana L.* seed oil with *Jatropha curcas* seed oil and kerosene .

3. To determine burning characteristics of blended *Ximения americana L.* seed oil with kerosene and *Jatropha curcas* seed oil with kerosene in existing kerosene burners.

1.4 Research questions

1. How does the fuel properties of unblended *Ximения americana L.* seed oil compare with kerosene and unblended *Jatropha curcas* seed oil?
2. How does unblended and kerosene-blended *Ximения americana L.* seed oil burning performance characteristics compare with those of *Jatropha curcas* seed oil and kerosene?
3. How does the burning performance characteristics of kerosene-blended *Ximения americana L.* seed oil compare with kerosene-blended *Jatropha curcas* seed oil and kerosene in modified stove?

1.5 Research justification

Bioenergy production can provide decentralized energy sources, helping to spur rural development especially in developing countries (Mueller, 2008; FAO, 2007; Ugarte, 2006). Vegetable oils have been found to have many similar fuel properties as diesel fuel and may be used as a substitute (Sustainable Energy Ireland, 2006; Belser, 2004; and Ferchau, 2000). This would offer a possible solution to the less reliable fossil oil supplies and ever rising fuel prices. It is also known that there are some natural seed oils that can be used directly as biofuel without conversion to biodiesel (Peterson and Jones, 2002; Bhat and Murthy, 2004; and Goodrum, 1987). Further, since more than 95% of world production of biodiesel uses edible vegetable oils such as from cotton, coconut, sunflower seed among others (Gui et. al., 2008), therefore, it is necessary to investigate on such potential biofuel oil sources which include *Ximения americana L.* comparing with other that are unedible oil.

1.6 Scope, Limitation and assumptions of the study

The scope of this research covered characterization and burning tests of seed oil from sour plum (*Ximения americana L.*) plant as a potential biofuel source and was compared with *Jatropha curcas* seed oil, a known biofuel source. The parameters that were under consideration during the research was limited to physical and chemical characteristics of sour plum seed oil as biofuel, burning tests parameters of unblended seed oil and in mixed ratios with kerosene in burners. Also burning tests were limited to modified burners and stove due to inability of seed oil to move up wicks in burners. Further, tests on amount of energy

produced and heating water using seed oil blends were not done on the same day. It was assumed that where blending was done, ratio of fuel property value was proportional to the ratio of blending. It was also assumed that the seed oil would burn as other hydrocarbon products. It was assumed that seeds moisture content before pressing was within limits that will not affect seed oil burning parameters. During data collection, it was assumed that unblended fuel samples were independent of one another. An additional assumption was that similar properties would be obtained, if other sour plum oil seeds were used.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

Currently in the world, Brazil and USA are the leading biofuel producers accounting for over 85% of production. Both countries produce mainly bio-ethanol with USA producing 10171.2 million gallons from maize and Brazil 6577.9 million gallons from sugarcane both in the year 2009 (Kanes, 2010). The fuel is mainly used in transportation and its demand is expected to grow significantly by upto 55 % by 2030 (World Energy Council, 2010).

In subsahara Africa firewood use at household level is widespread especially in rural areas, while in urban areas, there is a diverse fuel mix comprising firewood, charcoal, kerosene and electricity. In southern Africa, energy at household level is used for cooking and space heating. Although Electricity use is common, wood is used in rural households, while kerosene is used by many low income earners in towns, while coal is common nearer coal mines. North Africa is a major consumer of LPG and Kerosene at household level, although electricity could overtake this especially with fast expanding Rural electrification programme with Morocco and Egypt leading (Niez, 2010). However, biomass use including animal dung cakes, crop residues and wood in rural areas is common (World Energy Council, 2010). Overall, the widespread wood fuel use poses the challenges of indoor air pollution, environmental degradation and social burden to African countries (Johnson and Lambe, 2009).

Wood fuel is the most prevalent source of energy, despite the above mentioned challenges. It accounts for approximately 70% of total energy demand. The Kenya Intergrated Household Budget survey of 2005/2006 indicated that 68.3% of all Households in Kenya use firewood as the source of fuel for cooking (Ministry of Planning and National Development, 2006). Petroleum, though wholly imported, is the next most important energy source and accounts for about 26 % of the total energy demand, but accounts for 86 % of commercial energy sector demands (Nyoike, 2003). At household level in Kenya, it has been found that kerosene or paraffin was the third ranked cooking fuel and most common. It accounts for 44.6 % of urban dwellers (KIPRA, 2010) with Nairobi and Mombasa leading at 63.5 % and 53.5 %

respectively. Paraffin is also the leading source of lighting at household level with about 77.7% of households using it for lighting (KIPRA, 2010).

Ethanol is not popular, accounts for less than 1% of Kenya's energy requirement, and is used for blending with petrol and some is exported as motor spirit (CBS, 2005).

The Kenya National Energy mix indicates that final total energy consumption as of the year 2009 was 14353.8 metric tonnes of oil equivalent (Mtoe), while the total primary energy supply was 18,215.99 Mtoe with petroleum fuel accounting for about 28.57% of total Final Energy consumption. Electricity and combustible renewable sources account for 3.11% and 67.65 % respectively of the final total energy consumption (KIPRA, 2010).

2.1 Renewable Energy Resources

In the early 1970's New and Renewable energy Sources was seen as an infinite solution for the developing world's deteriorating energy situation. This was because they were seen as low-cost and appropriate alternative to conventional energy technologies and suitable for use by the poor of the third world (FAO, 2007; Urgate, 2006). Bhavagan and Karekezi (1992) found that some other New and Renewable energy Sources that were perceived to be low cost, such as solar water heaters, continued to face enormous problems in mobilizing support at policy level and in engineering large scale dissemination at the end user level. Later, despite obstacles, other New and Renewable energy Sources such as small hydro plants for shaft power and electricity generation, wind pumps for water lifting, biogas plants for cooking and lighting, photovoltaic units for lighting and refrigeration realized an unexpected level of success in addressing energy problems faced in agriculture and development initiatives in the rural areas (Muller, 2008; Urgate, 2006; and Bhagavan and Karekezi, 1992).

Biomass as a major energy resource in support of development, requires production on a renewable, sustainable basis. The use of liquid biomass as biofuel is an emerging technology that will significantly contribute as fossil fuel substitute in Kenya (Sustainable Energy Ireland, 2006). Biofuel oils constitute a carbon dioxide cycle in combustion, have better emissions, biodegradable and sustainable (Mbarawa, 2007; Belser, 2004; and Schumacher and Elser, 1997). They are also known to be environmentally friendly (Batey, 2004; Connemann, 1998) therefore offer a potential alternative substitute and supplement for fossil fuel sources (Sustainable Energy Ireland, 2006; Ugarte, 2006; and Davies, 2006).

2.2 Vegetable oils

Vegetable oils and fats are triglyceride esters of alcohol, glycerin and various straight chained fatty acids or lipids (Brown and Lamay, 2006; Stauffer, 2005). They have higher calorific value than that of other main foods (Obina and Aesina, 2006). Globally, demand for edible vegetable oil has been reported to be rising and was projected in the year 2008 to be up to 50 % in 15 years. Table 2.1 shows global vegetable oil production from selected plant sources during year 2000.

Table 2.1: Global vegetable oil production in year 2000

Vegetable oil	Production (1000 t)
Soya bean	26,000
Palm oil	23,300
Rape seed (canola)	13,100
Sunflower	8,600
Groundnut	4,200
Coconut	3,300
Palm kernel oil	2,700
Olive	2,500

Source:(Grace and Barus, 2008)

Although the demand for biofuel from vegetable oil was not clearly predictable then, this emerging market, is expected to continue affecting prices increase in the global vegetable oil industry (Grace and Barus, 2008). Kenya also imports most edible vegetable oil. Indeed, most countries in the world may not be able to grow sufficient oil producing plants to meet the expected fuel demand (FAO, 2007), due to climatic conditions since such plants better grow in the tropics (Hazell and Parchauril, 2006). However, biofuel crops need to be grown on marginal land, if they will be profitable (Mueller, 2008). Seed derived vegetable oils vary in amounts depending on plant sources as is shown in Table 2.2.

Table 2.2: Percentage oil content of some plant seeds

Crop	Oil Content (wt %)
Babassou	60 – 65
Copra	65 – 68
Cotton seed	18 – 20
<i>Jatropha</i>	60
Oil palm	45 – 50
Peanuts	45 – 50
Rapeseed	40 – 45
Safflower	30 – 35
Sesame	50
Sunflower	35 - 45
Sour plum*	60

*Plant studied for potential biofuel oil (source: Agnew and Agnew, 2003; Stout, 1990)

From the information on Table 2.2 it can be realized that it was worth to develop data to characterise the seed oil from sour plum as biofuel oil source; hence further making its potential known.

Studies have been conducted to determine if mixture of selected triglycerides might be a satisfactory biodiesel fuel. Triglycerides for study were chosen on the basis of known physical and thermodynamic properties to enable their use as fuel oil. Natural occurrence in some seed oil containing such a mixture might prove to be cost effective source of fuel oil (Goodrum, 1987). Further, plant breeding to change seed oil composition would be materially aided by bio-technology techniques (Duffield and Shapouri, 1998; Goodrum, 1987).

Vegetable oils are mainly used as food and as raw material in industries depending on the physical and chemical characteristics of the oils. Some of these oils are suitable for making soap, paint, vanishes, lubricant and plastics.

Table 2.3 shows some vegetable oil sources and their uses .

Table 2.3: Some vegetable oil sources and their uses

Plant Source	Uses
Sunflower	Edible (magarine, cooking, frying)
Safflower	Protective coating, paints, urethane, resins, cooking, magarine, soap and cosmetics
Castor	Jet engines lubricant, synthetic resins, fibres, soap, carbon paper, ointment, cosmetics, hairdressing, brake fluids, medicine and printing ink.
Coconut	Deep frying, magarine, shortening, soap, hydraulic brake fluid, synthetic rubber and fatty acids.

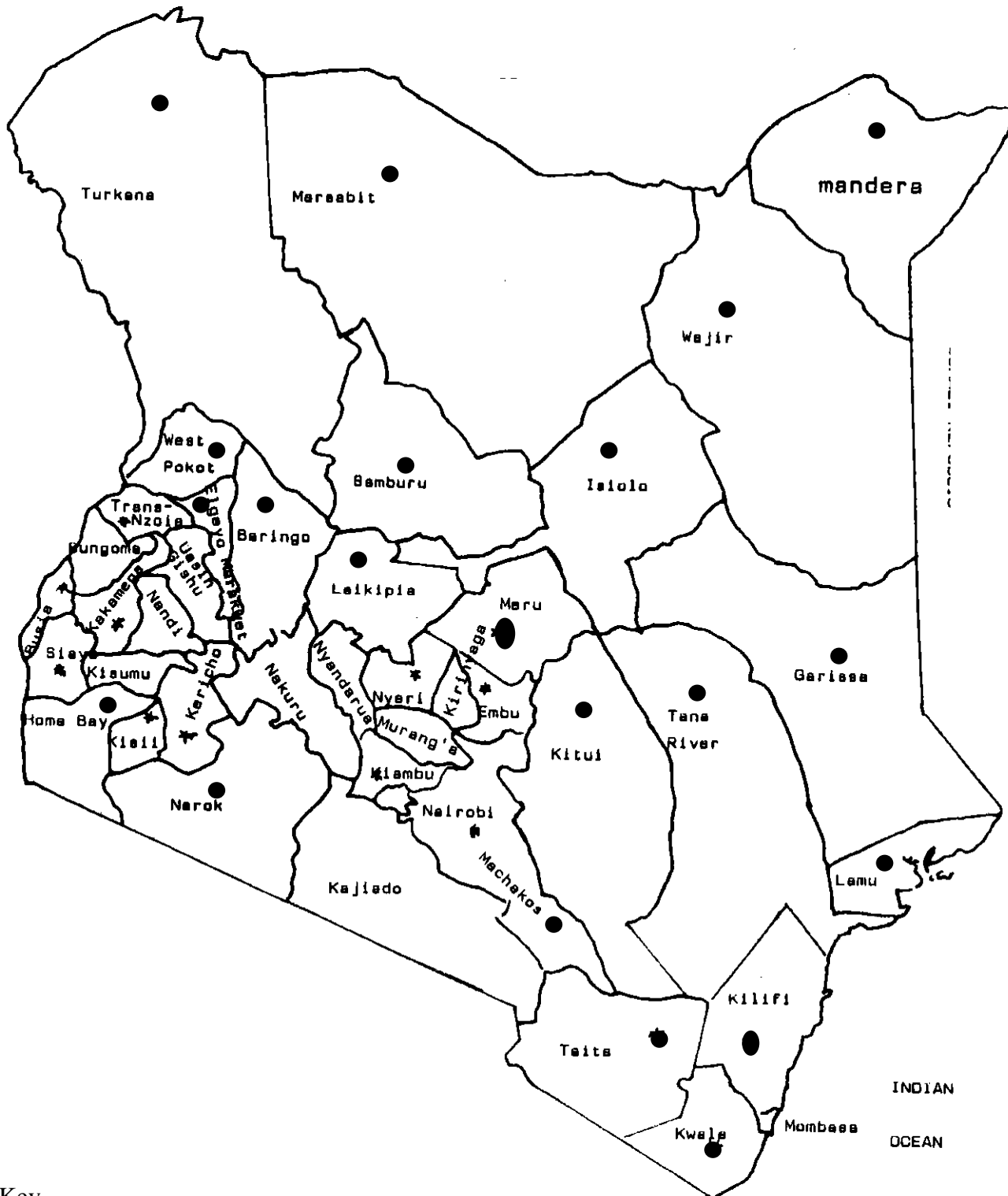
(source: Shitanda, 1994).

2.3 Indigenous oil seeds in Kenya

Indigenous oil seeds in Kenya are those from local naturally growing plants. Oil from the indigenous oil seeds especially those that grow in arid and semi arid areas have the potential as a substitute for the conventional vegetable oils. By 1971, KIRDI had done analytical and development work on the Mafuta nut (*Trichilea emitica*), Cashew Nuts (*Anacardium occidentale*), Macadamia (*Macadamia integrifolia*), Avocado (*Persea americano*) and Passion fruit (*Passiflora edulis*) seeds. Mafuta Nut grows in Tanzania, Mozambique, Ethiopia, Sudan and Kenya (Eckman and Hines, 1993). Indigenous oil seeds described by Shitanda (1994) are Cape nut, *Musime Podo*, *Pittosporum vindiflorum* and Doum palm (*Hyphaene compressa*) which are mainly from the wild. The Sour Plum (*Ximenia americana L.*) seeds in this research was also from the wild arid and semi arid zones of Kenya with current distributions as in Map Figure 2.1 (Sacande and Vautier, 2006; Maundu and Tengnas, 2005; and Agnew and Agnew, 2003).

2.4 Biology and uses of Sour plum (*Ximenia americana L.*)

Sacande and Vautier, 2006; Maundu and Tengnas, 2005; and Agnew and Agnew, 2003 describe plum (*Ximenia americana L.* of family olacaceae) as a small tree or shrub; up to 4m tall but sometimes upto 7m in *X. americana* var. *caffra*. It has spines which are 1cm, thin and straight leaves and branches with or without hairs. The bark is dark –brown to black and with textured scales. The leaves are alternate, simple, often in tufts on short shoots, oblong, to 6cm long, blue-green to yellow-green, hairless to soft hairy with rounded or notched tip. Figure 2.2 (a) and (b) shows picures of the sour plum leaves and fruit.



Key

- Sour plum tree found growing in natural habitat

Source: (Agnew and Agnew, 2003; UNoCHA, 2008)

Figure 2.1: Map showing areas sour plum trees grow in Kenya



Figure 2.2: (a) *X. americana L.* leaves and fruit



Figure 2.2: (b) *X. americana var. caffra* leaves and fruit (source: Burke, 2009)

These species in Figure 2.1 and 2.2 are spread throughout the tropics. However, *X. americana L.* variety is widespread than *caffra* (Curtis and Mannheimer, 2005). It is found in semi-arid bushland and many types of dry woodlands including sandy open woodland, stony slopes, ravines and coastal thickets. It grows at altitudes up to about 200m where rainfall exceeds 500mm per year on many soil types and that are often poor and dry. The flowers are unisexual and male and female flowers occur on different plants. Flowers are fragrant, small green-white in small branched clusters with a common stalk. The fruits are oval measuring

up to 3cm, shiny, thin skinned, light green, turning yellow, orange or pink-red on ripening as in Figure 2.2 and 2.3. The pulp is edible and it clings to a brittle-shelled stone within which is contained an oil rich, soft creamed coloured seed. One large seed has up to 60% oil (Burke, 2009; www.duerstlahtiglobal.com). Analysis of the seed oil revealed that the major components were oleic, hexacos-17-enoic (ximenic), linoleic, linolenic and stearic acids together with smaller quantities of triacont-21-enoic (lumequic), octadec-11-en-9-ynoic (ximenynic), arachidonic, erucic, and nervonic acids these are Fatty acids with more than 22 carbon atoms, Ximenia oil contains very long chain fatty acids with up to 40 carbon atoms. Over 96% of the percentage fatty acid composition is unsaturated (Řezanka and Sigler 2007 Saeed and Bashier, 2010).



Figure 2.3: *Ximenia americana* L. Ripe fruit (source: Burke, 2009)

Flowering and fruiting of Sour plum varies between localities, but typically occurs in dry season. In Kenya, flowering occurs in July and August, while fruiting takes place from January to April. In south Africa, flowering occurs in September to December, with fruiting taking place in December to February. In many places, it flowers and fruits throughout the year. On good sites, trees may produce fruit after 3 years of growth. The fruits are dispersed by animals (Maundu and Tengnas, 2005; www.worldagroforestrycentre.org). Projections made in a desktop study in Namibia in the year 2007 indicated that the sour plum tree distribution in that country was approximately 5 trees per hectare; further, it was concluded that one sour plum tree can produce approximately 213.6g seed per harvest (Burke, 2009).

In Kenya the plant is found in all regions, though its distribution varies with soil factors. Some common names are **English:** *Sour plum, False sandalwood, Tallow nut*; **Tugen:** *Muyengwo/(e)*, **Kikuyu:** *Mutura*, **Maasai:** *Ol-amai*, **Somali:** *Madarud*, **Luo:** *Olemo*, **Swahili, Giriama, Digo :***Mtundakula*. The wood is very hard, heavy and durable and is used for tool handles, firewood and building (Maundu and Tengnas, 2005). Other uses of Sour plant include edible fruit, medicinal value (fruit, root and leaves) and oil from the seed has multiple uses: it is traditionally used to soften leather, cosmetic (Sacande and Vautier, 2006; Maundu and Tengnas, 2005). It is also used for oiling cooking pots so that food does not stick to the cooking pot walls.

2.5 *Jatropha curcas*

Jatropha plant is perenial; it can grow in arid conditions (even deserts), on any kind of ground and does not require irrigation nor suffer in droughts. *Jatropha* is fast growing and it begins yielding seeds in the second to the fifth year depending on the amount of rainfall; and for the next forty to fifty years. Optimal yields are obtained from the sixth year. When planting, spaced at 2 metre intervals; around 2500 plants can be cultivated per hectare. The annual nut yield ranges from 0.5 to 1.2 tonnes per hectare. The kernels consist of oil to about 60 percent; the oil can be combusted as fuel without being refined. It can also be transformed into biodiesel fuel through esterification (Pramanik, 2002)

2.6 Seed oil extraction process

There are three stages of vegetable oil processing (Bachmann, 2001): Pre-treatment stage, extraction stage and post extraction stage.

2.6.1 Pre-treatment stage

This stage involves cleaning to remove foreign material like stones, leaves, and soil; decorticating and / or crushing, and preheating/scorching/cooking (Bachmann, 2001).

2.6.2 Extraction stage

Four extraction techniques were cited by Cenkowski (2006); solvent extraction using petroleum-ether, supercritical fluid extraction using carbondioxide (CO₂), screw pressing, and aqueous extraction. The method of procesing to isolate seedoils should not affect the endogenous nutritional components originally present in plant oils. Increasing processing temperatures can improve oil yield but at the same time can negatively affect oil quality

(Ferchau, 2000). Oils expelled at temperatures below 60° C are classified as “cold pressed” and have a positive market connotation (Goodrum, 1987).

2.6.3 Post-extraction stage

The expressed oil invariably contains a certain quantity of suspended particles that needs to be removed. Therefore, purification by sedimentation, filtration and centrifugation are done to improve its quality (Bachmann, 2001; Ferchau, 2000)

2.7 Biofuel blends and their combustion characteristics

Basic studies have shown that over a short period of time, 100 % VO fuels performed satisfactorily in unmodified diesel engines in terms of performance indicators including power output, torque, thermal efficiency and fuel consumption for a number of different vegetable oils in different makes and models of diesel engines (Sustainable Energy, 2006; Bhat and Murthy, 2004; EPA, 2002; Opondo, 2010). Further, Protzen (1997) successfully tested straight vegetable oil from Sesame, *Jatropha*, wild borage, Safflower, Sunflower on kerosene stoves and lamps. It was found that these oils could be used in burners and that the burners performed better when modified. In addition, Vegetable oils have been used as fuel blends; blend of peanut oil with petroleum-derived diesel (Ferchau, 2000; Clements, 1996), castor oil has been for many years used as an additive in special blends. The blends have been found to limit solubility in petrol and result in a fuel saving of nearly 4 % (Shitanda, 1994). Blending VOs and diesel fuels together lowers the viscosity of the resulting oil mixtures (USDOE, 2004; Stout, 1990).

Bio-diesel fuels, blends of biodiesel and distillate heating oils have been shown to reduce air emissions and offer other advantages compared to conventional fossil derived heating oil. Recent combustion tests by Brookhaven National Laboratory indicate that blends of heating oil and biodiesel fuel can lower nitrogen oxide emissions from residential oil burners by 10 percent to 20 percent when compared to conventional distillate fuel oil. In addition, sulfur oxides and green house gas emissions are also substantially lowered (Batey, 2004).

The combustion characteristics of liquid biofuels have been found to differ from those of regular fuels due to difference in fuel flow, physical phase change, fuel atomization to chemical reaction and heat exchange. However, substitution of fossil-based fuels with liquid biofuel depends on inherent properties of the fuel (World Energy Council, 2010).

2.8 Kerosene

Kerosene is the name given for the lighter end of a group of petroleum streams known as the middle distillates. The major components of kerosene are branched and straight chain paraffins and naphthalenes and these normally account for 70 percent of the material. Aromatic hydrocarbon, mainly alkyl benzenes and alkyl naphthalenes do not normally exceed 25 percent of kerosene streams. Olefins do not normally account for more than 5 % of the kerosenes (API, 2003). Table 2.4 shows some of the physical and chemical fuel properties of kerosene.

Table 2.4: Some kerosene fuel properties

Fuel	Pour point (°C)	Density (kg/dm ³) @ 15 °C	Flash point (closed cup) °C	Kinematic viscosity at 20°C (mm ² /sec)	Gravity (° API)	Sulfur (wt %)
Straight-run kerosene	-49	0.81	62	1.5 – 2.5	43	0.47
Hydrodesulfurized kerosene	-55	0.82	60	– 2.5	41.9	0.07

(source: American Petroleum Institute, 2003)

Kerosenes is the primary ingredient in a variety of jet fuels; it is most desirable for civil aviation because of its lesser fire hazard when refueling or when accidents occur (Chevron 2000); and are classified as Jet A-1, Jet A and AVTUR/JP-8. Kerosene is also used as diesel fuel No.1, domestic heating fuel (Fuel oil No.1) and to lesser extent as a solvent. Both diesel fuel and home heating oil No.1 are essentially equivalent to kerosene. The final products are kerosene that contains additives that are specific for the intended use. Otherwise, they are all virtually indistinguishable on the basis of their physical or chemical properties (API, 2003).

Some advantages of a kerosene-type fuel over gasoline include: It is a better lubricant for the fuel pumps because of its relatively high viscosity and it has a calorific value about 10 percent higher than gasoline (per unit volume) (API, 2003).

2.9 Some physical and chemical property characteristics of seed oil fuels

Properties of oil fuels vary with their natural composition. They have considerable influence on the performance and reliability of a burner (UNEP, 2006 a). Some of the biofuel oils properties determined and similar to petroleum fuel properties include: Density, specific

gravity, viscosity, calorific value, pour/cloud point, flash and fire point, ash content, carbon residue, Acid value, sulfur content and are as identified by Agrawal, 2008); Sustainable Energy Ireland, 2006); Ferchau, 2000; Stout, 1990; Goodrum, 1987; Bhat et. al., 2004; Opondo, 2010 and Chevron, 2000). Giuseppe and Eleonora, 2007 classified these properties as physical properties comprising Density, specific gravity, viscosity, calorific value, flash point, cloud point and chemical properties comprising carbon residue, sulphur content, Ash content and Acid value.

Determination of values of these properties for fuels help in choosing fuels for specific use and also for blending to obtain a mixture of desired properties. For instance, *Jatropha* SVO blended with diesel reduced its density and viscosity and could be used without preheating (Achten et. al., 2008; Mahanta et. al., 2006 and Pramanik, 2002).

2.9.1 Density and specific gravity

Density is the ratio of the mass of matter to its volume while specific gravity is the ratio of the mass of the liquid (oil) to the mass of equal volume of water at 288.5 K. The hydrocarbons in oil vary, therefore, the density of crude oils vary from one to another, similarly density of petroleum products vary. Density therefore is used to classify oils as heavy or light, for instance, LPG with density of 520 kg/m³ is classified as light while fuel oil at 900kg/m³ is heavy (OECD/IEA, 2005). Saeed and Bashier (2010) in their study of Physico-chemical analysis of *Ximenia americana L.* seeds oil found that it posses density of 0.9376g/ml.

The American Petroleum Institute (API) gravity is defined in terms of the specific gravity as in equation 2.1:

$$\text{API Gravity} = \frac{141.5}{\text{specific gravity}} - 131.5 \text{ (API degrees)} \quad (2.1)$$

The relationship between API gravity and specific gravity is such that the higher the API gravity, the higher the energy content per tonne. The higher the specific gravity, the higher the energy content per unit volume.

Specific gravity of VOs has been found to vary betwen 0.698 and 1.188 at 288 K (Peterson and Jones, 2002). It influences performance of pumps in fuel systems, atomization in combustion chambers, and furnaces (Abdullah, 2010). High relative density indicates a

low spontaneous ignition temperature and a corresponding resistance to diesel knock. Liquid fuel density can be measured by its volume or mass. In order to convert from one to the other, the fuel density or specific gravity is essential. Since volume changes with changes in temperature, then data on specific gravity are reported with reference to specific temperature, usually 15 °C. Specific gravity is also quoted as a percentage.

2.9.2 Viscosity

Bureau of Energy efficiency (2006) defined viscosity as that physical property of a fluid, which offers resistance to relative motion of its parts. Therefore, for oil, it corresponds to an internal fluid friction produced by the molecules of an oil as they flow past one another (Esposito, 1994). Viscosity is categorized into dynamic (μ) and kinematic viscosity (γ).

Dynamic viscosity (μ) of a liquid may be defined as the tangential force on unit area of either two parallel planes at unit distance apart when the space between them is filled with a liquid and one of the planes moves with a unit velocity in its own plane relative to the other. Kinematic viscosity (γ) is defined as the quotient of the dynamic viscosity and the density of the sample i.e

$$\gamma = \frac{\mu}{\rho} \quad \text{mm}^2/\text{sec} \quad (2.2)$$

since viscosity changes rapidly with temperature change, oil becomes thicker as temperature decreases and thins when heated; hence numerical value of viscosity has no significance unless temperature of test is specified e.g 40, 70, 100, and 180 °C.

Past studies (Niewiadomski, 1990) on kinematic viscosity for rapeseed varieties was approximately 65 mm²/s and 24 mm²/s at 30 °C and 60 °C respectively. This result was reported to be a good agreement between calculated and experimental values. Agrawal (2008) study on temperature-viscosity relationship also noted that *Jatropha* and *Karanja* (*Pongamia pinnata*) seed oils have high viscosity at room temperature and therefore, before use as straight vegetable oil in diesel engines, preheating using exhaust heat brought viscosity within the prescribed ASTM limits.

Viscosity ranking of some oils, seedoils and fuel oils are as in Table 2.5:

Table 2.5: Kinematic viscosity ranking of oils, seedoils and fuel oils

Fuel type	Kinematic viscosity (mm ² /s) at 37.8 °C
Ethanol	1.2
Diesel distillate	3.9
Safflower methyl ester	7.6
50/50 blend of diesel sunflower oil	10.9
Linseed	29.3
Coconut oil	29.4
Safflower oil	32.6
Soy bean oil	33.5
Sunflower oil	34.7
Cotton seed oil	36.8
Rapeseed oil	37.5
Peanut oil	40.6
SAE 10 lube oil	41.7
SAE 50 lube oil	270
Castor oil	293

(source: Stout, 1990)

Further, Saeed and Bashier (2010) found *Ximenia americana L.* seeds oil posses viscosity as shown in Table 2.6 at the stated temperature.

Table 2.6: Viscosity Data for *Ximenia americana L.*

Temperature (°C)	Viscosity (cp)
70	42
65	48.82
60	56.20
55	66.34
50	80.16
45	94.90
40	117.01
35	143.73
30	183.35
25	227.58

Source: (Saeed and Bashier, 2010)

Massey (1989) notes that viscosity of a fluid cannot be measured directly; but its value can be calculated from some equation relating it to quantities that are directly measurable. Viscosity is expressed by the number of seconds required for a certain volume of liquid at some standard temperature to flow out through an orifice or hole of a certain small diameter under the force of gravity.

$$\text{Therefore } \mu = \gamma\rho = \left[\left(0.0254 t - \frac{17.93}{t} \right) \times 10^{-6} \right] \rho \text{ m}^2/\text{s} \quad (2.3)$$

The saybolt viscometer is an industrial device that uses the capillary tube principle for measurement of viscosities of liquids. Redwood viscometer and Engler viscometer differ in detail, but not in principle (Massey, 1989; Holman, 1994).

2.9.3 Calorific value

The calorific value of an oil is the quantity of energy released as heat per unit mass of oil burned in oxygen under pressure at constant volume when the combustion products are cooled (normally) to the initial temperature of 298 K (UNEP, 2006a). The unit of measure is J/kg.

Since most fuels are a mixture of hydrogen and carbon as the main components; during combustion, hydrogen in fuel combine with oxygen, it forms water in gaseous or vapour form at high temperature of combustion. This water in most cases is carried away with other combustion products from container where combustion takes place. When combustion gases cools, water condenses to liquid state releasing heat called latent heat which is wasted in the atmosphere.

Calorific value or Heating value or heat of combustion of a fuel can be expressed as either gross or net. Gross value is all the heat released by a fuel when combusted including that carried away in the water released during combustion while net value excludes latent heat of the water formed during combustion. The difference between the two gross value and net value has been found to be between 5% to 6% of the gross value for solid and liquid fuels and about 10 % for natural gas (OECD/IEA, 2005). Calorific value of straight vegetable oils have been found to be 10 % lower than mineral diesel because of presence of oxygen (approximately 10 % w/w) in their molecular structure (Abdullah, 2010; Agrawal, 2008).

Jatropha oil calorific value is between 38.2-39.63 J/kg compared to diesel 42-46 J/kg (Pramanik, 2002).

The gross calorific value (Q_g) at constant volume is the heat released per mass of sample burned in oxygen in a bomb calorimeter under standard conditions such that the material after combustion consists of oxygen, carbon dioxide, sulfur dioxide, and nitrogen. The net calorific value (Q_{net}) is the gross calorific value less heat liberated from miscellaneous sources Q_s in the chamber. Gross calorific value (Q_g) is given by relationship equation 2.4.

$$Q_g = C_e \Delta \theta \quad (2.4)$$

Where C_e is effective heat capacity of the calorimeter (mJ/kg °C) and $\Delta \theta$ is the product of its mass and the specific heat capacity of the material it is made of. This heat capacity is determined separately by the combustion of benzoic acid of a certified calorific value under standard conditions (Brown and Lamay, 2004). Thus enables determination of heat liberated from miscellaneous sources Q_s in the combustion chamber. It is calculated from the equation 2.5:

$$C_e = \frac{Q_{ba}}{\Delta \theta_{ba}} \quad (2.5)$$

Q_{ba} = Calorific value of benzoic acid (MJ/kg)

$\Delta \theta_{ba}$ = temperature rise during the determination (°C)

While Q_{net} at constant volume is calculated from the equation:

$$Q_{net} = \frac{Q_g - Q_s}{m_s} \quad (2.6)$$

Where m_s is mass of the sample

2.9.4 Pour point/ cloud point

The temperature at which an oil solidifies or coagulates is its pour point. It indicates the suitability of the oil for cold weather operation. A high pour point indicates that in cold weather, the oil will not flow readily through the fuel system and will not produce a good spray when injected into the engine. Therefore, the pour point is important only when the engine is to be used at low temperatures. In such cases, the oil should have a pour point 16.8 °C to 21.8 °C below the operating temperature. Pour point is an indication of the temperature below which it may not be possible to have gravity feeding of fuel from the reservoir to the engine, however, if fuel is agitated, it may be pumped at temperatures below pour point

(UNEP, 2006 a). *Jatropha* oil has pour point of -3 °C (Achten, 2008).

2.9.5 Flash and fire point

When a liquid is heated, there is addition of energy to the molecules of the liquid which permits them to escape into the vapour–air mixture above. As a result, a vapour concentration can be envisaged that eventually becomes sufficient to support combustion on application of some flame; that temperature at which this occurs is flash point. An oil's flash point is the lowest temperature at which it will give off flameable vapours in sufficient quantity to flash or momentarily ignite when brought in contact with a flame (Bureau of Energy efficiency, 2005). Flashpoint of the seedoils and their blends with kerosene will determine the two parameters under investigation: flame height and fuel mass burned in that the vapour will determine flame height and also the rate of release of the vapour affect the fuel burning rate. Further, the flash point is important for safety purposes and serves as a measure of the fire hazard. It is used to evaluate the more volatile gasolines that may flash at temperatures below 0 °C. The flash point for kerosenes varies between 38 °C and 128.2 °C (Bureau of Energy efficiency, 2005; UNEP, 2006 a). Pramanik (2002) reported that *Jatropha* oil flash point to be 210 °C, and Mahanta, et. al., 2006) reported 240 °C well within range identified by Achten (2008).

2.9.6 Carbon residue

When a fuel is burned with a limited amount of oxygen, a residue is obtained called the carbon residue. It represents the heavier ends of the liquid fuel (also the gum content if any) that most probably will escape complete combustion and therefore yield carbon in an engine. High carbon residues contribute to deposits in the combustion chamber and around the nozzle tips, thus interfering with the spray shape (UNEP, 2006a; Bureau of Energy Efficiency, 2005). Experimental studies done on diesel Engines fueled using SVO from *Jatropha* and Karanja (*Pongamia pinnata*) indicate higher carbon residue between 0.07 -0.64 g kg⁻¹ despite the 10wt% of its oxygen content (Abdullah, 2010; Agrawal, 2008; and Achten, 2008).

2.9.7 Sulfur content

Hydrocarbon fuels may contain free sulfur, hydrogen sulfide, and other sulfur compounds. Sulfur or sulfur compounds are objectionable for several reasons. In some forms notably free sulfur and hydrogen sulfide, the sulfur is corrosive element of the fuel that can

corrode fuel lines and other engine parts. In all forms, sulfur will unite with oxygen to form sulfur dioxide that, in the presence of water at low temperatures may form sulfurous acid (UNEP, 2006 a). *Jatropha* SVO has been found to have 0 - 0.13 g kg⁻¹ sulfur content (Atchten, 2008) and therefore less corrosive when used in fuel systems, Engines and its combustion by-products not harmful to the environment.

2.9.8 Ash content

Ash content of the oil is a measure of the incombustible material in the oil in form of hard abrasive solids and soluble metallic soaps. The ash usually consists of such impurities such as sand and rust which are extremely abrasive-like sandpaper, soluble metallic soaps (Shitanda, 1994). These contribute to engine deposits, injector and fuel pump wear as well as piston ring wear and generally emission of particulate by straight vegetable oil such as *Jatropha* and Karanja (*Pongamia pinnata*) SVO (Agrawal, 2008). It has been reported that fuels should have ash content of less than 0.01, while refined oils generally have lower ash content (UNEP, 2006 a).

2.9.9 Acid Value

The acid value of vegetable oil indicates the quality of oil. It is expressed as the amount in milligrams of Sodium Hydroxide (NaOH) required to neutralize free fatty acids contained in one (1) gram of oil (Kardish and Tur'yan, 2004).

Acid value is affected by duration and conditions of storage of plant oil. Free fatty acids in crude *Jatropha* plant oils increase in the presence of moisture and oxidation due to hydrolysis of triglycerides hence degradation of oil. Bachmanns and Hirata (2007) reported percentage Free fatty acid values of three plant sources as crude *Jatropha* 14.9 %, crude palm oil 6.1 % and net crude coconut oil 1.2 %.

CHAPTER THREE

METHODOLOGY

3.0 Seed sample collection

Ximenia americana L. seeds were collected from Baringo, and Makueni Counties of Kenya (Figure 3.1). The Baringo North and Mogotio Districts samples were ripe fruit hand picked from the trees. The seeds were then peeled out of the pulp and dried in the sun; however, final moisture content was not determined. Samples from Makueni were obtained from the Kenya Forest Research Institute (KEFRI) Headquarters in Muguga where they had been dried and preserved. The seeds samples were mixed and stored in a polythene bag before pressing. Sample *Jatropha curcas* seeds were obtained from Kwale and Kibwezi Districts; these were the places the plant had been adopted by farmers and large seed amount could be obtained. *Jatropha* seeds from both sites were mixed, stored in polythene bag before pressing. Seed sample collection sites in Kenya are as in Figure 3.1.

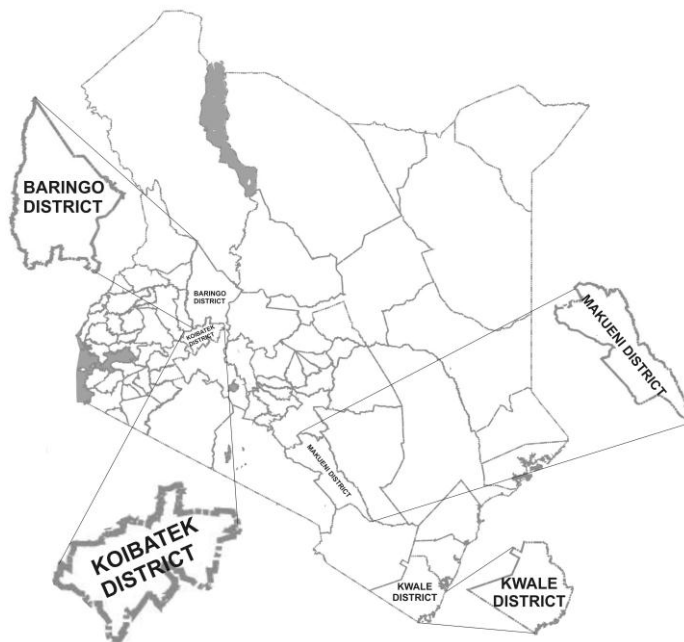


Figure 3.1: Seed Sample collection sites in Kenya

3.1 Oil Extraction

To obtain seed oil samples, the sour plum seeds were pressed using a screw press at the Kenya Industrial Research Development Institute (KIRDI) in Nairobi. Similarly, *Jatropha*

seeds were pressed using a screw press at the Energy Africa Limited *Jatropha* seed press in Shimba Hills in Kwale. The extracted oils were seaved using 1mm seave to remove particles, then stored in airtight plastic bottles. The Kerosene sample was bought from retail petrol station outlet in Nakuru Town.

3.2 Procedure for data collection

Data was collected by conducting experiments on sample seed oils in the laboratory as described in sections 3.2.2 to 3.6.

3.2.1 Experimental Design

The fuel properties determined were classified as physical and chemical properties. Therefore, two-factor experiment was considered. Randomized block design was used during determination of fuel properties experiments. Since these experiments were conducted for more than one day, this experiment design removes time effects which are random effect factors so that it does not vary given physical or chemical property value which is the fixed effect factor required from each property determination experiment. All tests in each block were run in random order to find each characteristics value.

Completely Randomized experiment design was used in allocation of experimental units: tin lamps and stoves to various treatments: percentage blends of kerosene with seed oil. The purpose of randomization was to eliminate factors that would produce trends in data that would be contrary to parameter values being investigated. In randomizing the experimental units, each unit (tin lamp) was identified by sticking a numbered label on its surface. Labels with percentage blends of oil were made and folded to conceal label then mixed and picked at random without replacement to assign the percentage blends of oil to the tin lamps. In running two replicate burning tests, the six treatments/units combination denoted B_nU_n , (B represent blend percentage such as 10% Kerosene 90% Sour plum and subscript n represent numerical identity of blend percentage such as 1 and U represent unit e.g tin lamp; subscript n represent numerical identity of unit such as 1) were numbered from 1 to 12 i.e 2 replicates multiplied by 6 blends. Then a random sample size 12 was chosen without replacement from integers 1 through 12 as illustrated in Table 3.1.

Table 3.1: Randomization of experimental units

Test Number	Test Condition	Random order in which tests were conducted
1	B ₁ U ₁ 20% Ke 80% Xa Lamp 1	12
2	B ₁ U ₁ 20% Ke 80% Xa Lamp 1	6
3	B ₂ U ₂ 50% Ke 50% Xa Lamp 2	2
4	B ₂ U ₂ 50% Ke 50% Xa Lamp 2	9
5	B ₃ U ₃ 30% Ke 70% Xa Lamp 3	1
6	B ₃ U ₃ 30% Ke 70% Xa Lamp 3	10
7	B ₄ U ₄ 100% Xa Lamp 4	5
8	B ₄ U ₄ 100% Xa Lamp 4	7
9	B ₅ U ₅ 10% Ke 90% Xa Lamp 5	11
10	B ₅ U ₅ 10% Ke 90% Xa Lamp 5	4
11	B ₆ U ₆ 40% Ke 60% Xa Lamp 6	8
12	B ₆ U ₆ 40% Ke 60% Xa Lamp 6	3

A similar procedure was done to assign blends to the stoves.

In all the experiment tests, two replications of observations was done in order to improve the precision of the estimates of parameter mean.

3.2.2 Conduct of Experiments

From the *Ximenia americana L.* seed oil sample obtained, quantities were drawn to test each sour plum seed oil fuel property parameter characteristic: Density, specific gravity, viscosity, calorific value, pour/cloud point, flash/fire point, ash content, carbon residue, acid value, sulfur content. Figure 3.2 shows a sample of unblended sour plum seed oil.



Figure 3.2: Unblended Sour plum oil

Further, about 40ml of sour plum (*Ximenia americana L.*) oil was drawn from sample to test seed oil burning characteristic parameters: flame height and burning rate; then 40ml varying blends of *Ximenia americana L.* seed oil with kerosene was used to test burning characteristic parameters: flame height and burning rate. Similarly, *Jatropha curcas* seed oil sample was drawn and blended with varying ratio of kerosene to make upto 40ml volume and tests to obtain data on its burning characteristic parameters.

Finally, samples of both *Ximenia americana L.* and *Jatropha* seed oil was drawn and blended separately in ratios 10%, 20% and 50% with kerosene upto 275 ml volume. Then burning characteristic change in temperature of one litres of water heated over improvised wick stove was measured.

3.3 Determination of *Ximenia americana L.* seed oil fuel properties

Characterization experiments aimed at collecting the mean values of the identified *Ximenia americana L.* seed oil fuel properties as biofuel. The experiments on fuel properties were as described in the section 3.3.1 to 3.3.9.

3.3.1 Determination of Density

The density and specific gravity of the oil and water was determined using a hydrometer. A clean dry hydrometer was dipped in sample oil at room temperature approximately 23°C K and density was read. Density of water at this temperature was similarly measured and value recorded. The specific gravity of oil was calculated as in equation 3.1

$$\text{Specific gravity} = \frac{\rho_{15.5(o)}}{\rho_{15.5(w)}} \quad (3.1)$$

Where $\rho_{15.5(o)}$ and $\rho_{15.5(w)}$ are density of oil and water respectively each at 15.5 °C

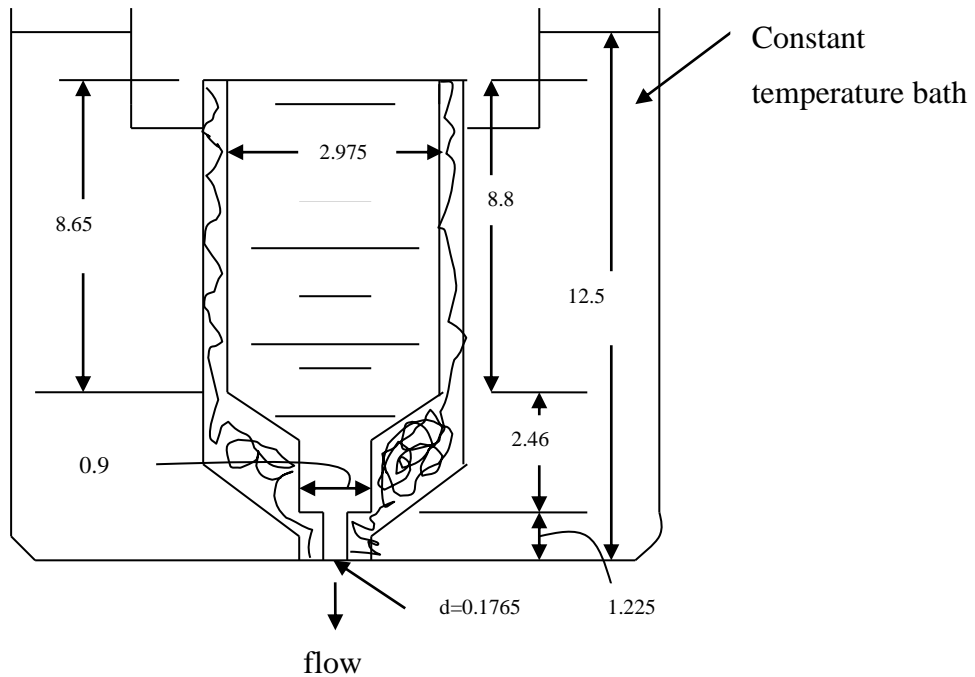
Temperature correction

Since the density of sample was measured at temperature $\theta_1 = 23^\circ\text{C}$, correction was done to the measured density at required temperature $\theta = 15.5^\circ\text{C}$ using the equations 3.2:

$$\rho_o = \rho_o + (\theta_1 - \theta) \times 0.00068 \text{ if } \theta_1 > \theta \quad (3.2)$$

3.3.2 Determination of Viscosity

Viscosity was measured by use of a saybolt viscosimeter, which is shown schematically in Figure 3.3.



(All dimensions in centimetres)

source: Holman, 1994

Figure 3.3: Schematic diagram of the saybolt viscometer

The inner chamber held the sample of oil tested. A separate outer compartment surround the inner chamber. It contained a quantity of oil whose temperature was controlled by an electrical thermostat and heater. When oil sample reached $\theta_1 = 313$ K, the metering orifice at the bottom of the centre chamber, was opened and the time 't' it took to fill 60 mL container was then recorded. The mean value of three time readings concordant to 1 percent was taken as the value 't'. Therefore, the kinematic viscosity γ was calculated using the relation equation 3.3.

$$\gamma = \left(0.0254 t - \frac{17.93}{t} \right) \times 10^{-6} \text{ mm}^2/\text{s} \quad (3.3)$$

t represents the time in seconds to drain 60 mL of liquid.

3.3.3 Determination of Calorific value

In the experiment, a bomb calorimeter was used to determine the calorific value of the oil sample. The sample weighing 0.2g was put in a preweighed capsule. Platinum wire 7cm long and 10cm of ignition thread were measured and tied to the bombshell holder.

The sample was then placed in a nickle crucible. Distilled water measuring 5ml was pipetted into the bombshell cup. Oxygen under pressure (100 bars) was pumped into the bombshell cup for combustion. Initial temperature was taken while stirring was done to give steady temperature. The sample was ignited and timed for 10 minutes and final temperature was taken. The following calculations were then done:

Gross calorific = rise in temperature x instrument heat capacity

Instrument heat capacity given was 2036.8 J/s

Correction Value = (weight of capsule x capsule factor) + (thread and wire factor)

Capsule factor = 6845 kJ

Av. Weight of capsule about 0.09 g

Net Calorific value was worked out using equation 3.4:

$$\text{Net Calorific Value} = \frac{\text{gross calorific value} - \text{correction value}}{\text{Weight of sample}} \times 100 \text{ (KJ/g)} \quad (3.4)$$

3.3.4 Determination of Pour point

A sample of the oil was placed in a small bottle fitted with a thermometer at the top. The sample was first heated and then cooled. Finally, it was kept in a cooling medium and the temperature and fluidity was observed at temperature intervals of 3 °C until it solidified. The pour point θ_p was at 3 °C above the temperature at which the oil become solid. (UNEP, 2006a).

3.3.5 Determination of flash and fire point

Flash point and fire point were determined using the open cup tester that had a heater. The oil sample was poured into the sample compartment of the open cup tester to the labeled mark. The initial temperature of sample was recorded and the heater was then switched on. A flame was introduced at intervals to the vapour of the fuel until a pop sound was heard. This was the flash point and this temperature was recorded.

3.3.6 Determination of Carbon residue

This test provide some indication of the relative coke forming tendency of seed oil under degradation conditions. Conradson carbon test was done to determine this property. A sample of the fuel was put in a crucible, which was heated to a temperature about 500 °C. At the end of the heating period, the test crucible containing the carbonaceous residue was cooled in a desiccator and weighed.

The percentage by mass of the carbonaceous-type residue to the original sample was the carbon residue (ASTM D189-01; Bureau of Energy efficiency 2005; and http://www.camincargo.biz/Polaris/lab_maintenance/helpdocs/methoddefinitions.htm).

3.3.7 Determination of Sulfur content

About seven (7) cm of platinum wire and ten (10) cm of ignition thread were measured and tied to the bombshell cup terminals. A preweighed sample was put in a nickel crucible and put in the bombshell cup. Five (5) ml of Sodium Carbonate (NaCO_3) was pipetted and put in the bombshell holder. Oxygen was added at 100 bars pressure for combustion. This was put in the electrolytic water. Stiring was done to give steady temperature and the initial temperature was noted. Ignition was done and timed for 10 minutes. Final temperatures were taken and the gases released collected into a conical flask (Jessup, 1960). Ten (10) ml of conc. Hydrochloric acid (HCl) and 200ml of distilled water was added. The contents were boiled on a hot plate to digest. While boiling, 10 % Barium Chloride (BaCl_2) was added. Contents were then filtered. The filter paper and the residue were put in a preweighed clean platinum dish. These were ashed at 550 °C. The sample was allowed to cool and the final weight measured. The percentage by mass of the final sample residue to the original sample was the percentage sulphur content.

3.3.8 Determination of Ash content

Ash content of oil was determined by weighing 0.5625g (m_o) sample of the oil into a platinum crucible previously tared to within 0.001 g. The crucible was heated gently using cooking gas to a point where the sample ignited and allowed to burn spontaneously untill carbon residue was obtained. The carbon residue was then mixed with distilled water and filtered using an ashless filter paper and filtrate retained. The residue on the filter paper was placed into the platinum crucible and ignited in muffle furnace at a temperature 550°C, till the carbon residue disappeared. The retained filtrate was poured into the crucible and evaporated to dryness over water bath. The crucible was removed from the furnace and the weight of the ash (m_a) determined.

The percentage ash content (AC) was calculated using the equation 3.5 allowing a difference of 0.1g between the duplicates. (UNEP, 2006a; Shitanda, 1994).

$$AC = \frac{m_a}{m_o} \times 100\% \quad (3.5)$$

Where m_a = mass of the ash m_o = mass of the oil

3.3.9 Determination of Acid value

About 25 ml diethyl ether was mixed with 25 ml ethanol and 1ml of phenolphthalein indicator. Five (5) ml of the oil was measured and mixed with the neutral solvent and titrated with 0.1 sodium hydroxide while shaking constantly until a pink colour persisted. The mass of the oil was determined using an analytical scale. Acid value was found as follows equation 3.6:

$$\text{Acid value} = \frac{\text{titrate value (ml of alkali)} \times 5.61}{\text{Weight of oil used}} \quad (3.6)$$

Fuel property values obtained were compared in terms of Percentage difference between the sour plum oil properties obtained and those of *Jatropha* and Kerosene. Paired t-test was used to determine whether there was significant difference between the obtained fuel properties having a percentage difference of below 10%. Pairing done was Sour plum and kerosene pair; then sour plum and *Jatropha* seed oil pair. Those properties found to have a percentage difference of above 10% were concluded to be having significant difference. These properties were further analysed when the oil was blended with kerosene in relation to fuel burning parameters under investigation: flame height and burning rate in order to determine effect of the properties on the burning parameters. Regression analysis procedure was used to test influence of fuel properties: Viscosity, density, carbon residue and Ash content on the mean burning rate and flame height burning parameter values.

3.4 Determination of burning characteristics of unblended Sour Plum (*Ximenia americana L.*) seed oil

The experiment aimed at obtaining the mean values of seed oil burning parameters: flame height and burning rate of unblended sour plum seed oil. *Ximenia americana L.* seed oil was drawn from the expressed sample and put in a 40 ml tin lamp. The tin lamp had its wick holder protruding from the lowest point on the base slanting sideways to aid oil capillarity up the wick. The tin lamp was placed on electronic weighing scale. The wick length beyond

the sprout or wick holder was 10mm. Behind the wick, a scale ruler held by a clamp was set to enable reading of the flame height. Flame height readings were taken at an interval of 180 seconds visualized through a digital camera in front of the wick holder. Figure 3.3 shows experiment setup.

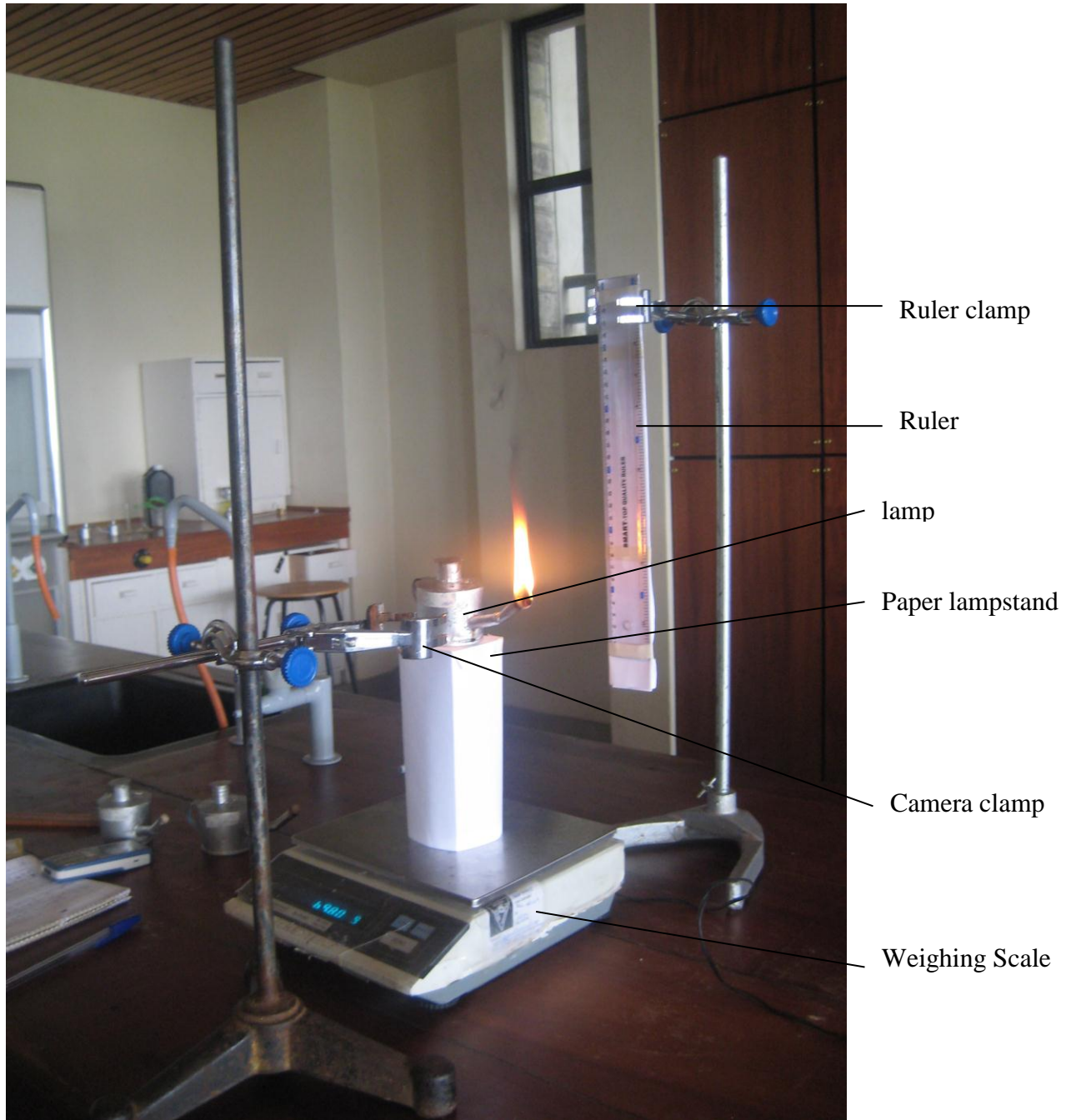


Figure 3.4: Experimental setup for sour plum and Jatropha seed oils burning tests

The camera was zoomed to x 2 for clarity of reading flame height on ruler. Average flame height was calculated from photographs of flame as an average height after every three

minutes. Average burning rate was calculated from the weight loss history measured in three minutes interval by the electronic balance with the minimum division of 0.001 – 0.10 g (Koseki 2001). *Jatropha* seed oil was put in a similar tin lamp and set in the same way and same procedures followed as outlined in section 3.4 to obtain mean values of flame height and burning rate. Two replications of each of the experiments was done. Obtained data was compared with other fuel oils burning characteristics means using t-test.

3.5 Determination of burning characteristics of blended sour plum (*Ximenia americana L.*) seed oil

The experiment aimed at obtaining the mean values of flame height and burning rate as the parameters of seed oil blended with kerosene. Sample sour plum (*Ximenia americana L.*) seed oil was drawn and blended with varying amounts of kerosene: 10%, 20 %, 30 %, 40 % and 50 %. Each blended sample was put in a 40 ml tin lamp having its wick holder protruding from the lowest point on the base slanting sideways to aid oil capillarity up the wick. The tin lamp was placed on electronic weighing scale. The wick height above the holder was 10mm. The wick was then lit. In the background, a scale rule, held by a clamp was set to enable reading of flame height at an interval of three minutes through a digital camera with the burning oil in the lamp between the camera and the scale rule.

The camera was zoomed to x 2 for clarity of reading flame height on ruler. Equal amount of blended oil was put in another similar tin lamp and set on top of an electronic weighing scale then burned. Average burning rate was calculated from weight loss history measured in 3 minutes interval by the electronic balance with the minimum division of 0.001 – 0.10g (Koseki, 2001). Similarly, *Jatropha* seed oil blended with kerosene in 10 %, 20 %, 30 %, 40 % and 50 % ratios was prepared and each put in a similar tin lamp and same procedures followed. Mean values of flame height and burning rate were obtained. Similarly, unblended kerosene was put in a similar lamp and the experiment procedure done to obtain mean values of flame height and burning rate. Two replications of each of the experiments was done.

Correlation analysis procedure was used to test if there was a correlation between mean flame height and mean burning rate of kerosene, the two seed oils and their varying blends with kerosene. T-test was used to compare the mean mass burned and mean flame height of the unblended and blended fuels.

3.6 Determination of burning characteristics of kerosene blended Sour Plum (*Ximenia americana L.*); and *Jatropha curcas* seed oils in modified stove.

The experiment aimed at obtaining the mean temperature change when one litre of water was heated using varying ratios of *Ximenia americana L.* Seed oil blended with kerosene; then *Jatropha curcas* with kerosene blends as fuel and unblended kerosene. About 275 ml of each of the seed oils blended in ratios: 10% , 30 % , and 50 % randomly chosen was put into six 40 ml tin lamps. The tin lamp wick holder protruding from the lowest point on the base slanting sideways to aid oil capillarity up the wick. Adjustable wick Wheel Brand model 641 stove was modified so that the six tin lamps with oil were placed underneath outer top cover of the stove. The protruding wicks of the tin lamps were between inner perforated burner and outer cover. One litre of water was put into an aluminium cooking pan. The modified stoves were lit and the water in the cooking pans heated over the stoves. Temperature of the water was measured at an interval of 3 minutes for 15 minutes. A similar experiment was done when the stove was using unblended kerosene. Mean temperature readings were recorded at the 3 minutes time interval.

Correlation analysis procedure was used to test if there was a correlation between mean power produced by the fuels in experiment section 3.5 and mean power transferred to the water during heating using the fuels in experiment procedure section 3.6. ANOVA was used to compare the mean energy produced by the unblended and blended fuels.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Sour plum seed oil, *Jatropha* seed oil and kerosene property characterization

Characterization of sour plum seed oil was done and results tabulated in Table 4.1 alongside documented kerosene and *Jatropha* seed oil fuel properties.

Table 4.1: Sour plum (*Ximenia americana L.*) seed oil and other oils characterization

FUEL PROPERTY	Kerosene	<i>Jatropha curcas</i> Seed oil	Sour Plum Seed oil	Units
Density	0.78	0.914	0.974	g/cm ³ at 15 °C
Specific gravity	0.811	0.8601	0.8931	
Viscosity	2.0	46.82	204.95	mm ² /s at 27 °C
Calorific Value	43.1	39.63	42.61	mJ/Kg
Pour /Cloud point	-6	8	10	°C
Flash /Fire point	38	235	230	°C
Carbon residue	0.01	0.38	6.06	% mass
Sulfur content	0.01	0.13	0	% mass
Acid value	0.02	4.24	3.4	mgKOH/g
Ash content	0.05	0.15	0.006	% mass

The data on fuel properties obtained from experiments to characterize sour plum seed oil were compared with documented kerosene and *Jatropha* seed oil fuel properties. Fuel properties that had about 10% difference from kerosene were specific gravity, calorific value, ash content and sulphur content, these fuel properties were considered to have had less effect on the burning parameters of the seed oil as compared to kerosene. The remaining properties had difference above 10% compared to kerosene. However, Pour point being a property that is important in lower temperature application of oil was not considered further for study on its influence on burning parameters. On the other hand, Acid value, being a chemical property would require study on specific free fatty acid composition analysis in order to determine specific free fatty acid that could influence seed oil burning parameters and therefore was not considered further in the study.

However, Giuseppe and Eleonora (2007) identified in literature among others by Knothe (2005) that there was a relationship between the chemical structure of oil and some physical

properties of vegetable oil; in particular acidic composition of triglycerides and the calorific value, viscosity, flash point. They further reported that the energy content increases in accordance with the increase in the length of the fatty acid chain, and therefore with the increase in carbon atoms, but decreases when the percentage of carbon decreases with respect to the oxygen. Moreover, the calorific content of the fuel decreases in accordance with the reduction in the hydrogen content. With respect to viscosity; it was reported that the viscosity of oils is directly related to the level of unsaturation and the length of the fatty acid chains. The viscosity tends to decrease when there is an increased presence of double bonds and grows with an increase in the length of the hydrocarbon chain and according to the level of polymerisation in the oil. The length of the fatty acid chain also influence the flash point. The longer the hydrocarbon chain and the higher the level of unsaturation of the vegetable oil is, the higher the flash point will be. These findings explain the high calorific value, flash point, and viscosity of sour plum seed oil since from literature on its fatty acid composition by Řezanka and Sigler, 2007; Saeed and Bashier, 2010, the seed oil has large percentage unsaturated fatty acids and long carbon chain.

Therefore, the following sour plum fuel properties were found to have had above 10% difference from similar kerosene properties: Density, viscosity, fire point, carbon residue and ash content. These fuel properties were thought to have influenced seed oil burning parameters mean mass burning rate and mean flame height.

Viscosity indicates internal resistance to flow; this can be attributed to strong oil inter-molecular attraction. The high density could be as a result of the large number of carbon atoms in the acid chain hence molecular mass is high per unit volume. The Flash point of the sour plum seed oil was found to be high compared to kerosene indicating that when the seed oil is burned, more energy must be supplied to break atomic and molecular bonds. Carbon residue of sour plum seed oil was in the range of residual oil i.e above 1%; an indicator that the seed oil did not completely burn, therefore, when its burning is incomplete, it can be a source of carbon in form of soot: a powder form of carbon that is combustible only with sufficient air to give carbon dioxide and carbon monoxide (Verhoeven, 1989; Kuznetsov, 2005). The sulfur content on the other hand was zero percent indicating that the corrosive effects associated with sulfur together with sulfur dioxide emissions to the environment when burned are not produced by sour plum seed oil. Finally, ash content indicate that there was less salts such as sodium, vanadium, calcium, magnesium, silicon, iron, aluminum, nickel

among others has less corrosion and fouling of combustion equipment even at high temperatures (Bureau of Energy Efficiency, 2005).

Properties that had about 10% difference between corresponding properties in Kerosene were analyzed using paired t-test since it was hypothesized that the fuel properties pair samples were related. The tabulated data is such that corresponding to Sour plum seed oil fuel property is a particular fuel property of kerosene serving as its counterpart. Table 4.2 shows the matched pairs analysis.

Table 4.2: Kerosene and Sour plum seed oil fuel properties matched pair analysis

Fuel Property	Kerosene X_i	Sour Plum Seed Oil Y_i	Difference D_i $(X_i - Y_i)$	Difference squared D_i^2
Specific gravity	0.811	0.8931	-0.0821	0.00674041
Calorific Value	43.1	42.61	0.49	0.2401
Sulfur content	0.01	0	0.01	0.0001
N=3			$\sum D_i = \mathbf{0.4179}$	$\sum D_i^2 = \mathbf{0.2469}$

Therefore the mean of the differences $\bar{D} = \frac{\sum D_i}{n} = 0.1393$ and

the variance of the difference $(\sigma_{diff.})^2 = \frac{\sum D_i^2 - (\bar{D})^2 \cdot n}{n - 1} = 0.0944$

assuming the differences are normally distributed and independent

The hypotheses therefore are:

$H_0: \mu_1 = \mu_2$ which is equivalent to test $H_0: \bar{D} = 0$

$H_a: \mu_1 < \mu_2$

the test statistic t was as follows:-

$$t = \frac{\bar{D} - 0}{\sigma_{diff.} / \sqrt{n}} = 0.0228 \quad \text{with } n-1=3-1 = 2 \text{ degrees of freedom}$$

Comparing the calculated value of t with its tabulated value at 0.05 significance level, rejection region $R: t < -4.303$. The obtained value of $t = 0.0228$ is in the acceptance region and

thus null hypothesis $H_0: \bar{D} = 0$ accepted and conclude that the difference in the listed fuel

properties of kerosene and sour plum was insignificant and therefore, based on these properties, sour plum can substitute kerosene.

The remaining properties with over 10% difference between corresponding property in Jatropha and Kerosene were further analyzed to find their effect on flame height and burning rate burning characteristics when unblended and blended with kerosene.

4.1 Burning characteristics of Sour plum (*Ximenia americana L.*) seed oil

Results of experiments conducted to determine mean mass burned and flame height characteristics of unblended fuels were plotted on bar graphs as shown in Figure 4.1 and 4.2.

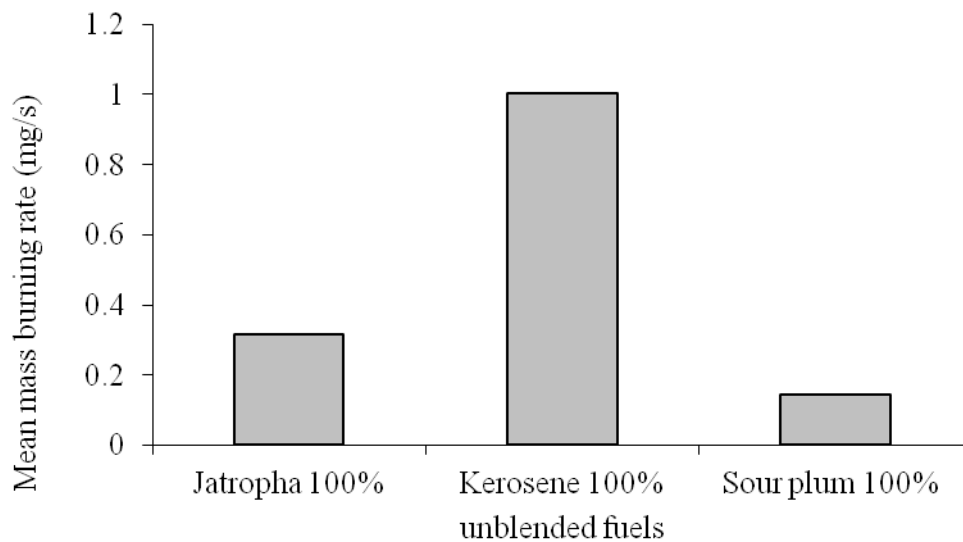


Figure 4.1: Mean mass burning rate of unblended fuels

Figure 4.1 shows that Kerosene mean mass burning rate was higher than Jatropha and sour plum indicating that more mass of kerosene per unit time had burned as compared to Jatropha and sour plum. This could be attributed to fire point fuel property, in which heat energy must be supplied until temperature is reached that the fuel change state from liquid to vapour then ignite. Kerosene reaches this before either Jatropha or sour plum, and by then, kerosene has burned hence the high mass burned per unit time. Other fuel properties such as density and viscosity could aid firepoint since kerosene flows easily due to low viscosity releasing high volume and mass of the fuel to be available for burning in the lamp wick for the time interval this parameter was measured.

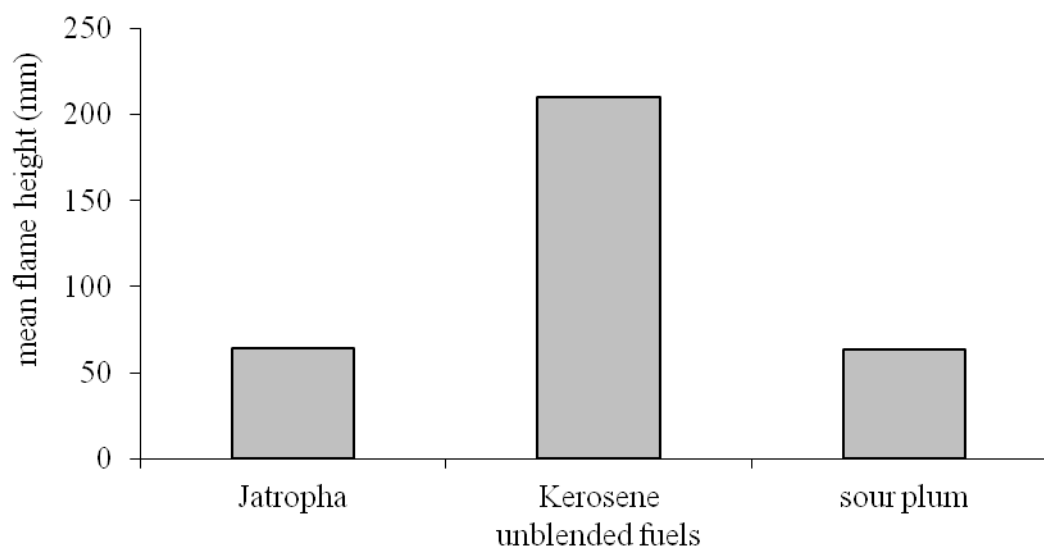


Figure 4.2: Mean flame height of unblended fuels

The flame height of sour plum seed oil was lowest of the three oils. This could be due to effect of viscosity, fire point, carbon residue and ash content fuel properties. Since sour plum viscosity and fire point are high, the volume of fuel vapour burned is less than kerosene or jatropha that have low viscosity and fire point. In addition, deposits of both carbon and ash on the wick after burning could have limited the flow of the fuel during burning.

Graph of unblended fuel properties together with parameters mean mass burned and mean flame height are as in Figure 4.3:

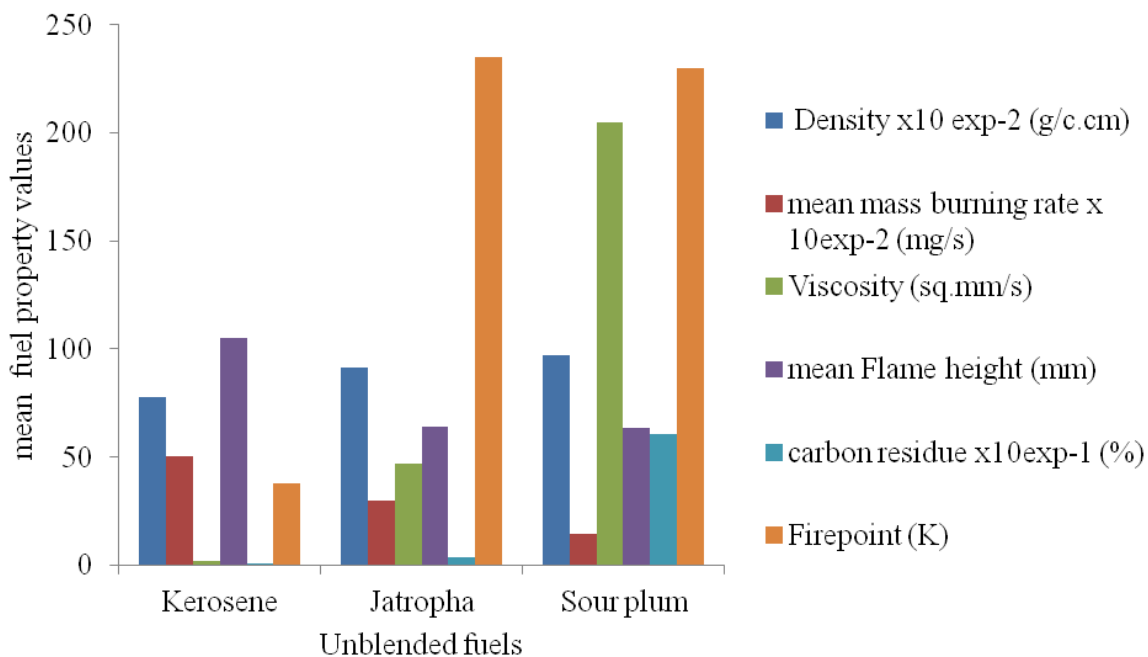


Figure 4.3: Selected fuels properties and mean parameter values

Figure 4.3 illustrate that both mean mass burning rate and flame height parameters for the three fuels were such that, with high values of fuel properties such as viscosity, density and fire point; both parameters recorded reduced values. Sour plum seed oil recorded the lowest mean mass burning rate and flame height while kerosene recorded the highest values of the three oils; probably, Sour plum and Jatropa seed oils being of high firepoint compared to kerosene; during heating and combustion the high fire point requires high energy input before the fuel ignites and burns; and while burning, the rate of burning the mass per unit time is also low. Further, carbon residue could be affecting the flame height; the higher this property value is, the lower the flame height probably since residue of carbon inhibits flow of fuel for burning. Viscosity and density of unblended Jatropa and sour plum were higher than kerosene; this high viscosity could be due to the oil molecules having high friction, therefore their molecules could be closely bound together thus resisting flow.

4.1.1 Burning characteristics of unblended Sour plum (*Ximenia americana L.*) seed oil

When sour plum seed oil was burned then mean mass burned and flame height above the burner wick measured and recorded at an interval of three minutes for thirty (30) minutes, it was found that the mean mass burned was 0.236 grams in three minutes or 1.461 mg/s while

the mean flame height was 63.25 mm. The wick of lamp used to test the three fuels did not burn and therefore did not influence either the mean mass burning rate or the flame height parameters recorded in the experiments. However, as fuel burned, black solid residue formed at tip of wick and could have limited the fuel mass flow for combustion and height of flame above the wick. The solid residue may have consisted of carbon which ignites only at high temperatures about 700 °C (Kuznetsov, 2005). Black deposits were observed on the tip of the wick when all oils were burning, probably due to presence of carbon and gum in the seed oil. Overall trend was that the mean mass of fuel burned reduced with time, so that amount burned in the first three minutes was less than amount burned in the last three minutes of the thirty minutes burning tests were done. This trend could be due to reduction of fuel in the tin lamp over time and also limitations of capillarity through the wick as fuel amount reduced in the tin lamp.

4.1.2 Mean mass burning rate and flame height characteristics of blended sour plum (*Ximenia americana L.*) seed oil

When the two parameters: mean mass burning rate and flame height above the burner wick were measured and recorded at an interval of three minutes for thirty (30) minutes for sour plum seed oil/Kerosene blended samples, there was increase in mean values of both parameters.

This increase was also a trend as kerosene blending percentage increased from 10 % to 50 % by volume as illustrated in the graphs Figure 4.4.

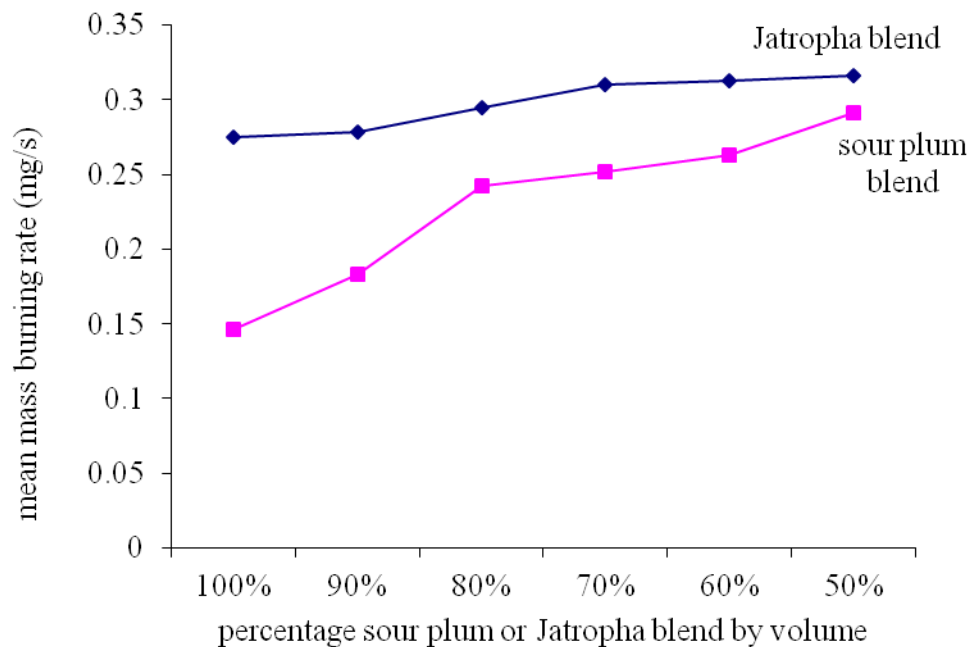


Figure 4.4: Mean mass burning rate of unblended Sour plum and Jatropha oil

The Figure 4.4 shows that when sour plum and Jatropha seed oils were blended with kerosene, the mean mass burned per second increased with increased percentage of kerosene. There is difference in burning rate on blending sour plum with 10% kerosene; this difference is also noted when blend increases to 20% and is highest at 50% blend. This is unlike Jatropha that its burning rate realized little difference with increasing blend of kerosene above 10% ratio. In both seed oil blends, as the kerosene in the blend increase, kerosene could have improved fuel properties such as fire point and viscosity that are both reduced and therefore fuel blends can easily flow to burner wick tip due to lower viscosity and ignites at lower fire points since relatively large quantity of fuel vapour burns compared to unblended sour plum or Jatropha for equal length of time.

The calculated mean viscosity of blended sour plum was plotted with mean mass burning rate as shown in Figure 4.5:

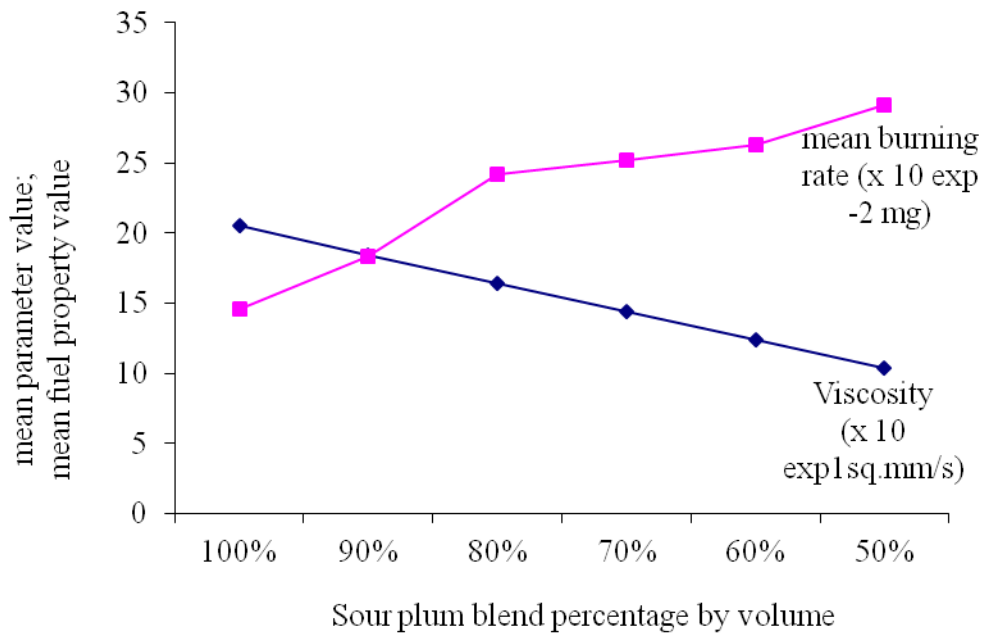


Figure 4.5: Viscosity and mean Mass burning rate of blended sour plum

The mean mass burned and viscosity relationship in Figure 4.5 illustrates that the mean mass burned of kerosene-blended sour plum increases as its viscosity reduce. Reduction of viscosity is as a result of blending with kerosene that has relatively low viscosity compared to sour plum. Increased mean mass burned of fuel blends could be due to reduced viscosity on blending sour plum with kerosene. When blended, sour plum oil molecules friction is reduced, hence low resistance to flow and therefore increasing volume of fuel vapour when heated hence mass burned of fuel vapour per unit time increases mean mass burning rate.

The calculated mean of fire point was plotted with mean flame height in Figure 4.6:

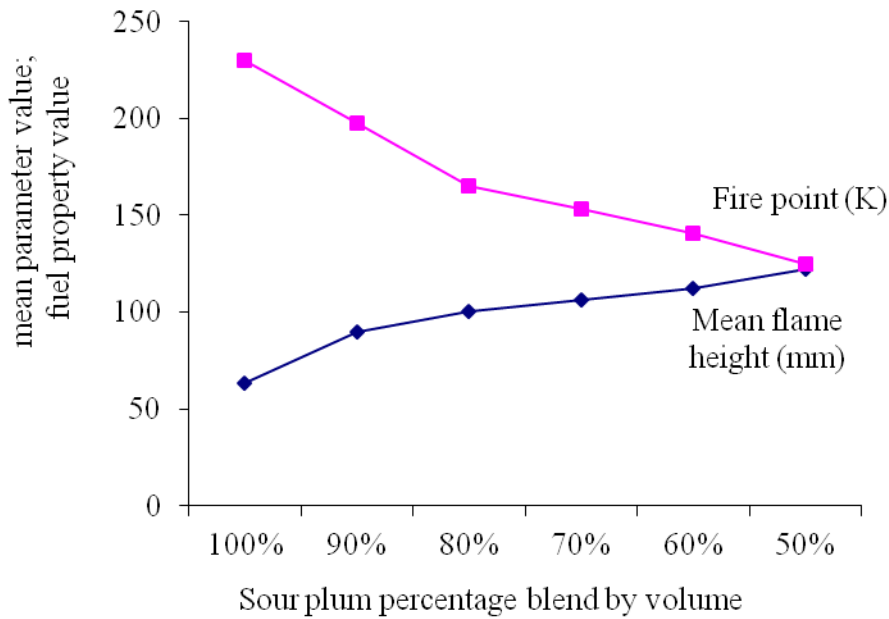


Figure 4.6: Mean flame height and fire point of blended sour plum

The calculated mean of fire point when plotted with measured flame height burning characteristic as in graph Figure 4.6 illustrates that the flame height measured for blended sour plum increased as fire point reduced with increased kerosene blend. The observed increase in mean flame height parameter values could be attributed to effect of fire point as fuel property in kerosene that made blend ignite at lower ignition temperature therefore more vapour of fuel burned due to ease of fuel to form vapour spread over the wick tip, ignite and support burning.

Further, as illustrated in figure 4.7, carbon residue and ash content deposit could have been low compared to burning unblended seed oils, thus more fuel was available on wick tip with less residue deposit.

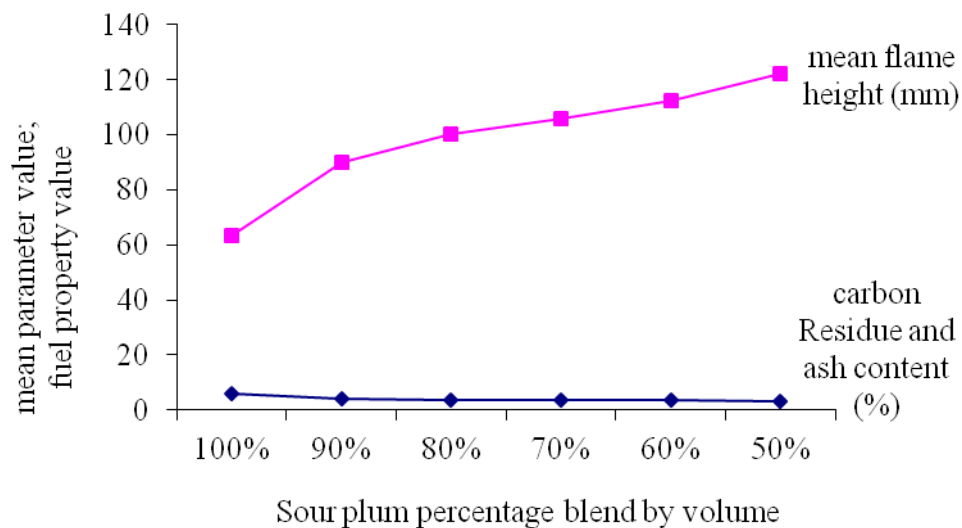


Figure 4.7: Mean flame height, carbon and ash content of blended sour plum

Therefore blending sour plum seed oil improved burning rate and flame height close to Kerosene as found in other vegetable seed oil (Agrawal 2008).

4.2 Burning characteristics of *Jatropha curcas* seed oil

The unblended *Jatropha* seed oil recorded low mean value of the two parameters: mean mass burning rate of 0.5385 g and 64.25mm flame height above the burner wick, but higher than sour plum seed oil. These parameters improved upon blending with kerosene, although there was little difference between some blend parameters as illustrated in the bar graphs Figures 4.8 and 4.9.

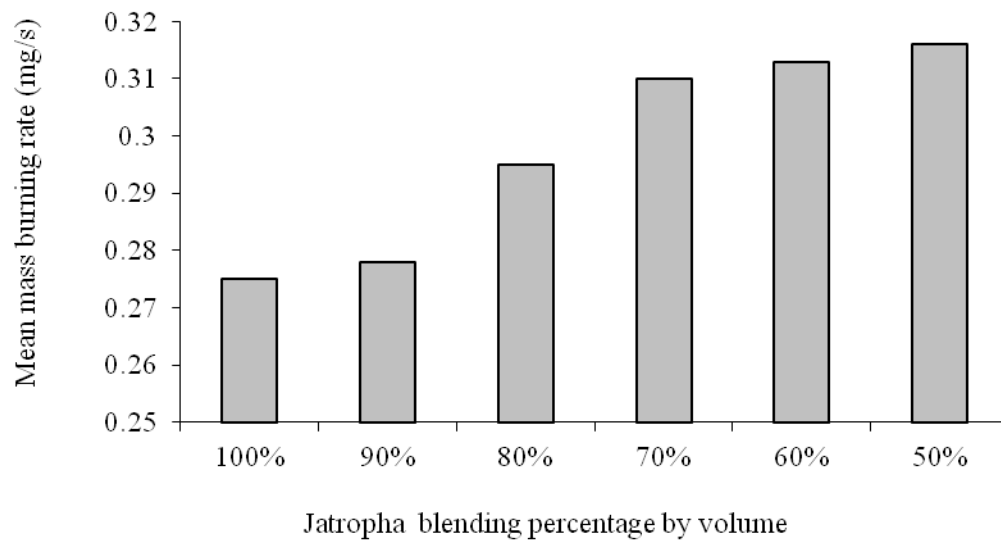


Figure 4.8: Mean mass burning rate of kerosene-blended Jatropha seed oil

Figure 4.8 shows that blending 90% Jatropha with 10% Kerosene has little difference in mean mass burning rate compared to when blended at 80% with kerosene. However, difference could be realized above 70% blends. At 50%, there is little difference compared to 60% blend.

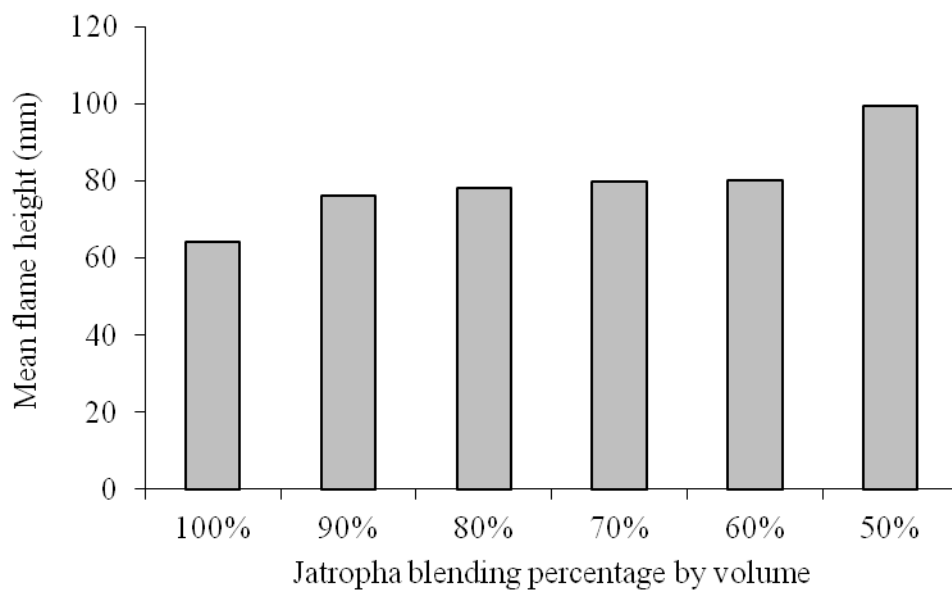


Figure 4.9: Mean flame height of kerosene-blended Jatropha seed oil

Referring to Figure 4.9, the mean values of Jatropha-kerosene blend flame height parameter there was difference in flame height when blended with kerosene at 90%, subsequent higher blends of kerosene had little difference, however, notable difference exist between 40% and 50% blends. Therefore, with higher kerosene blends, higher flame heights

are realized. This could be attributed to improved fuel properties with increased kerosene in the blends.

The data obtained from experiments to determine the mean parameters: mass burning rate and flame height of unblended and kerosene-blended sour plum seed oil and *Jatropha* seed oil was subjected to correlation analysis as shown Tables 4.3 and 4.4.

Table 4.3: *Jatropha curcas* seed oil sample variables correlation analysis

Fuel Percentage Blend	Jc Mean Mass burning rate in g/s (X)	Jc Mean Flame Height in mm (Y)	X ²	Y ²	XY
100% Jc	2.775	64.250	8.952	4128.063	178.294
90%Jc 10%Ke	2.778	76.250	7.701	5814.063	211.823
80%Jc 20%Ke	2.992	78.000	7.717	6084.000	233.376
70%Jc 30%Ke	2.947	79.750	8.685	6360.063	235.023
60%Jc 40%Ke	3.100	80.000	9.610	6400.000	248.000
50%Jc 50%Ke	3.156	99.500	9.960	9900.250	314.022
Sum	17.748	477.750	52.625	38686.438	1420.538

Jc – *Jatropha curcas*

Ke – Kerosene

The Pearson’s product-moment correlation coefficient r was applied on the raw data where sample seed oil burning characteristics parameters mean mass burning rate and flame height are denoted x and y respectively.

Therefore Pearson’s product moment correlation coefficient r was obtained as follow:

$$r = \frac{1.2255}{(0.145)(10.373)} = 0.815$$

The value of r obtained indicates that there was correlation between the sample variables: mass burning rate and flame height of *Jatropha curcas* seed oil. It can also be said that, since $r^2 = 0.664225$, then 66.42% variation in flame height is explained by mass burning rate of *Jatropha* seed oil.

Since sample correlation coefficient r is the estimator of population correlation coefficient ρ (rho), the null and alternative hypothesis are:

$$H_0 : \rho = 0$$

$$H_1: \rho \neq 0.$$

The value of correlation coefficient $r = 0.815$ computed from sample size of 6 for *Jatropha curcas* seed oil sample variables mass burning rate and flame height compared to tabulated value 0.8114 at $\alpha = 0.05$ level of significance was larger. Conclusion was drawn that it is statistically significant. Therefore, in the population of *Jatropha curcas* seed oil, there was indeed association between mass burning rate and flame height.

Similarly, Pearson's product moment correlation coefficient of burning characteristics mass burning rate and flame height denoted x and y for Sour plum seed oil was determined in Table 4.4 analysis as follows:

Table 4.4: Sour plum seed oil sample variables correlation analysis

Fuel percentage Blend	Xa Mean Mass burning rate in g/s (x)	Xa Mean Flame Height in mm (y)	x^2	y^2	Xy
100% Xa	1.461	63.25	2.134521	4000.5625	92.40825
90% Xa 10% Ke	1.831	90	3.352561	8100	164.79
80% Xa 20% Ke	2.419	100	5.851561	10000	241.9
70% Xa 30% Ke	2.519	106	6.345361	11236	267.014
60% Xa 40% Ke	2.631	112.5	6.922161	12656.25	295.9875
50% Xa 50% Ke	2.908	122	8.456464	14884	354.776
Sum	13.769	593.75	33.062629	60876.8125	1416.87575

Xa- Sour plum seed oil, Ke - Kerosene

Therefore Pearson's product moment correlation coefficient r for sour plum seed oil was obtained as follow:

$$r = \frac{9.025}{(0.494)(18.739)} = 0.975$$

The value of r obtained indicates that there was correlation between the sample variables: mass loss rate and flame height. It can also be said that, since $r^2 = 0.9506352$, then 95.06% variation in flame height is explained by mass loss rate of Sour plum seed oil and vice versa.

Since sample correlation coefficient r is the estimator of population correlation coefficient ρ (rho), the null and alternative hypothesis are:

$$H_0 : \rho = 0$$

$$H_1: \rho \neq 0.$$

The value of correlation coefficient $r = 0.975$ computed from sample size of 6 for Sour plum seed oil sample variables mass burning rate and flame height compared to tabulated value 0.8114 at $\alpha = 0.05$ level of significance was larger. Conclusion was drawn that it is statistically significant. Therefore, in the population of sour plum seed oil, there was indeed association between mass burning rate and flame height.

The data collected on mean mass burning rate and mean flame height of the fuels was analyzed using t -test to compare their mean values. Since randomization was used prior to data collection, underlying distribution does not affect t -test. Results are as in Table 4.5.

Table 4.5: Summary of t-test analysis results for the difference of means

Fuel Pair	Characteristic	Calculated t-value	Tabulated t-value (0.01)	Tabulated t-value (0.05)	Conclusion on mean difference
Unblended Ke, Xa, Jc and blended Xa	Mean mass burned	1.256	3.707	2.447	Not significant
Unblended Ke, Xa, Jc and blended Jc	Mean mass burned	1.013	3.707	2.447	Not significant
Blended Xa and Jc	Mean mass burned	4.057	4.060	2.776	Not significant
Unblended Ke, Xa, Jc and blended Xa	Mean flame height	0.176	3.707	2.447	Not significant
Unblended Ke, Xa, Jc and blended Jc	Mean flame height	0.770	3.707	2.447	Not significant
Blended Xa and Jc	Mean flame height	7.656	4.604	2.776	Significant

Ke – Kerosene Xa – Sour plum seed oil Jc – *Jatropha curcas* seed oil

The results as in Table 4.7 was found that for blended sour plum and *Jatropha* flame height pair, the mean difference was significant, probably because the paired t -test is more discriminating. Although difference is reported to be statistically significant, there was no practical difference observed in flame height.

Further, effect of some sour plum fuel properties on mean mass burning rate and flame height burning parameters was determined by Regression analysis (Devore and Farnum, 1999). The fuel properties considered were density, Viscosity, fire point, carbon residue added to Ash content. These fuel property values had been found to have difference above 10% compared to similar kerosene fuel properties. The effect of each the fuel property as predictor variables of mass burning rate and flame height burning parameter was considered.

Multiple regression results using the enter method in SPSS indicated a significant model ($F_{3,6}=612.293$, $p < 0.05$).

Adjusted R square = .997 i.e the model account for 99.7% of variance in flame height. Significant variables are shown below:

Predictor Variable	Beta	<i>p</i>
Mean viscosity	-.394	$p > 0.05$
Mean carbon residue and ash content	- .632	$p = 0.024$
Mean fire point	0.003	$p > 0.05$

Mean viscosity and mean firepoint were not significant predictors in this model. However, absolute t and small p for these two indicate that these variables have a large impact on flame height.

Results of multiple regression on impact of viscosity and firepoint of sour plum seed oil on mass burning rate indicated insignificant predictors in the model, although, there was indication from values of absolute t and p for these two that these variables have a large impact on mass burning rate.

4.3 Burning characteristics of kerosene-blended and unblended fuels in modified stove

Results of heating water over different fuels were recorded and tabulated in Table 4.6.

Table 4.6: Water Temperature readings and rise in temperature

TIME (min.)	100 % Ke	50% Ke 50% Xa	30%Ke 70% Xa	10% Ke 90% Xa	50% Ke 50% Jc	30% Ke 70% Jc	10 %Ke 90% Jc
0	16	18	16	17	16	16	16
3	27	29	26	25	28	27	24
6	40	38	35	30	40	39	34
9	55	46	40	34	50	50	42
12	70	52	43	36	59	59	49
15	79	57	46	37	64	66	54
Rise in Temperature (ΔT) °C	63	39	30	20	48	50	38

Ke – Kerosene Xa – Sour plum seed oil Jc – *Jatropha curcas* seed oil

Table 4.6 indicates that initial water temperature before heating was above 0 °C, about 17 °C and overall rise in water temperature varied with fuel used to heat. Unblended kerosene recorded 63 °C change in water temperature, this declined with declining kerosene ratio in blend to 30 °C for 30% Ke and 70% *Jatropha* seed oil. On the other hand, sour plum seed oil blended with kerosene recorded 50 °C change in water temperature for 30% Kerosene and 70 % sour plum seed oil blend; this reduced to 38 °C for 10% kerosene and 90% sour plum seed oil.

The recorded readings were plotted on graphs Figures 4.10 for blended sour plum and kerosene fuels.

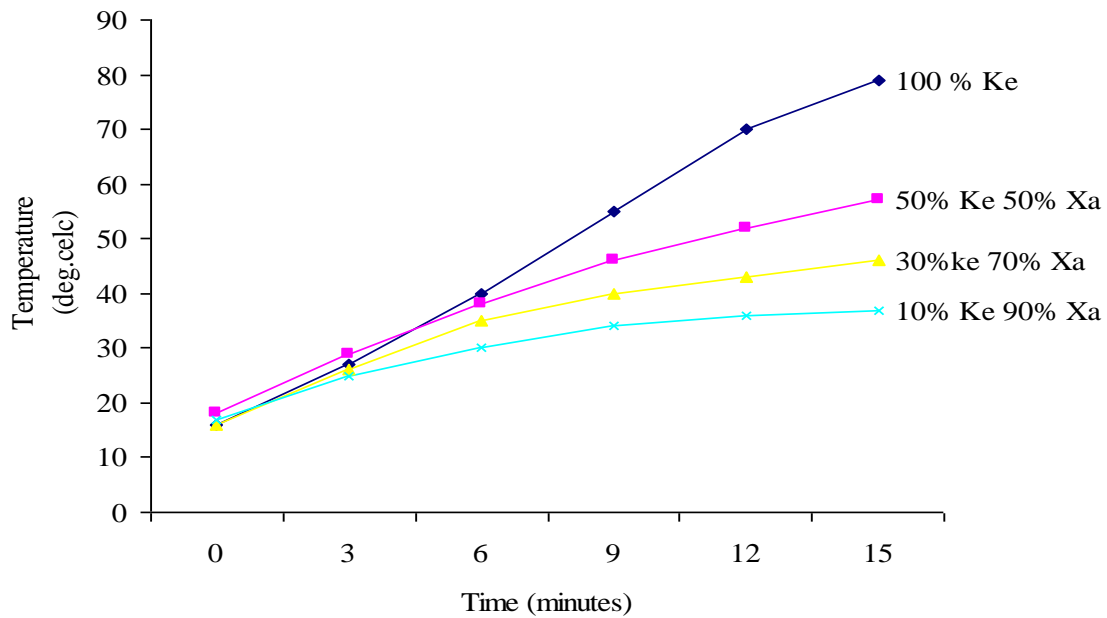


Figure 4.10: Sour plum-Kerosene blend water Temperature –Time graph

Referring to graphs Figure 4.10, after three minutes of heating water over different fuels, it was found that, all the fuels could heat the water almost at same rate, thereafter, kerosene exhibits better heat transfer compared to sour plum blends. It can be concluded that as the volume of kerosene in blend increased, the fuel can heat the water better than blends with lower percentage of kerosene. Therefore, comparing blend of sour plum, 50% sour plum blend with kerosene can be a better kerosene substitute than 30% blend; which is better than 10% blend.

Figure 4.11 is graph of temperature readings of water heated using blended *Jatropha* blends and kerosene fuels in stoves.

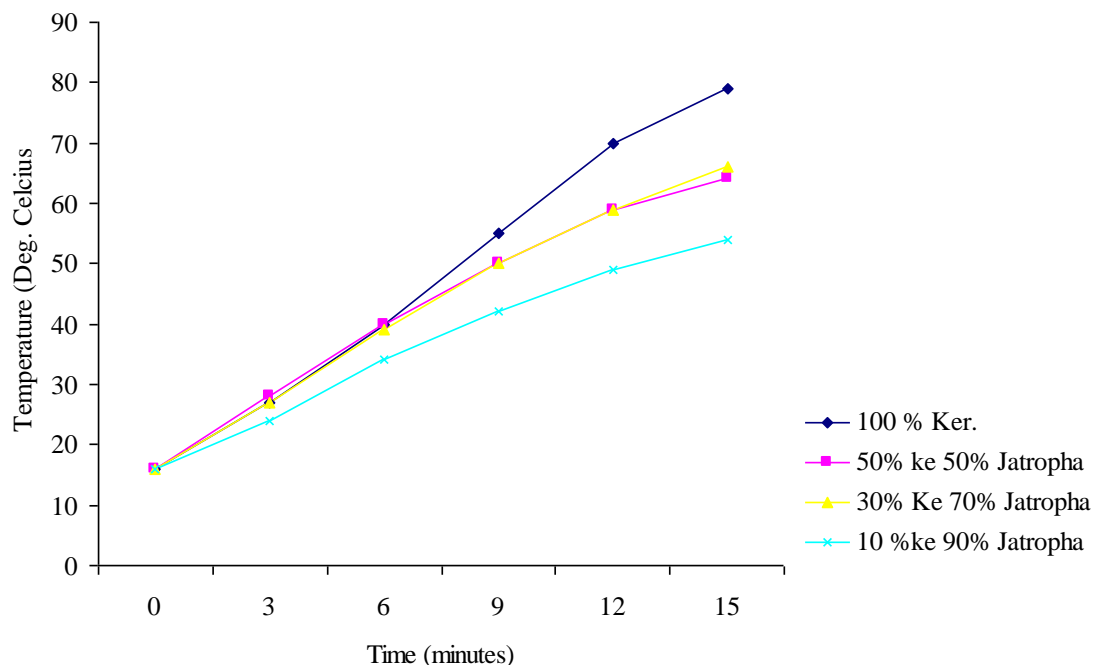


Figure 4.11: Kerosene-*Jatropha* fuel blend water Temperature–Time graph

Referring to Figures 4.11, initial water temperature before heating was above 0 °C; a mean of 17 °C; hence all graphs start above 0 °C. During the first six minutes, all fuels except 90% *Jatropha* blend demonstrated close capabilities to raise the water temperature. Thereafter, unblended kerosene exhibited higher water temperature readings while 90% *Jatropha* blend continued to record lowest temperature values. Two blends 50% and 30% *Jatropha* blend, however recorded close temperature readings. Eventually, these two could be better substitutes to kerosene compared to 90% *Jatropha* blend.

The Water Temperature-Time graphs for various fuels blended and unblended support an interpretation that mean temperature change of heated water using blends of kerosene, Sour plum and *Jatropha* seed oils increase with increased ratio of kerosene. This could be attributed to the earlier finding that higher blends of Kerosene in the seed oils improves the fire point of the blends among other fuel properties, therefore, lower temperatures and therefore energy will be required to ignite and sustain burning of the fuel.

The expected energy produced by the fuel for the 15 minutes the water was being heated was worked out as follows:

$$\text{Energy (kJ)} = C_v \times m \times \text{no.}w \times t \quad (4.1)$$

where: C_v is Fuel Calorific Value (J/Kg),
 m is Mass loss Rate for single wick (mg/s),
 $\text{no.}w$ is No. wicks in stove and
 t is Time to raise water Temperature (s)

The resulting values were tabulated in Table 4.7 and as illustrated in graph Figure 4.12 and 4.13.

Table 4.7: Calculated mean energy and power produced by selected fuels

Time interval (min.)	Mean Energy (KJ)								
	100% Ke	100% Xa	100% Jc	50% Ke 50% Xa	30% Ke 70% Xa	10% Ke 90% Xa	50% Ke 50% Jc	30% Ke 70% Jc	10% Ke 90% Jc
3	233.53	67.23	128.06	133.01	116.30	84.34	140.99	129.45	118.73
6	467.06	134.47	256.12	266.01	232.60	168.68	281.98	258.89	237.46
9	700.59	201.70	384.18	399.02	348.91	253.02	422.98	388.34	356.20
12	934.13	268.93	512.24	532.02	465.21	337.36	563.97	517.78	474.93
15	1167.66	336.17	640.29	665.03	581.51	421.70	704.96	647.23	593.66
Power (W)	1297.40	373.52	711.44	738.92	646.12	468.55	783.29	719.14	659.62

Ke – kerosene Xa – sour plum seed oil Jc – *Jatropha curcas* seed oil

Since the single wick mass burning rate values had been obtained in experiments described in section 3.5 and recorded in Tables beginning appendix 2, and respective unblended fuel calorific values are recorded in Table 4.1 therefore, mean energy produced per fuel was calculated and tabulated for the fifteen (15) minutes the water was heated over the six (6) wick modified stove. Power produced by the fuel when heating the water was then worked out as energy per unit time in seconds, hence mean power as tabulated.

The calculated mean energy produced by the fuels are plotted in graphs Figure 4.12 and 4.13.

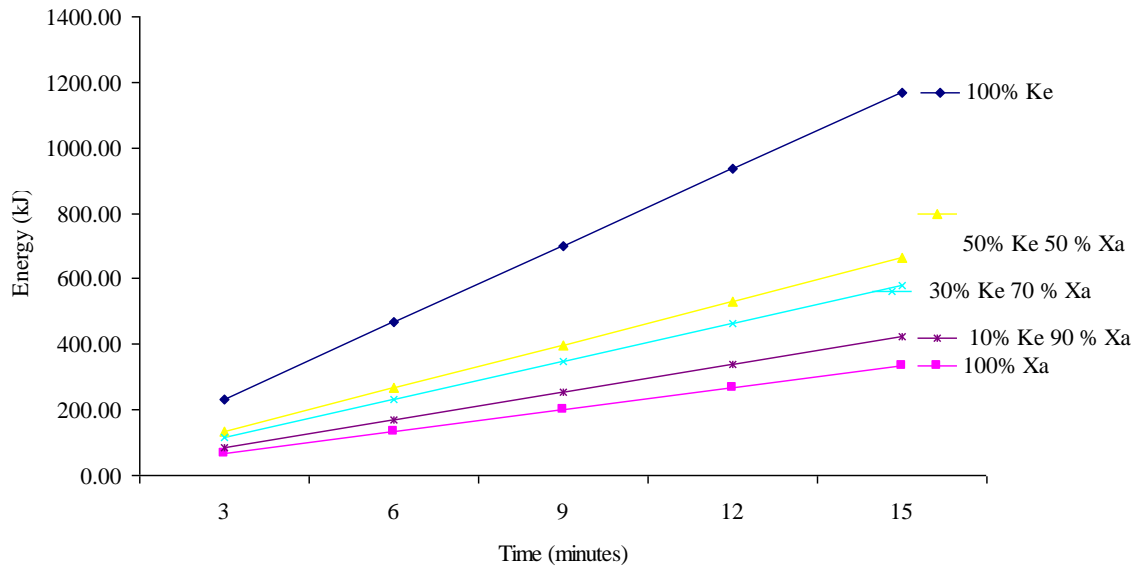


Figure 4.12: Kerosene and Sour plum seed oil fuel energy Produced

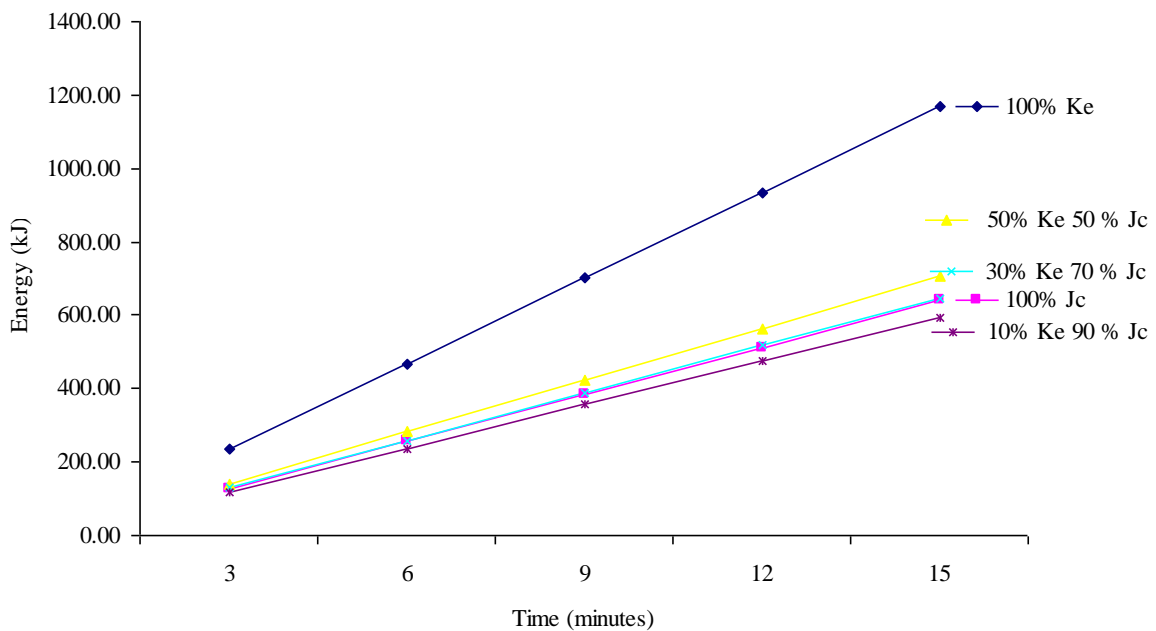


Figure 4.13: Kerosene and Jatropha seed oil fuel energy Produced

Both graphs 4.12 and 4.13 indicate that mean energy produced by the fuels increased linearly with time and that kerosene had higher gradient or power output compared to

blended sour plum and Jatropha seed oil. As blend ratio of kerosene increased, mean energy and power increased.

Analysis of Variance (ANOVA) was done on energy produced by the fuels. Table 4.8 gives summary of ANOVA.

Table 4.8: Summary of Analysis of Variance of Energy produced by fuel blends

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	68617.880	8	8577.235	2.647E8	.000
Within Groups	.001	27	.000		
Total	68617.881	35			

Referring to Table 4.8, calculated ratio F when Compared with tabulated value $F(8,27) = 2.31$ and $F(8,27) = 3.26$ at 1% and 5% level of significance respectively; the calculated $F \gg 2.31$ or 3.26 . It was concluded that there was significant difference. The column labeled ‘sig.’ shows that $p < \alpha$ for both 1% and 5 % significance level. Thus the null hypothesis that the mean energy produced by the fuels was equal was rejected. Therefore, energy produced by the fuels differ.

The data on energy produced was verified for assumptions for the one-way ANOVA F-test; in particular: that the population from which the samples were obtained must be normally or approximately normally distributed, result were as in Table 4.9.

Table 4.9: Test of normality of data on Energy produced by fuel blends

	PERCENTAGE BLEND	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
ENERGY (kJ)	100 % Ke	.441	4	.	.630	4	.001
	100% Xa	.307	4	.	.729	4	.024
	100% Jc	.441	4	.	.630	4	.001
	50% Ke50% Xa	.307	4	.	.729	4	.024
	30% Ke 70% Xa	.441	4	.	.630	4	.001
	50% Ke 50% Jc	.283	4	.	.863	4	.272
	30% Ke70%Jc	.307	4	.	.729	4	.024
	10% Ke 90%Jc	.441	4	.	.630	4	.001

a. Lilliefors Significance Correction

	PERCENTAGE BLEND	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
ENERGY (kJ)	100 % Ke	.441	4	.	.630	4	.001
	100% Xa	.307	4	.	.729	4	.024
	100% Jc	.441	4	.	.630	4	.001
	50% Ke50% Xa	.307	4	.	.729	4	.024
	30% Ke 70% Xa	.441	4	.	.630	4	.001
	50% Ke 50% Jc	.283	4	.	.863	4	.272
	30% Ke70%Jc	.307	4	.	.729	4	.024
	10% Ke 90%Jc	.441	4	.	.630	4	.001

b. ENERGY (kJ) is constant when PERCENTAGE BLEND = 10% Ke 90% Xa. It has been omitted.

Referring to Table 4.9, using Shapiro-wilk test, all p -values for energy produced values are greater than $\alpha = 0.01$ for 100 % sour plum, 50% kerosene-blended sour plum, 50% kerosene-blended Jatropha and 30% kerosene-blended Jatropha. The hypothesis of assumption of (approximate) normality of the populations from which the samples were obtained was not rejected, thus normality assumption was valid. However, since the values of Energy produced by the remaining fuels had p -values equal to $\alpha = 0.01$; then normality assumption was violated. Other measures of normality checking in particular skewness and kurtosis tests were used for the fuels that had violated normality assumption as illustrated Table 4.10.

Table 4.10: Skewness and Kurtosis tests Descriptive Statistics

	N	Sum	Mean		Std. Deviation	Skewness		Kurtosis	
			Statistic	Std. Error		Statistic	Std. Error	Statistic	Std. Error
Energy	4	596.620	149.155	28.239	56.478	1.953	1.014	3.832	2.619

Table 4.10 indicates that the skewness value for mean energy produced by the fuels is not more than twice its standard error, hence within symmetry.

Further, the second assumption for the one-way ANOVA F-test done was that the variances of the populations must be equal.

Results of the test on variances of populations was as in Table 4.11:

Table 4.11: Test of Homogeneity of Variance of populations

Test		Levene Statistic	df1	df2	Sig.
ENERGY (kJ)	Based on Mean	1.286	7	24	.299
	Based on Median	.886	7	24	.533
	Based on Median and with adjusted df	.886	7	15.000	.541
	Based on trimmed mean	1.228	7	24	.326
a. ENERGY (kJ) is constant when PERCENTAGE BLEND = 10%Ke 90% Xa. It has been omitted.					

From Table 4.11, the test that was used was “Based on Median”. This table provides results of the test of hypotheses that the population variances are equal and alternate hypothesis that the population variances are not equal. Referring to column labeled Sig., the p -value given for the “Based on Median” test in this last column is sufficiently large $p > \alpha = 0.01$. Therefore, it was concluded that the assumption of constant variances should not be rejected; hence the constant variance assumption was valid.

Since it was found that there was significant difference in the mean Energy produced by the fuel blends, a post-hoc follow-up test was done. Tukey test was applied because homogeneity of variance assumption was met (Equal Variance Assumed). Results of the test was as in Table 4.12:

Table 4.12 Energy (kJ) produced Tukey Multiple Comparisons

(I) Percentage Blend	(J) Percentage Blend	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
100 % Ke	100% Xa	166.297500*	.004025	.000	166.28396	166.31104
	100% Jc	105.475000*	.004025	.000	105.46146	105.48854
	50%Ke50%Xa	100.527500*	.004025	.000	100.51396	100.54104
	30% Ke 70% Xa	117.230000*	.004025	.000	117.21646	117.24354
	10%Ke 90% Xa	149.192500*	.004025	.000	149.17896	149.20604
	50% Ke 50% Jc	92.535000*	.004025	.000	92.52146	92.54854
	30%Ke70%Jc	104.087500*	.004025	.000	104.07396	104.10104
	10%Ke 90%Jc	114.800000*	.004025	.000	114.78646	114.81354

*. The mean difference is significant at the 0.05 level.

Referring to Table 4.12, comparing the p -value as listed under column labeled ‘sig.’, with α , it is less than $\alpha = 0.05$; therefore conclusion was that the fuel mean energy are not equal. This conclusion further is clarified by homogeneous subset Table 4.13:

Table 4.13: Tukey Homogeneous subset

Mean Energy (kJ)										
Percentage Blend	N	Subset for alpha = 0.05								
		1	2	3	4	5	6	7	8	9
100% Xa	4	67.235								
10% Ke 90% Xa	4		84.34							
30% Ke 70% Xa	4			116.303						
10% Ke 90% Jc	4				118.732					
100% Jc	4					128.058				
30% Ke70%Jc	4						129.445			
50% Ke50% Xa	4							133.005		
50% Ke 50% Jc	4								140.998	
100 % Ke	4									233.532
Sig.		1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 4.13 displays Means for groups in homogeneous subsets. Since each fuel blend are on separate subset, therefore, there are significant difference in each fuel blend mean energy produced. This concurs with the significant pairwise difference at 5% level of significance in which the p -value = 0; it is less than $\alpha = 0.05$, thus rejecting the hypothesis that the mean energy produced by fuels are equal. Although sour plum and Jatropha seed oils had higher specific gravity than kerosene and therefore expected to deliver more energy per unit volume burned, the significant difference in mean energy produced could be due to high viscosity and fire point given that percentage blends of seed oils with kerosene ranged 50% and above. Given that vegetable oil has high viscosity and fire point, for it to flow and enable constant delivery of energy during burning, the viscosity and fire point should have been within the

limit as in 20% biodiesel blend with Diesel. Since the fuel blend used were raw vegetable oil, its viscosity could have further been limited by gums which kerosene could not have adequately acted as a solvent to improve the viscosity of the blend.

The actual energy transfer to the water was obtained as follows:

Energy gained by water = Mass of water x specific heat capacity of water x Temperature rise

$$Q (w) = M(g) \times C(J/g^{\circ}C) \times (\Delta T) ^{\circ}C \quad (4.2)$$

The temperature rise ΔT of heated water was the value recorded after fifteen (15) minutes obtained when fuel was used to heat water. Calculated values for energy gained by the water heated are as tabulated Table 4.14 and shown by graph Figures 4.14 and 4.15.

Table 4.14: Mean energy and power gained by heated water

Time interval (min.)	ENERGY (kJ)						
	100% Ke	50% Ke 50% Xa	30% Ke 70 % Xa	10% Ke 90 % Xa	50% Ke 50 % Jc	30% Ke 70 % Jc	10% Ke 90 % Jc
3	50.82	50.82	46.2	36.96	50.82	55.44	50.82
6	110.88	92.4	87.78	60.06	110.88	110.88	106.26
9	180.18	129.36	110.88	78.54	180.18	157.08	157.08
12	249.48	157.08	124.74	87.78	249.48	198.66	198.66
15	291.06	180.18	138.6	92.4	291.06	221.76	231
Power (W)	980.467	677.600	564.667	395.267	246.400	256.667	195.067

Ke – Kerosene Xa – Sour plum seed oil Jc – *Jatropha curcas* seed oil

Referring to Table 4.14, since mean energy was energy gained by the water in the time interval of three (3) minutes when temperature readings were taken, then power gained was worked out as energy per unit time in seconds, hence mean power tabulated.

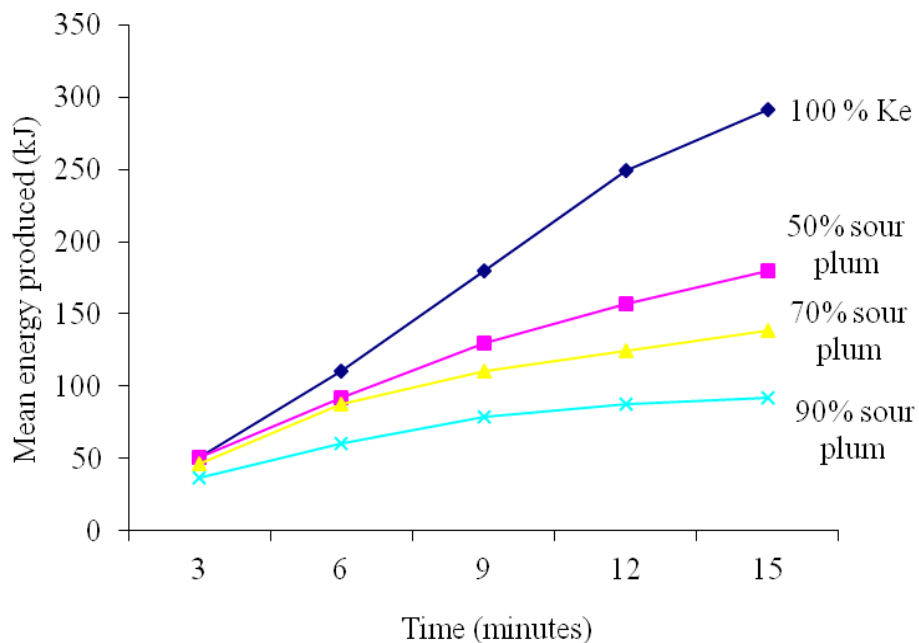


Figure 4.14: Energy gained by water heated using Kerosene and Sour plum seed oil fuels

The energy transferred to the water by heating using different fuels was as illustrated in Figure 4.14 in which unblended kerosene had higher mean energy transfer compared to the sour plum fuel blends. Among the sour plum blends, 50 % blend had better mean energy transfer compared to 70% and 90% blends. This difference could be due to improved fuel properties as a result of blending with kerosene. Therefore 50% sour plum blend could be better substitute for kerosene compared to higher blend of sour plum.

Graphic illustrated results of energy gained by water heated using Jatropha seed oil blends are as in Figure 4.15:

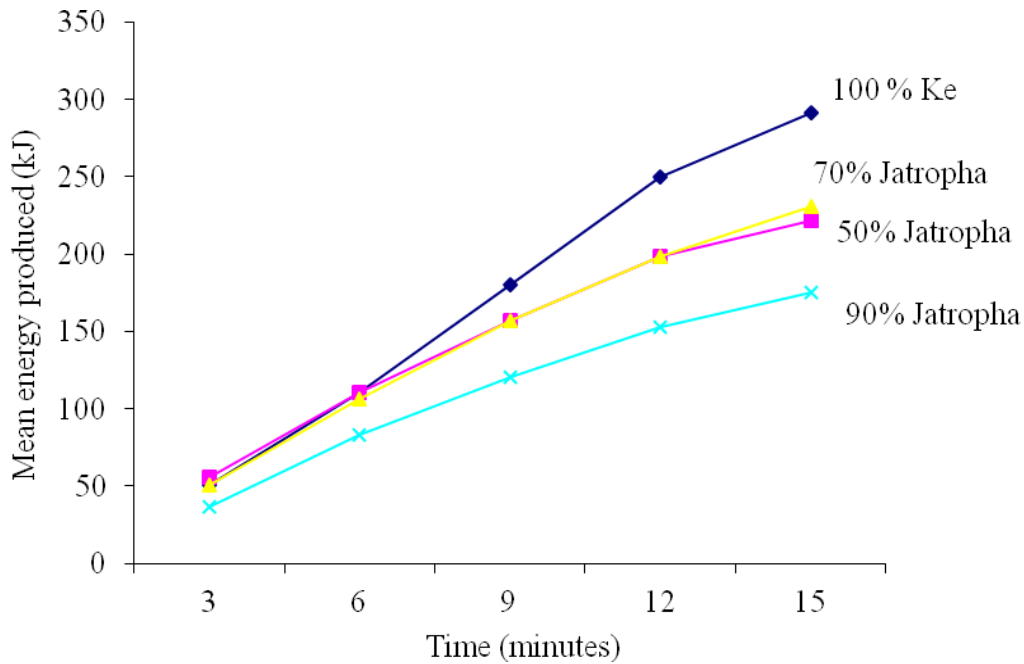


Figure 4.15: Energy gained by water heated using Kerosene and Jatropha seed oil fuels

Observation as illustrated in Figure 4.15 shows that after the first six minutes, the water gained energy from the burning fuels such that all fuels except 90 % blended *Jatropha* gained the relatively close values. Thereafter, 50% and 70% Jatropha blend remained close as energy gained by water from unblended kerosene remained high indicating that mean power produced from kerosene was consistently high probably due to better fuel properties that enable better burning than Jatropha oil. Therefore, based on findings as indicated on the graph, 70% Jatropha blend could substitute 50% blend. It can therefore be concluded that higher than 50% Jatropha blend will be required to be able to substitute kerosene.

Further, data obtained on burning tests of unblended and blended oils to heat one litre of water were analyzed using correlation where mean power produced by fuels was correlated with mean power gained by the water. Data for mean power produced was obtained from fuel burning tests experiment procedure section 3.5. Pearson's product-moment correlation coefficient r was calculated using the raw data where mean power produced by fuels denoted x was correlated with mean power gained by the water denoted y . With this consideration,

Pearson's product moment correlation coefficient of parameter value was worked out as follows:

Table 4.15: Power correlation analysis

Percentage Blend	Mean power produced (W) (x)	Mean power transferred (W) (y)	x ²	Y ²	Xy
100% Ke	1297.4	323.4	1683246.76	104587.56	419579.16
50% Ke 50 % Xa	738.92	677.6	546002.7664	459141.76	500692.192
30% Ke 70 % Xa	646.12	564.667	417471.0544	318848.8209	364842.642
10% Ke 90 % Xa	468.55	395.267	219539.1025	156236.0013	185202.3529
50% Ke 50 % Jc	783.29	246.4	613543.2241	60712.96	193002.656
30% Ke 70 % Jc	719.14	256.667	517162.3396	65877.94889	184579.5064
10% Ke 90 % Jc	659.62	195.067	435098.5444	38051.13449	128670.0945
Sum	5313.04	2659.068	4432063.791	1203456.186	1976568.604

Ke- Kerosene Xa- Sour plum seed oil Jc – *Jatropha curcas* seed oil

Therefore Pearson's product moment correlation coefficient r obtained was:

$$r = \frac{1976568.604}{\sqrt{(4432063.791)(1203456.186)}} = 0.855$$

The value of r indicates that there was strong correlation between the variables: mean power produced by fuels and mean power transferred to the water. It can also be said that, since $r^2 = 0.732$, then 73% variation in mean power gained by the water is explained by mean power produced by fuels.

Since sample correlation coefficient r is the estimator of population correlation coefficient ρ (rho), the null and alternative hypotheses are:

$$H_0 : \rho = 0 \text{ and } H_1 : \rho \neq 0.$$

For $\alpha = 0.05$ and $n = 7$, the critical value of r obtained from table is 0.7545 . Thus H_0 is rejected if $r > 0.7545$ or $r < -0.7545$. Since the computed value of $r = 0.855$ falls above the upper-tailed critical value of 0.7545, H_0 is rejected and conclusion drawn that at the $\alpha = 0.05$ level of significance, linear correlation exist in the population of fuels between mean power gained by the water and mean power produced by the fuels.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

The study on the potential of Sour plum (*Ximenia americana L.*) seed oil as biofuel guided by the specific research objectives found the following:

1. When sour plum seed oil was characterized for fuel properties; it was found that the following properties: specific gravity, calorific value, ash content and sulphur content, had values less or about 10% difference from those of kerosene and therefore had no significant difference. Indeed the following properties: Density, viscosity, fire point, carbon residue and ash content had over 10% difference in value from those of kerosene and Jatropha; therefore were significantly different from those of Jatropha and kerosene. On further investigation, it was concluded that they influenced burning parameters under consideration: mean burning rate and flame height of the seed oil.

The two burning characteristic parameters of unblended *Ximenia americana L.* seed oil were determined; it was found that mean burning rate was 1.461 mg/s far less than that of kerosene burning rate of 10.033 mg/s and less than half that of Jatropha burning rate of 3.156 mg/s. On the other hand mean flame height was 63.25mm and was comparable to Jatropha 64.25mm, but more than half that of kerosene 105mm; however, there was correlation between the burning parameters of kerosene blended sour plum and Jatropha.

2. When sour plum seed oil was blended with kerosene at ratios 10%, 20%, 30%, 40% and 50% then calculation of the fuel property values with over 10% difference from those of kerosene done, it was found that as fuel property values proportionally reduced with increasing kerosene blend, their respective burning rate and flame heights increased. Multiple regression analysis done on effect of fuel properties on burning rate and flame height confirmed that indeed, Viscosity, firepoint, carbon residue and Ash content were variables that influenced their values.
3. Finally, it was observed that the sour plum and Jatropha blended fuels in modified stove could heat and raise temperature of one litre of water. It was found that 50% blend of sour plum with kerosene and 70% blend of Jatropha with kerosene seed oil recorded higher temperature of heated water compared to other ratios. The calculated mean energy produced by the blended fuels when analysed using ANOVA was found to be significantly different probably due to influence of the Density, viscosity, fire

point, carbon residue and ash content fuel properties. However, it was found that energy and power produced by the fuels correlated with energy and power transferred to water heated over these fuels.

The answers to Research questions were positive. The following sour plum fuel properties: specific gravity, calorific value, ash content and sulphur content could be compared with those of Jatropha and kerosene, however, the following fuel properties: Density, viscosity, fire point, carbon residue and ash content were significantly different from those of Jatropha and kerosene. Although mean mass burning rate and flame height burning performance characteristics of unblended sour plum were lower than jatropha and kerosene, when blended with kerosene, the parameter values of sour plum improve and were relatively close to those of Jatropha and kerosene. Further, when kerosene-blended sour plum seed oil was burned in modified stove, its burning performance characteristics indicated that 50% blend with kerosene was an optimal blend close to unblended kerosene. Therefore, based on findings on values of fuel properties, burning parameters and correlation between mean energy and power produced and transferred during burning of the fuels in modified stove; sour plum seed oil qualifies as potential biofuel.

The following are recommendations for further research on Sour plum (*Ximenia americana L.*) seed oil:

1. Effect of degumming on burning rate and flame height
2. Determination of influence of pure component physical and chemical properties of sour plum seed oil on burning rate and flame height
3. Smoke gases characteristics of burned Sour plum seed oil to determine its suitability in indoor use for lighting.
4. Identification of key sour plum oil quality factors that are affected by extraction/filtration processes.

REFERENCE

- Abdullah, (2010). A study on spray characteristics of straight vegetable oil. Universiti Malaysia Pahang.
http://umpir.ump.edu.my/1816/1/A_Study_On_Spray_Characteristics_Of_Straight.pdf accessed on 7/5/2012.
- Achten, W. M. J., Varchot, L., Franken, Y. J. (2008). *Jatropha Bio-diesel production and use. Biomass and bioenergy* (2008), doi:10.1016/j.bioembio.2008.03.003
- Agrawal, A. K. (2008). *Scope and Limitations of Utilisation of Non-edible Vegetable Oils as a Substitute Fuel for Diesel Engines – An Experimental Study.* Indian Institute of Technology Kanpur
- Agnew, A.D.C and Agnew,. (2003). *Uplands plant of East Africa.* East Africa Educational Publication. Nairobi
- Akbar, E. and Yaakob, Z. (2009). Characteristics of *Jatropha curcas* oil seed from Malaysia and its potential as Biodiesel Feedstock. *European Journal of Scientific Research* Vol. 29 No. 3 (2009) pp. 396 - 403.
- American Petroleum Institute, (2003). *Robust summary of information on Kerosene/jet fuel*
- Bacon, R. Bhatajaria, S. and Kojima, M. (2010). *Expenditure of low-income Households on Energy: Evidence from Africa and Asia.* World Bank. www.worldbank.org/ogmc (or /oil or /gas or /mining), www.ifc.org/ogmc (or /oil or /gas or /mining) accessed 18/11/2011.
- Bachmann, J. (2001). *Small-scale oilseed processing value added and processing guide.* ATTRA New York. Accessed at http://www.atra.org/attar_publications/oilseed.pdf on 14/2/2008.
- Bachmanns, H. J. and Hirata, S. (2007). *Biodiesel production from crude Jatropha curcas L. Seed oil with a high content of free fatty acids.* *Bioresource Technology* 99 (2008). www.sciencedirect.com, www.Jatropha-alliance.org accessed on 16/6/2012
- Batey, J. E. (2004). *combustion testing of a bio-diesel fuel oil blend in residential oil burning equipment. Final report.* Massachusetts oil heat council and national oil Heat research alliance.
- Belser, E. and Hedland, N. (2004). *A model for biodiesel production. Synergy of the Americas.* Accessed at www.cubiodiesel.org/pdf/synergy5.pdf on 19/10/2008

- Bhagavan, M. R. and Karekezi, S. (ed) 1992. Energy for rural development. Zed books Ltd London.
- Bhat, Y. C. and Murthy, N. S. (2004). Use of madhua oil (*Madhua indica*) as a diesel fuel extender. Accessed at www.ieindia.org/publish/ag/06004/june04ag3.pdf on 19/10/2008.
- Braun, J. (2007). Bi-Annual Overview of the World Food Situation presented to the CGIAR Annual General Meeting, Beijing December 3, 2007
- Brown, T. L. and Lamay, H. E. (2006). Chemistry the central science (10th ed.). Pearson Education Inc. New Jersey.
- Bureau of Energy efficiency, (2005). Fuels and combustion. Ministry of power, India. Accessed at [www.em-ea.org/GuideBooks/books-2/2.1fuels and combustion.pdf](http://www.em-ea.org/GuideBooks/books-2/2.1fuels%20and%20combustion.pdf) accessed on 19/10/2008
- Burke, A. (2009). Ximenia Survey in West Caprivi. Enviro Science
- CBS, (2005). Republic of Kenya statistical abstracts. Ministry of planning and National Development. The Government printer Nairobi.
- Cenkowski, S. (2006). Extraction of sea buckthorn seed and pulp oils. University of Manitoba
- Chevron products Co. (2000). Aviation fuel Technical review (FTR – 3) USA.
- Clements, D. L. (1996). Blending rules for formulating biodiesel fuel. Accessed at www.biodiesel.org/resources/reportsdatabase/reports/gen/19 on 11/10/2008
- Connemann, J. (1998). Biodiesel in Europe 1998: Biodiesel processing Technologies. Curitiba-parania
- Curtis. B. and Mannheimer, C. (2005). Tree Atlas of Namibia. National Botanical Research Institute. Windhoek.
- Davies, R. M. (2006). Biodiesel and vegetable oil as a fuel. Accessed at [www.face-online.org.uk/resources/factsheet/discovery biodiesel.pdf](http://www.face-online.org.uk/resources/factsheet/discovery_biodiesel.pdf) on 9/10/2008.
- Devore, J. L. and Farnum, N. R. (1999). Applied statistics for Engineers and Scientists. Duxbury Press. New York
- Duffield, J. and Shapouri, H. (1998). US biodiesel development: New markets for conventional and genetically modified Agricultural products. Accessed at www.ers.usda.gov/publications/AER70/AER770.pdf accessed on 9/10/2008
- Eckman, K. and Hines, D. A. (1993) *Trichlea emitica*. Accessed at [www.fao.org/docrep/X5327e/x5327 elq.htm#topOfpage](http://www.fao.org/docrep/X5327e/x5327_elq.htm#topOfpage) on 11/10/2008

- Ejigu, M. (2008). Toward energy and livelihoods security in Africa: Smallholder production and processing of bioenergy as a strategy. *Natural Resources Forum* 32 (2008) 152–162.
- EPA, (2002). A comprehensive analysis of biodiesel impact on exhaust emissions. Draft technical report.
- Esposito, A. (1994). *Fluid power with applications* (3rd ed.). Redent /printicehall. New Jersey.
- FAO/GBEP, (2007). A Review of The Current State of Bioenergy Development in G8 +5 Countries. www.globalbioenergy.org accessed on 11/10/2008
- Ferchau, E. (2000). Equipment for decentralised cold pressing of oilseeds. Folker center for renewable energy. Accessed at ww.folkercenter.dk accessed on 14/2/2008
- German Advisory Council (WBGU), (2008). On Global Change. Bioenergy Factsheet
- Giuseppe, T. and Eleonora, M. (2007). Analysis of the Physical and Chemical Characteristics of Vegetable Oils as Fuel. *Journal of Agricultural Engineering* 2007, 3, 39-47
- Goodrum, J. W. (1987). Review of biodiesel research at University of Georgia. Accessed at www.biodiesel.com on 14/2/2008
- Grace, O.M. and Borus, D. J. (ed), (2008). Vegetable oils of tropical Africa. Conclusions and Recommendations based on PROTA 14: Vegetable oils. PROTA Foundation, Nairobi Kenya.
- Gui, M. M., Lee, K. T. and Bhatia, S. (2008). Feasibility of edible oil versus non-edible oil versus waste edible oil as biodiesel feed stock. *Energy* 33. 1646-1653.
- Haciseferogullari, H., Ozcan, M. M. and Duman, E. (2011). Biochemical and Technological properties of seeds and Oils of *Caparris spinosa* and *capparis ovata* plants growing wild in Turkey. *Journal of Food Processing Technology* 2011 2:6 <http://dx.doi.org> accessed on 20/2/2012
- Hazell P. and Pachauri, R. K. (2006). Bioenergy and agriculture: promises and Challenges. International Food Policy Research Institute.
- Holman, J. P. (1994). *Experimental methods for engineers*. Mcgraw_Hill Inc. London.
- <http://chartsbin/views/oau>. Historical crude prices 1861 to present accessed on 3/9/2012
- http://www.camincargo.biz/Polaris/lab_maintenance/helpdocs/methoddefinitions.htm
- <https://onlinecourses.science.psu.edu/stat503/node/15> accessed on 5/1/2012
- <http://www.worldagroforestry.org/downloads/publications/PDFs/B15956.PDF>

- IEA/OECD, (2010). Energy Poverty: How to make modern Energy access universal? A special early excerpts of the world Energy outlook 2010 for the UN General assembly on the Millenium Development Goals.
- IEA, (2009). World Energy Outlook 2009
- Jessup, R.S. (1960). Precise measurement of heat of combustion with a bomb calorimeter. Monograph 7. National Bureau of Standards.
- Johnson, F. X. and Lambe, F. (2009). Access, climate and Development. Stockholm Environmnet Institute (SEI). www.ccdcommission.org accessed on 28/10/2011.
- Kanes, S. (2010). Biofuels outlook. www.scotiabank.com. Accessed on 25/4/2013
- Kardish, E. and Tur'yan, Y. I. (2004). Acid Value determination in vegetable oils by indirect titration in aqueous-alcohol media. National Laboratory of Israel Givat ram, Jerusalem. *Croatica Chemica Acta* 78 (1) 999-103 (2005)
- Karlson, M. (2007). The Energy challenge for achieving the MDG. UN –Energy. Report Kenya Intergrated Household Budget Survey 2005/06 (Revised Edition) KIHBS, (2006) Basic Report. Ministry of Planning and Development.
- Kenya National Bureau of Statistics (KNBS), (2012). Kenya Facts and Figures 2012. Nairobi
- KIPRA, (2010) A Comprehensive Study and Analysis on Energy Consumption Patterns in Kenya. A Synopsis of the Draft Final Report. <http://www.KIPRA.org/> accessed on 5/1/2012
- Knothe, G. (2005): Dependence of biodiesel fuel properties on the structure of fatty acid alkyl esters, *Fuel Processing Technology* 86, 1059-1070.
- Koseki, H. Nasume, Y. and Iwata, Y. (2001). Evaluation of the burning characteristics of vegetable oils in comparison with fuel and lubricating oils. *Journal of fire sciences*. 2001, vol 9 no. 1 pp 31-44.
- Kuznetsov, I.V. (2005). Fuel combustion and optimum use of heat energy Industrialization of stoves. Accessed on 13/7/2012 at <http://www.stove.ru/index.php?lng=1>
- Mahanta, P., Mishra. S. C and Kushwah, Y. S. (2006). A comparative study of Pongamia and Jatropha Curcus oil as Diesel substitute. *International Journal of Energy*:Vol. 7, No.1, March 2006. <http://www.rericjournal.ait.ac.th/index.php/eric/article/viewFile/11/7> accessed on 7/5/2012
- Mainhardt-Gibbs, H. (2011). World Bank and Energy Development Study – Implications for Sustainable Development, Poverty Reduction and Climate Change. Report. Newyork.

- Maundu, P. and Tengnas, T. (eds) (2005). Useful trees and shrubs for Kenya. Technical Handbook No. 35. World Agroforestry centre. Nairobi
- Massey, B. S (1989). Mechanics of fluid (sixth edition). Chapman and Hall London.
- Mbarawa, M. (2007). Performance, emission and economic assessment of clove stem oil-diesel blended fuels as alternative fuels for diesel engines. Accessed at <http://www.science direct .com/whalecom0/science> on 2/4/2008.
- Ministry of Planning and National Development, (2006). Kenya Intergrated Household Budget survey (KIHBS) 2005/06 (Revised Edition). Basic Report.
- Mueller, A. (2008). Bioenergy,Sustainable livelihoods and the rural poor. Thematic debate on rural Development round table 1. Accessed at www.un.org/ecosoc/doc/statements08/summary%20-%20pane20120bioenergy%20final.pdf on 10/10/2008
- Niewiadomski, H. (1990). Rapeseed chemistry and technology. Polish scientific publishers. Oxford
- Niez, A. (2010). Comparative study on rural electrification policies in emerging economies – Keys to successful policies. IEA (International Energy Agency) Information Paper.
- Nyoike, P. (2003). Autonomy of the Kenya Electricity Regulatory Board energy policy: is the Kenyan Electricity Regulatory Board Autonomous? Ministry of energy, Kenya.
- OECD/IEA, (2005). Energy statistics manual
- Obina, O. and Aesina, O. B. (2006). Extraction and qualitative assessment of African sweet orange seed oil. African Journal of Food, Agriculture, Nutrition and Development vol. 6 No.2 2006. Accessed at www.ajfand.net/issue-XI-files/pdfs/OFDEGBU_1540.pdf on 11/10/2008
- Opondo, R. N. (2010). Evaluation of transesterified waste vegetable oil for use as biodiesel fuel.Thesis. Egerton University.
- Peterson, L. C. and Jones, S. (2002). Using unmodified vegetable oils as a diesel fuel Extender – a Literature review. Accessed at http://journeytoforever.org/biofuel_library/idahovegoilslitreview.pdf on 10/10/2008
- Pramanik, K. (2002). Properties and use of Jatropha curcas oil and diesel fuel blends in compression ignition engine. Elsevier Science Limited.
- Reith, T. S. (2000). Biofuel production:Chemistry. accessed at www.biodiesel.com on 14/2/2008.

- Řezanka, T. and Sigler, K., 2007. Identification of very long chain unsaturated fatty acids from Ximenia oil by atmospheric pressure chemical ionization liquid chromatography–mass spectroscopy. *Phytochemistry* 68, 925–934.
- Protzen, E. (1997). On the development of a prototype Jatropha-oil fueled Jiko and a Jatropha-oil fueled Lamp. Accessed at <http://www.Jatropha.de/cooker/protzen2.html>. accessed on 14/2/2008
- Sacande, M. and Vautier, H. V. (2006). Seed leaflet *Ximenia americana* L. No. 112 April 2006. Millenium seed project. Accessd at http://www.sl.life.ku.dk/upload/ximenia_112.pdf on 19/11/2007.
- Saeed, A.E.M. and Bashier, R. S. M. (2010). Physico-chemical analysis of *Ximenia americana* L. seed oil and structure elucidation of some chemical constituents of its seed oil and fruit pulp. *Journal of Pharmacognosy and Phytotherapy* Vol. 2(4), pp. 49-55, June 2010. <http://www.academicjournals.org/jpp> or http://sustech.edu/staff_publications/20110504075056338.pdf accessed on 7/5/2012.
- Schumacher, L. and Elser, N. (1997). Sample analysis from Biodiesel test: A final report to The National biodiesel board of Missouri-Columbia. Missouri.
- Shitanda, D. (1994). Physical properties of crude oil from indigenous oilseeds in Kenya compared to those of petroleum and conventional vegetable oils. Thesis . Nairobi 1994.
- Siegel, A. F. (1988). *Statistics and Data Analysis*. John Wiley & Sons Inc. Newyork
- Stauffer, E. (2005). A review of the Analysis of Vegetable oil Residues from Fire Debris Samples: Spontaneous Ignition, Vegetable Oils, and Forensic Approach. *Journal of Forensic Science*, September 2005 Vol. 50, No. 5. [www. Astm.org](http://www.astm.org) accessed on 10/1/2012
- Stout, B. A. (1990). *Hankbook of energy for world Agriculture*. Elsevier applied science. London.
- Sustainable Energy Ireland, (2006). Quality assurance for rapeseed oil as vehicle fuel. accessed at www.biodiesel.or/resources/reportsdatabase/reports/gen/19921_gen302.pdf on 10/10/2008.
- Tennakoon, D. (2008). Energy poverty: Estimating the level of energy poverty in Srilanka. Practical Action. Accessed at <http://www.sa-energy.net/m/ENERGY.pdf> on 6/9/2012
- Turkenberg, W.C. (1998). *World Energy Assessment: Energy and The Challenge of Sustainability Chapter 7: Renewable Energy Technologies*. UNDP Newyork.

- Ugarte, D.G. (2006). Bioenergy and agriculture. Developing bioenergy: Economic and social issues. Accessed at www.ifpgri.org/2020/focus/focus14/focus14_02.pdf on 10/10/2008
- UNEP, (2006 a). Thermal equipment: Fuel and combustion. Accessed at www.energyefficiencyasia.org on 9/9/2008
- UNEP, (2006 b). Kenya: Integrated assessment of the Energy Policy With focus on the transport and household energy sectors
- UNESCAP-APCAEM, (2008).Challenges, opportunities and the way forward. Regional forum on bioenergy sector development Accessed at www.unapcaem.org/activities%20files/A0801/AideMemoir.pdf on 9/10/2008
- UNoCHA, (2008). Kenya Administrative boundaries Map. www.UNocha.org
- US Department of Energy, (2005). Energy efficiency and Renewable energy. Accessed at <http://www.osti.gov/bridge> on 13/4/2008
- US Department of Energy, (2004). Biodiesel handling use guidelines. Accessed on 13/4/2008 www.fao.org/DOCREP/005/X3940Agroforestry Parklands in subsaharan Africa. Accessed on 13/3/2008
- Verhoeven, N. A. (1989). Kerosene Wick Stoves. Masters thesis. Eindhoven University of Technology, Eindhoven, The Netherlands.
- www.duerstlahtiglobal.com. Ximenia Oil: duerst lahti global Fair trade products with a story. Accessed on 7/5/2012.
- www.worldagroforestrycentre.org/sites/TreesDBS/AFT.htm ximenia americana L. Accessed on 13/3/2008
- World Energy Council, (2010). Survey of Energy Resources. www.worldenergy.org/documents/ser_2010_report_1.pdf

APPENDICES

APPENDIX 1: 100 % sour plum seed oil burning tests data

REPLICATION I

REPLICATION II

TIME INTERVAL (Se)	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT T (mm)	TIME INTERVAL (Se)	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT (mm)
0	77.34	0	0	0	80.22	0	0
180	77.11	0.23	70	180	79.89	0.33	65
360	76.87	0.24	75	360	79.64	0.25	70
540	76.64	0.23	65	540	79.28	0.36	70
720	76.42	0.22	70	720	78.94	0.34	70
900	76.2	0.22	70	900	78.6	0.34	70
1080	75.99	0.21	60	1080	78.28	0.32	60
1260	75.77	0.22	60	1260	77.96	0.32	65
1440	75.56	0.21	60	1440	77.67	0.29	60
1620	75.35	0.21	55	1620	77.41	0.26	50
1800	75.14	0.21	50	1800	77.16	0.25	50
	SUM	2.2	635		SUM	3.06	630
	MEAN	0.22	63.5		MEAN	0.306	63

mean weight loss (g)

0.263

Mean flame height (mm)

63.25

APPENDIX 2: 10 % Kerosene 90 % *Ximenia americana L.* seed oil blend burning tests data

REPLICATION I

REPLICATION II

TIME INTERVAL (Se)	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT (mm)	TIME INTERVAL (Se)	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT (mm)
0	74.61	0	0	0	70.35	0	0
180	74.1	0.51	90	180	70	0.35	100
360	73.6	0.5	100	360	69.7	0.3	90
540	73.15	0.45	90	540	69.41	0.29	100
720	72.67	0.48	100	720	69.18	0.23	90
900	72.32	0.35	85	900	68.91	0.27	95
1080	71.99	0.33	90	1080	68.64	0.27	85
1260	71.68	0.31	90	1260	68.35	0.29	80
1440	71.37	0.31	90	1440	68.11	0.24	85
1620	71.1	0.27	90	1620	67.86	0.25	80
1800	70.78	0.32	90	1800	67.59	0.27	80
	SUM	3.83	915		SUM	1.31	885
	MEAN	0.383	91.5		MEAN	0.276	88.5

mean weight loss (g) 0.3295

mean flame height (mm) 90

Appendix 3: 20 % Kerosene 80 % *Ximenia americana L.* Seed oil blend burning tests data

REPLICATION I

REPLICATION II

TIME INTERVAL	MASS (g)	WEIG HT	FLAME HEIGHT	TIME INTERVAL	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT
0	76.98	0	0	0	71.85	0	0
180	76.47	0.51	130	180	71.38	0.47	110
360	76.04	0.43	110	360	70.91	0.47	110
540	75.64	0.4	100	540	70.44	0.47	110
720	75.22	0.42	80	720	69.98	0.46	110
900	74.77	0.45	100	900	69.53	0.45	110
1080	74.32	0.45	110	1080	69.1	0.43	110
1260	73.91	0.41	90	1260	68.66	0.44	110
1440	73.5	0.41	90	1440	68.23	0.43	100
1620	73.09	0.41	80	1620	67.83	0.4	80
1800	72.69	0.4	80	1800	67.43	0.4	80
	SUM	2.11	970		SUM	2.19	1030
	MEAN	0.429	97		MEAN	0.4420	103

mean weight loss (g)

0.4355

mean flame height (mm)

100

Appendix 4: 30 % Kerosene 70 % *Ximenia americana L.* oil blend burning tests data

REPLICATION I

REPLICATION II

TIME INTERVAL	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT	TIME INTERVAL	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT
0	73.88	0	0	0	74.5	0	0
180	73.35	0.53	130	180	73.94	0.56	130
360	72.84	0.51	130	360	73.38	0.56	130
540	72.36	0.48	130	540	72.82	0.56	130
720	71.89	0.47	130	720	72.28	0.54	130
900	71.48	0.41	110	900	71.79	0.49	120
1080	71.08	0.4	70	1080	71.32	0.47	120
1260	70.73	0.35	60	1260	70.84	0.48	120
1440	70.41	0.32	50	1440	70.4	0.44	110
1620	70.11	0.3	50	1620	69.93	0.47	110
1800	69.81	0.3	50	1800	69.5	0.43	110
	SUM	4.07	910		SUM	5	1210
	MEAN	0.407	91		MEAN	0.5	121

mean weight loss (g)

0.4535

mean flame height (mm)

106

Appendix 5: 40 % Kerosene 60 % *Ximenia americana L.* seed oil blend burning tests data

REPLICATION I

REPLICATION II

TIME INTERVAL	MASS (g)	WEIG- HT	FLAME HEIGHT	TIME INTERVAL	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT
0	75.44	0	0	0	71.6	0	0
180	74.78	0.66	140	180	71.04	0.56	130
360	74.19	0.59	140	360	70.5	0.54	130
540	73.64	0.55	130	540	70	0.5	130
720	73.12	0.52	120	720	69.54	0.46	130
900	72.66	0.46	120	900	69.11	0.43	120
1080	72.23	0.43	100	1080	68.69	0.42	110
1260	71.78	0.45	90	1260	68.28	0.41	100
1440	71.36	0.42	90	1440	67.86	0.42	100
1620	70.94	0.42	90	1620	67.47	0.39	100
1800	70.5	0.44	80	1800	67.07	0.4	100
	SUM	4.94	1100		SUM	4.53	1150
	MEAN	0.494	110		MEAN	0.453	115

mean weight loss (g)

0.4735

mean flame height (mm)

112.5

Appendix 6: 50 % Kerosene 50 % *Ximenia americana L.* seed oil blend burning tests data

REPLICATION I

REPLICATION II

TIME INTERVAL	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT	TIME INTERVAL	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT
0	71.53	0	0	0	76.19	0	0
180	70.88	0.65	130	180	75.69	0.5	120
360	70.27	0.61	130	360	75.19	0.5	110
540	69.69	0.58	130	540	74.69	0.5	110
720	69.13	0.56	130	720	74.22	0.47	110
900	68.59	0.54	130	900	73.73	0.49	120
1080	68.04	0.55	130	1080	73.23	0.5	110
1260	67.48	0.56	130	1260	72.74	0.49	110
1440	66.92	0.56	130	1440	72.27	0.47	120
1620	66.4	0.52	130	1620	71.78	0.49	120
1800	65.89	0.51	130	1800	71.36	0.42	110
	SUM	5.64	1300		SUM	4.83	1140
	MEAN	0.564	130		MEAN	0.483	114

mean weight loss (g)

0.5235

mean flame height (mm)

122

Appendix 7: 100 % *Jatropha curcas* seed oil burning tests data

REPLICATION I

REPLICATION II

TIME INTERVAL	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT	TIME INTERVAL	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT
0	71.8	0	0	0	75.68	0	0
180	71.42	0.38	75	180	75.07	0.61	70
360	71.02	0.4	75	360	74.45	0.62	65
540	70.62	0.4	75	540	73.86	0.59	70
720	70.22	0.4	75	720	73.24	0.62	50
900	69.83	0.39	65	900	72.64	0.6	65
1080	69.44	0.39	70	1080	72.04	0.6	55
1260	69.05	0.39	55	1260	71.45	0.59	65
1440	68.66	0.39	60	1440	70.87	0.58	60
1620	68.27	0.39	60	1620	70.28	0.59	55
1800	67.89	0.38	55	1800	69.69	0.59	65
	SUM	3.91	665		SUM	5.99	620
	MEAN	0.391	66.5		MEAN	0.599	62

mean weight loss (g)

0.495

mean flame height (mm)

64.25

Appendix 8: 10% Kerosene 90% *Jatropha curcas* seed oil blend burning tests data

REPLICATION I

REPLICATION II

TIME INTERVAL	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT	TIME INTERVAL	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT
0	74.12	0	0	0	72.07	0	0
180	73.71	0.41	70	180	71.49	0.58	70
360	73.26	0.45	70	360	70.93	0.56	75
540	72.84	0.42	80	540	70.35	0.58	75
720	72.39	0.45	80	720	69.79	0.56	75
900	71.95	0.44	80	900	69.23	0.56	75
1080	71.49	0.46	80	1080	68.66	0.57	75
1260	71.07	0.42	80	1260	68.1	0.56	75
1440	70.61	0.46	80	1440	67.56	0.54	75
1620	70.18	0.43	80	1620	67	0.56	75
1800	69.74	0.44	80	1800	66.45	0.55	75
	SUM	4.38	780		SUM	5.62	745
	MEAN	0.438	78		MEAN	0.562	74.5

mean weight loss 0.500 (g)

mean flame height (mm)

76.25

Appendix 9: 20% Kerosene 80% *Jatropha curcas* seed oil blend burning tests data

REPLICATION I

REPLICATION II

TIME INTERVAL	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT	TIME INTERV	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT
0	72.44	0	0	0	73.57	0	0
180	71.84	0.6	60	180	73.03	0.54	95
360	71.24	0.6	60	360	72.52	0.51	95
540	70.65	0.59	60	540	72.03	0.49	95
720	70.07	0.58	70	720	71.52	0.51	95
900	69.49	0.58	60	900	71.05	0.47	95
1080	68.93	0.56	60	1080	70.54	0.51	95
1260	68.35	0.58	60	1260	70.08	0.46	95
1440	67.79	0.56	60	1440	69.63	0.45	95
1620	67.23	0.56	60	1620	69.18	0.45	95
1800	66.69	0.54	60	1800	68.71	0.47	95
	SUM	5.75	610		SUM	4.86	950
	MEAN	0.575	61		MEAN	0.486	95

mean weight loss (g)

0.530

mean flame height (mm)

78

Appendix 10: 30 % Kerosene 70 % *Jatropha curcas* seed oil blend burning tests data

REPLICATION I

REPLICATION II

TIME INTERV AL (Se)	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT (mm)	TIME INTERV AL (Se)	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT (mm)
0	81.44	0	0	0	85.04	0	0
180	80.91	0.53	80	180	84.53	0.51	80
360	80.41	0.5	80	360	83.9	0.63	80
540	79.81	0.6	80	540	83.49	0.41	80
720	79.21	0.6	80	720	82.97	0.52	80
900	78.65	0.56	80	900	82.45	0.52	75
1080	78.08	0.57	80	1080	81.93	0.52	80
1260	77.51	0.57	80	1260	81.42	0.51	80
1440	76.94	0.57	80	1440	80.91	0.51	80
1620	76.36	0.58	80	1620	80.4	0.51	80
1800	75.83	0.53	80	1800	79.88	0.52	80
	SUM	5.61	800		SUM	5.16	795
	MEAN	0.561	80		MEAN	0.516	79.5

mean weight loss (g)

0.538

mean flame height (mm)

79.75

Appendix 11: 40% Kerosene 60% *Jatropha curcas* seed oil blend burning tests data

REPLICATION I				REPLICATION II			
TIME INTERV	MASS (g)	WEIG HT	FLAME HEIGH	TIME INTERV	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT
0	71.58	0	0	0	70.88	0	0
180	70.97	0.61	85	180	70.36	0.52	60
360	70.36	0.61	85	360	69.82	0.54	65
540	69.75	0.61	85	540	69.27	0.55	80
720	69.13	0.62	85	720	68.76	0.51	80
900	68.52	0.61	85	900	68.24	0.52	80
1080	67.93	0.59	85	1080	67.73	0.51	80
1260	67.36	0.57	85	1260	67.24	0.49	80
1440	66.78	0.58	80	1440	66.72	0.52	80
1620	66.18	0.6	80	1620	66.24	0.48	80
1800	65.56	0.62	80	1800	65.74	0.5	80
	SUM	6.02	835		SUM	5.14	765
	MEAN	0.602	83.5		MEA	0.514	76.5

mean weight loss (g) 0.558 mean flame height (mm) 80

Appendix 12: 50 % Kerosene 50 % *Jatropha curcas* seed oil blend burning tests data

REPLICATION I				REPLICATION II			
TIME INTERV	MASS (g)	WEIG HT	FLAME HEIGH	TIME INTERV	MASS (g)	WEIGH T LOSS	FLAME HEIGHT
0	78.99	0	0	0	76.45	0	0
180	78.42	0.57	105	180	75.84	0.61	100
360	77.87	0.55	90	360	75.24	0.6	100
540	77.3	0.57	100	540	74.66	0.58	100
720	76.75	0.55	95	720	74.08	0.58	100
900	76.21	0.54	95	900	73.44	0.64	100
1080	75.64	0.57	100	1080	72.92	0.52	100
1260	75.1	0.54	100	1260	72.33	0.59	100
1440	74.56	0.54	100	1440	71.76	0.57	100
1620	74.03	0.53	100	1620	71.18	0.58	100
1800	73.48	0.55	95	1800	70.6	0.58	110
	SUM	5.51	980		SUM	5.85	1010
	MEAN	0.551	98		MEAN	0.585	101

mean weight loss (g) 0.568 mean flame height (mm) 99.5

Appendix 13: 100 % Kerosene burning tests data

REPLICATION I

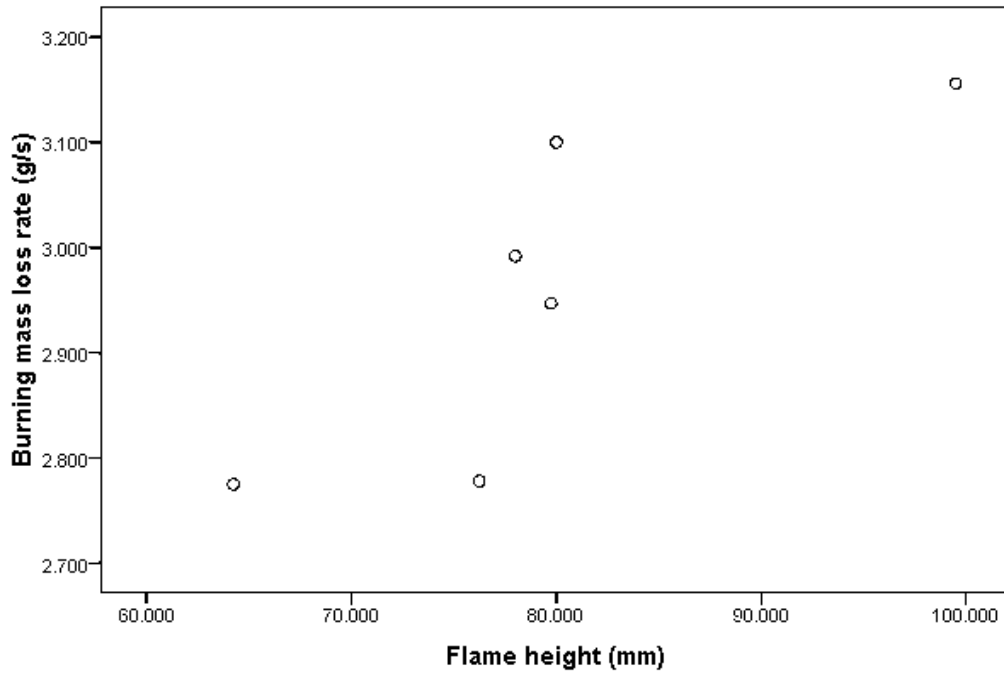
REPLICATION II

TIME INTERVAL (Se)	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT (mm)	TIME INTERVAL (Se)	MASS (g)	WEIGHT LOSS (g)	FLAME HEIGHT (mm)
0	74.75	0	0	0	72.68	0	0
180	73.87	0.88	110	180	71.81	0.87	105
360	72.96	0.91	100	360	70.91	0.9	105
540	72.07	0.89	110	540	70.03	0.88	100
720	71.18	0.89	110	720	69.14	0.89	100
900	70.23	0.95	110	900	68.26	0.88	100
1080	69.31	0.92	105	1080	67.33	0.93	100
1260	68.39	0.92	105	1260	66.42	0.91	110
1440	67.45	0.94	105	1440	65.5	0.92	110
1620	66.53	0.92	105	1620	64.62	0.88	105
1800	65.66	0.87	105	1800	63.71	0.91	100
	SUM	9.09	1065		SUM	8.97	1035
	MEAN	0.909	106.5		MEAN	0.897	103.5

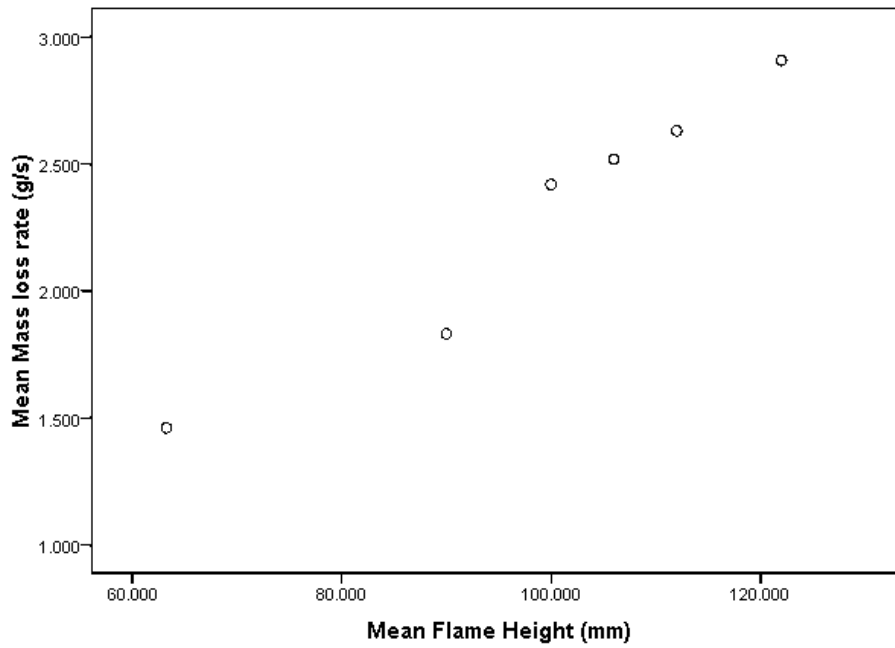
mean weight loss (g) 0.903

mean flame height (mm) 105

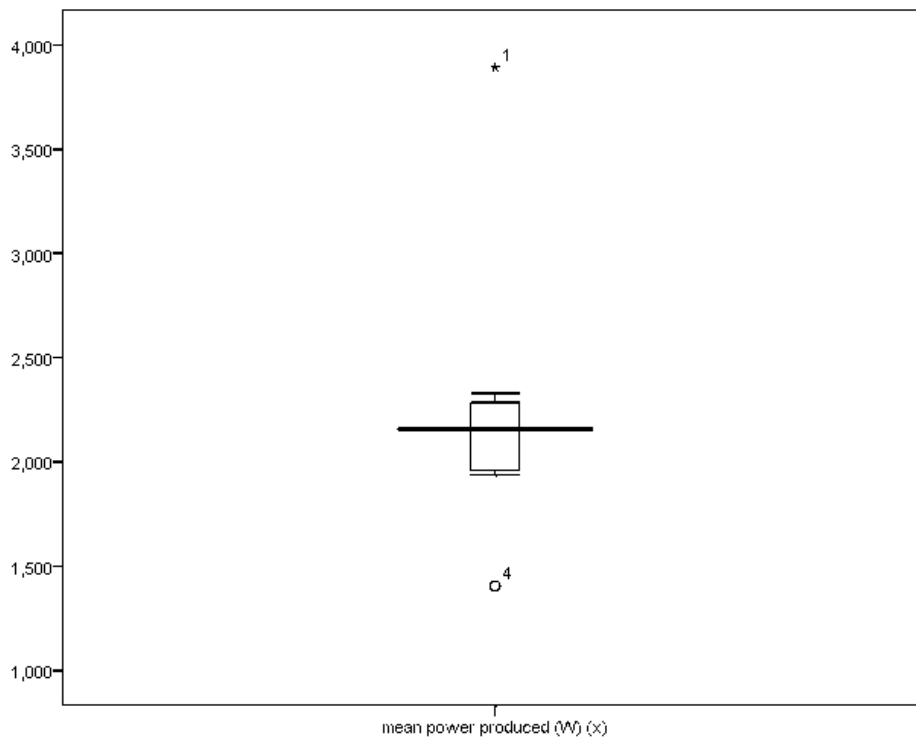
Jatropha seed oil burning mass lossrate and flameheight



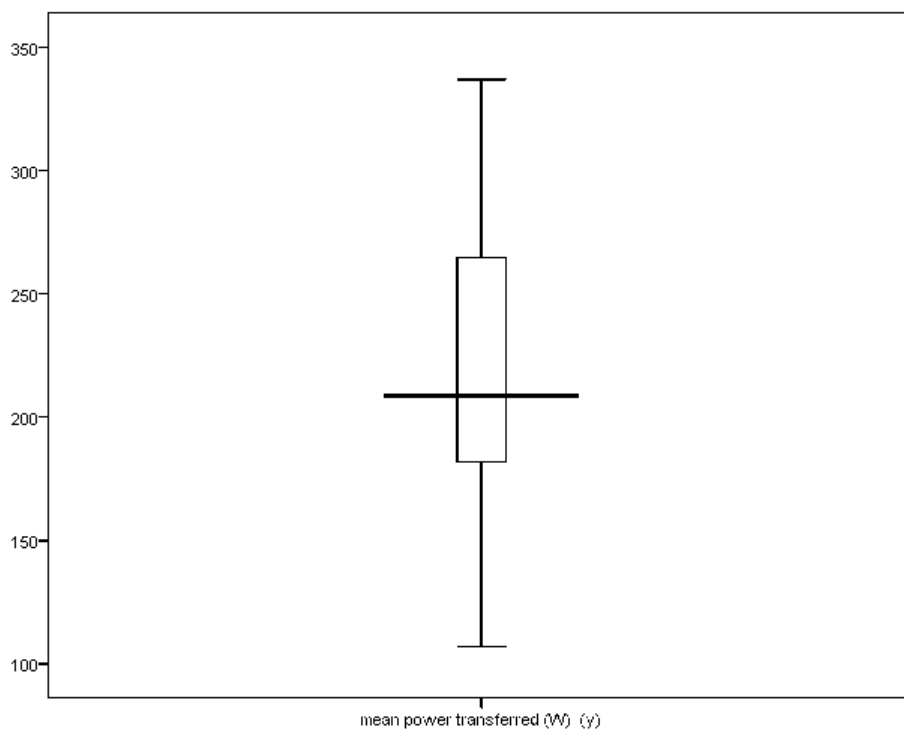
Sour Plum seed oil Scatter Plot



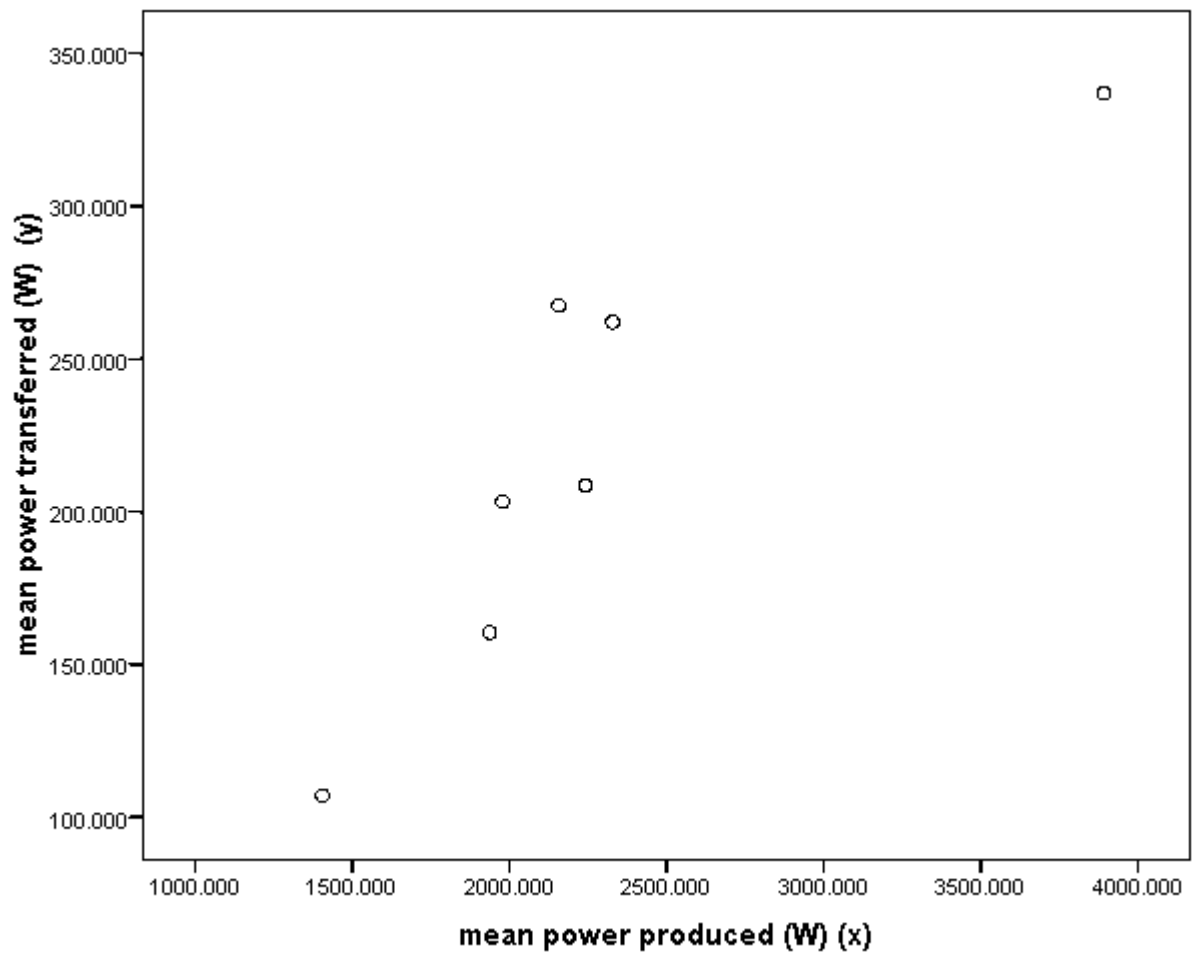
Mean power Produced data Box plot



Mean power transferred data Box plot



Scatter plot



Pearson's product moment correlation coefficient of parameter values

$$r = \frac{\frac{1}{n} \sum xy - \bar{x} \bar{y}}{S_x S_y}$$

Where $\bar{x} = \frac{\sum x}{n}$ and $\bar{y} = \frac{\sum y}{n}$ are the respective mean values of characteristics x and y measured and n is the sample size.

$$S_x = \sqrt{\frac{1}{n} \sum x^2 - \bar{x}^2} \quad \text{and} \quad S_y = \sqrt{\frac{1}{n} \sum y^2 - \bar{y}^2} \quad \text{are sample standard deviations.}$$

Substituting for Jatropha curcas seed oil sample variables mean burning rate and flame height:

Substituting for the respective values in the equations;

$$n = 6, \quad \bar{x} = \frac{\sum x}{n} = 2.958 \text{ mg/s} \quad \bar{y} = \frac{\sum y}{n} = 79.625 \text{ mm}$$

$$\frac{1}{n} \sum xy - \bar{x} \bar{y} = 1.2255$$

$$S_x = \sqrt{\frac{1}{n} \sum x^2 - \bar{x}^2} = 0.145$$

$$S_y = \sqrt{\frac{1}{n} \sum y^2 - \bar{y}^2} = 10.373$$

Substituting for sour plum seed oil sample variables mean burning rate and flame height values in the equations;

$$n = 6, \quad \bar{x} = \frac{\sum x}{n} = 2.295 \text{ mg/s} \quad \bar{y} = \frac{\sum y}{n} = 98.875 \text{ mm}$$

$$\frac{1}{n} \sum xy - \bar{x} \bar{y} = 9.025$$

$$S_x = \sqrt{\frac{1}{n} \sum x^2 - \bar{x}^2} = 0.494$$

$$S_y = \sqrt{\frac{1}{n} \sum y^2 - \bar{y}^2} = 18.739$$

Similarly substituting to obtain power correlation analysis:

$$r = \frac{\frac{1}{n} \sum xy - \bar{x} \bar{y}}{S_x S_y}$$

Where $\bar{x} = \frac{\sum x}{n}$ and $\bar{y} = \frac{\sum y}{n}$ are the respective mean

values of characteristics x and y measured and n is the sample size.

$S_x = \sqrt{\frac{1}{n} \sum x^2 - \bar{x}^2}$ and $S_y = \sqrt{\frac{1}{n} \sum y^2 - \bar{y}^2}$ are sample standard deviations.

$$n = 7, \quad \bar{x} = \frac{\sum x}{n} = 2277.71 \text{ W} \quad \bar{y} = \frac{\sum y}{n} = 220.82 \text{ W}$$

$$\frac{1}{n} \sum xy - \bar{x} \bar{y} = 44195.08$$

$$S_x = \sqrt{\frac{1}{n} \sum x^2 - \bar{x}^2} = 716.15$$

$$S_y = \sqrt{\frac{1}{n} \sum y^2 - \bar{y}^2} = 70.11$$

t- test for difference in unblended fuels mean mass burned and blended Jatropha seed oil

FUEL	MEAN MASS BURNED (mg) (x_2)	FUEL	MEAN MASS BURNED (mg) (x_1)	$(x_1 - \bar{x}_1)$	$(x_1 - \bar{x}_1)^2$	$(x_2 - \bar{x}_1)$	$(x_2 - \bar{x}_1)^2$
100% Ke	903	90% Jc 10% ke	329.5	-113.6	12905	-311	96721
100% Xa	263	80% Jc 20% ke	435.5	-7.6	57.76	927	859329
100% Jc	538.5	70% Jc 30% ke	453.5	10.4	108.16	-616	379456
		60% Jc 40% ke	473.5	30.4	924.16		
		50% Jc 50% ke	523.5	80.4	6464.16		

ke – kerosene

Jc- Jatropha curcas seed oil

Xa – Sour plum seed oil

$$\text{Mean } (\bar{x}_1) = 443.1 \quad \text{Mean } (\bar{x}_2) = 879 \quad \sum(x_1 - \bar{x}_1)^2 = 20459.2 \quad \sum(x_2 - \bar{x}_2)^2 = 1335506$$

$$\text{Combine population variance } s_c^2 = \frac{\sum(x_1 - \bar{x}_1)^2 + \sum(x_2 - \bar{x}_2)^2}{(n_1 - 1) + (n_2 - 1)} = 225994.2$$

$$\text{Standard deviation } s_d = s_c \sqrt{\frac{n_1 + n_2}{n_1 n_2}} = 347.175$$

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{s_d} = 1.256$$

t- test for difference in unblended fuels mean mass burned and blended sour plum seed oil

FUEL	MEAN MASS BURNED (mg) (x ₂)	FUEL	MEAN MASS BURNED (mg) (x ₁)	(x ₁ - \bar{x}_1)	(x ₁ - \bar{x}_1) ²	(x ₂ - \bar{x}_1)	(x ₂ - \bar{x}_1) ²
100% ke	903	90% Xa 10% ke	495	-34.3	1176.49	-311	96721
100% Xa	263	80% Xa 20% ke	500	-29.3	858.49	927	859329
100% Jc	538.5	70% Xa 30% ke	530.5	1.2	1.44	-616	379456
		60% Xa 40% ke	558	28.7	823.69		
		50% Xa 50% ke	563	33.7	1135.69		

ke – kerosene

Jc- Jatropha curcas seed oil

Xa – Sour plum seed oil

$$\text{Mean } (\bar{x}_1) = 529.3 \quad \text{Mean } (\bar{x}_2) = 879 \quad \sum(x_1 - \bar{x}_1)^2 = 3995.8 \quad \sum(x_2 - \bar{x}_2)^2 = 1335506$$

$$\text{Combine population variance } s_c^2 = \frac{\sum(x_1 - \bar{x}_1)^2 + \sum(x_2 - \bar{x}_2)^2}{(n_1 - 1) + (n_2 - 1)} = 223250.3$$

$$\text{Standard deviation } s_d = s_c \sqrt{\frac{n_1 + n_2}{n_1 n_2}} = 345.06$$

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{s_d} = 1.013$$

t- test for difference in mean mass burned for blended sour plum seed oil and blended Jatropha seed oil

FUEL	MEAN MASS BURNED (mg) (x_2)	FUEL	MEAN MASS BURNED (mg) (x_1)	$y = (x_2 - x_1)$	$(y_1 - \bar{y}_1)$	$(y_2 - \bar{y}_2)^2$
90% Xa 10% Ke	329.5	90% Jc 10% ke	495	-165.5	-79.3	6288.49
80% Xa 20% Ke	435.5	80% Jc 20% ke	500	-64.5	21.7	470.89
70% Xa 30% Ke	453.5	70% Jc 30% ke	530.5	-77	9.2	84.64
60% Xa 40% Ke	473.5	60% Jc 40% ke	558	-84.5	1.7	2.89
50% Xa 50% Ke	523.5	50% Jc 50% ke	563	-39.5	46.7	2180.89

ke – kerosene

Jc- Jatropha curcas seed oil

Xa – Sour plum seed oil

Since the data is paired, then $x_2 - x_1$ is the variable, let $y = x_2 - x_1$

Variable mean $\bar{y} = -86.2$

Standard deviation of y : $S = \sqrt{\frac{\sum (y - \bar{y})^2}{n - 1}} = 47.507$

Standard deviation of \bar{y} : $S_{\bar{y}} = \frac{S}{\sqrt{n}} = 21.246$

$t = \frac{|\bar{y} - 0|}{S_{\bar{y}}} = 4.057$

t- test for difference in unblended fuels mean flame height and blended sour plum seed oil

FUEL	MEAN FLAME HEIGHT (mm) (x_2)	FUEL	MEAN FLAME HEIGHT (mm) (x_1)	$(x_1 - \bar{x}_1)$	$(x_1 - \bar{x}_1)^2$	$(x_2 - \bar{x}_1)$	$(x_2 - \bar{x}_1)^2$
90% Xa 10% ke	90	100% ke	105	-13.25	175.5625	-16.1	259.21
80% Xa 20% ke	100	100% Xa	63.25	27.5	756.25	-6.1	37.21
70% Xa 30% ke	106	100% Jc	64.25	-14.25	203.0625	-0.1	0.01
60% Xa 40% ke	112.5					6.4	40.96
50% Xa 50% ke	122					115.6	13363.36

ke – kerosene

Jc- Jatropha curcas seed oil

Xa – Sour plum seed oil

$$\text{Mean } (\bar{x}_1) = 77.5$$

$$\text{Mean } (\bar{x}_2) = 106.1$$

$$\sum(x_1 - \bar{x}_1)^2 = 1134.875$$

$$\sum(x_2 - \bar{x}_2)^2 = 13700.75$$

$$\text{Combine population variance } s_c^2 = \frac{\sum(x_1 - \bar{x}_1)^2 + \sum(x_2 - \bar{x}_2)^2}{(n_1 - 1) + (n_2 - 1)} = 2472.6$$

$$\text{Standard deviation } s_d = s_c \sqrt{\frac{n_1 + n_2}{n_1 n_2}} = 36.31$$

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{s_d} = 0.176$$

t- test for difference in unblended fuels mean flame height and blended Jatropha curcas seed oil

FUEL	MEAN FLAME HEIGHT (mm) (x_2)	FUEL	MEAN FLAME HEIGHT (mm) (x_1)	$(x_1 - \bar{x}_1)$	$(x_1 - \bar{x}_1)^2$	$(x_2 - \bar{x}_1)$	$(x_2 - \bar{x}_1)^2$
90%Jc 10%Ke	76.25	100% ke	105	17.75	315.0625	-6.45	41.6025
80%Jc 20%Ke	78	100%Xa	63.25	58.5	3422.25	-4.7	22.09
70%Jc 30%Ke	79.75	100%Jc	64.25	16.75	280.5625	-2.95	8.7025
60%Jc 40%Ke	80					-2.7	7.29
50%Jc 50%Ke	99.5					16.8	282.24

ke – kerosene

Jc- Jatropha curcas seed oil

Xa – Sour plum seed oil

$$\text{Mean } (\bar{x}_1) = 46.5$$

$$\text{Mean } (\bar{x}_2) = 82.7$$

$$\sum(x_1 - \bar{x}_1)^2 = 4017.875$$

$$\sum(x_2 - \bar{x}_2)^2 = 361.925$$

$$\text{Combine population variance } s_c^2 = \frac{\sum(x_1 - \bar{x}_1)^2 + \sum(x_2 - \bar{x}_2)^2}{(n_1 - 1) + (n_2 - 1)} = 729.97$$

$$\text{Standard deviation } s_d = s_c \sqrt{\frac{n_1 + n_2}{n_1 n_2}} = 19.73$$

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{s_d} = 0.77$$

t- test for difference in mean flame height for blended sour plum seed oil and blended Jatropha seed oil

FUEL	MEAN FLAME HEIGHT (mm) (x_2)	FUEL	MEAN FLAME HEIGHT (mm) (x_1)	$y = (x_2 - x_1)$	$(y_1 - \bar{y}_1)$	$(y_2 - \bar{y}_2)^2$
90% Xa 10% Ke	90	90% Jc 10% ke	76.25	13.75	-9.65	93.1225
80% Xa 20% Ke	100	80% Xa 20% Jc	78	22	-1.4	1.96
70% Xa 30% Ke	106	70% Xa 30% Jc	79.75	26.25	2.85	8.1225
60% Xa 40% Ke	112.5	60% Xa 40% Jc	80	32.5	9.1	82.81
50% Xa 50% Ke	122	50% Xa 50% Jc	99.5	22.5	-0.9	0.81

ke – kerosene

Jc- Jatropha curcas seed oil

Xa – Sour plum seed oil

Since the data is paired, then $x_2 - x_1$ is the variable, let $y = x_2 - x_1$

Variable mean $\bar{y} = 23.4$

Standard deviation of y: $S = \sqrt{\frac{\sum (y - \bar{y})^2}{n - 1}} = 6.834$

Standard deviation of \bar{y} : $S_{\bar{y}} = \frac{S}{\sqrt{n}} = 3.056$

$t = \frac{|\bar{y} - 0|}{S_{\bar{y}}} = 7.656$

t- test for difference in mean power produced for unblended fuels and blended sour plum seed oil

FUEL	MEAN POWER (W) (x_2)	FUEL	MEAN POWER (W) (x_1)	$y = (x_2 - x_1)$	$(y_1 - \bar{y}_1)$	$(y_2 - \bar{y}_2)^2$
100% Ke	1297.40	50% Ke 50 % Xa	558.47	382.22	146093.703	558.47
100% Xa	373.52	30% Ke 70 % Xa	-272.60	-448.86	201471.331	-272.60
100% Jc	711.44	10% Ke 90 % Xa	242.88	66.63	4440.026	242.88

ke – kerosene

Jc- Jatropha curcas seed oil

Xa – Sour plum seed oil

Since the data is paired, then $x_2 - x_1$ is the variable, let $y = x_2 - x_1$

Variable mean $\bar{y} = 176.251$

Standard deviation of y: $S = \sqrt{\frac{\sum (y - \bar{y})^2}{n - 1}} = 419.527$

Standard deviation of \bar{y} : $S_{\bar{y}} = \frac{S}{\sqrt{n}} = 242.214$

$t = \frac{|\bar{y} - 0|}{S_{\bar{y}}} = 0.728$

t- test for difference in mean power produced for unblended fuels and blended Jatropha seed oil

FUEL	MEAN POWER (W) (X ₂)	FUEL	MEAN POWER (W) (X ₁)	y = (x ₂ - x ₁)	(y ₁ - \bar{y}_1)	(y ₂ - \bar{y}_2) ²
100% Ke	1297.40	50% Ke 50 % Jc	783.29	514.11	440.68	194194.520
100% Xa	373.52	30% Ke 70 % Jc	719.14	-345.63	-419.06	175610.318
100% Jc	711.44	10% Ke 90 % Jc	659.62	51.82	-21.62	467.261

ke – kerosene

Jc- Jatropha curcas seed oil

Xa – Sour plum seed oil

Since the data is paired, then $x_2 - x_1$ is the variable, let $y = x_2 - x_1$

Variable mean $\bar{y} = 73.43$

Standard deviation of y: $S = \sqrt{\frac{\sum (y - \bar{y})^2}{n - 1}} = 430.274$

Standard deviation of $\bar{y} : S_{\bar{y}} = \frac{S}{\sqrt{n}} = 248.419$

$t = \frac{|y - 0|}{S_y} = 0.296$

t- test for difference in mean power produced for blended sour plum and blended Jatropha seed oil

FUEL	MEAN POWER (W) (X2)	FUEL	MEAN POWER (W) (X1)	$y = (x_2 - x_1)$	$(y_1 - \bar{y}_1)$	$(y_2 - \bar{y}_2)^2$
50% Ke 50 % Xa	738.92	50% Ke 50 % Jc	783.29	-44.36	58.45	3416.755
30% Ke 70 % Xa	646.12	30% Ke 70 % Jc	719.14	-73.02	29.80	887.845
10% Ke 90 % Xa	468.55	10% Ke 90 % Jc	659.62	-191.07	-88.25	7788.017

ke – kerosene

Jc- Jatropha curcas seed oil

Xa – Sour plum seed oil

Since the data is paired, then $x_2 - x_1$ is the variable, let $y = x_2 - x_1$

Variable mean $\bar{y} = -102.818$

Standard deviation of y: $S = \sqrt{\frac{\sum (y - \bar{y})^2}{n - 1}} = 77.758$

Standard deviation of $\bar{y} : S_{\bar{y}} = \frac{S}{\sqrt{n}} = 44.893$

$t = \frac{|\bar{y} - 0|}{S_{\bar{y}}} = 2.29$

Multiple regression Analysis output

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.999 ^a	.999	.997	1.073797

a. Predictors: (Constant), Xa mfpoint(K), Xa mcarash(%), Xa mVis(sq.mm/s)

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2117.996	3	705.999	612.293	.002 ^a
	Residual	2.306	2	1.153		
	Total	2120.302	5			

a. Predictors: (Constant), Xa mfpoint(K), Xa mcarash(%), Xa mVis(sq.mm/s)

b. Dependent Variable: Xa mFH(mm)

Coefficients^a

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
1 (Constant)	182.208	2.317		78.640	.000		
Xa mVis(sq.mm/s)	-.214	.075	-.394	-2.865	.103	.029	34.748
Xa mcarash(%)	-12.330	1.945	-.632	-6.339	.024	.055	18.270
Xa mfpoint(K)	-.002	.111	-.003	-.016	.989	.012	81.164

a. Dependent Variable: Xa mFH(mm)