Abstract—The world is facing twin energy-related threats—inequitable and insecure supplies of energy at affordable prices and environmental harm caused by inappropriate use of conventional energy such as fossil fuel. Fossil fuels being non-renewable, have a potential to be exhausted. Moreover, combustion of fossil fuels causes pollutant emissions such as carbon monoxide (CO), carbon dioxide (CO₂), oxides of sulphur (SOₓ), oxides of nitrogen (NOₓ) and particulate matter (PM). These emissions have contributed to climate change, global warming and adverse effects on plants and animals. These emissions are responsible for about 1.6 million deaths of children per year on top of other respiratory diseases mostly affecting women and children.

A lot of research has been done in an effort to come up with renewable energy utilisation so as to replace or reduce fossil fuel use. Biofuels are good alternatives and research on their use in internal combustion (IC) engines is well advanced. It has been shown that biodiesel can be used in IC engines with no or minor modifications and they emit less CO₂, CO and pm with slight reduction in power. Available literature indicates that biofuel reduce the burning rate of wick cook stoves and reduce smoke. However, very limited research has been done on biofuel use in lamps. No known work has been done on evaluating the performance and emissions from straight vegetable oil/kerosene blends used in pressure lamp.

This paper presents a review of literature on performance and emission of kerosene lamps, lantern lamps and pressure lamps. The possibility of use of straight vegetable oil in pressure lamps is also examined. The results obtained will provide an insight into the design of a modified pressure lamp running on straight vegetable oil.

Keywords— in-door air pollution, Kerosene, lamp performance, Renewable energy

I. INTRODUCTION

The potential of traditional fossil fuels to be exhausted is increasing of late [1]. This has led to escalation of oil prices which has in turn affected many developing countries whose fuel consumption has increased due to the rapid industrialization being experienced. Combustion of fossil fuels in vehicles, cooking, lighting, manufacturing plants and burning of biomass for domestic or industrial use has led to global degradation. This global degradation has health issues including diseases associated with pollutant emissions from fossil fuel use such as obstructive lung diseases, adverse pregnancy outcome, lung cancer, bronchitis, and other respiratory infections. These have been responsible for 2.7 % of the global disease burden and nearly 1.6 million deaths per year [2]. A lot of effort is being directed to curbing the anthropogenic contribution to global degradation [3]; such as use of renewable fuels.

One-third of the world population or about 1.6 billion people, live without electricity [4]. In Kenya, electricity penetration is estimated to be 28.9 % with a demand increase of 7% per annum [31]. In 1990, 80 % of Kenya’s electricity came from hydro sources while in 2008, 45 % of electricity came from hydro, 15 % was from geothermal while burning petroleum based fuels contributed 40 % [5]. This shows that there is an increasing demand for fossil fuel and this is part of the reason behind petroleum price increase. Consequently, majority of Kenyans will have to fore-go other things to afford the commodity. This will worsen the living standards of the majority of rural and low income earners in Kenya who currently are living below the poverty line.

A study by Mill [6] indicated that a substantial fraction of energy budget in rural areas goes towards liquid fuel for illumination. Over 80 % of Kenyans use kerosene for lighting and cooking [1]. The majority of middle level and low level income earners in Kenya use biomass or kerosene for lighting and cooking [1]. Tin kerosene lamps and lantern lamps are used to light small rooms. Pressure lamps are used for lighting and heating large rooms and out-door lighting. Even in areas supplied with electricity, pressure lamps have become common due to the frequent power interruptions brought about by the high demand for power which surpasses the supply.

Due to the effects of fossil fuel emission coupled with depletion of oil wells, there is need to study how kerosene lamps contribute to these emissions. This paper presents a review of literature on performance and emission of kerosene tin lamps, lantern lamps and pressure lamps. The possibility of use of straight vegetable oil in pressure lamps is also examined. The results obtained will provide an insight into the design of a modified pressure lamp running on straight vegetable oil.
II. ENERGY SCENARIO

The world is facing twin energy-related threats; the inadequate and insecure supplies of energy at affordable prices and that of environmental harm caused by inappropriate use of energy. Soaring energy prices leading to high cost of living and the recent citizens’ unrests have reminded many governments of the essential role affordable energy plays in economic growth and human development [7]. The vulnerability of the global energy system to supply disruptions has also been put into perspective. Safeguarding energy supplies is once again at the top of the international policy agenda. Unfortunately, the current pattern of energy supply carries the threat of severe and irreversible environmental damage. Reconciling the goals of energy security and environmental protection requires strong and co-ordinated government action and public support [7].

Energy is mainly consumed in manufacturing, commercial, transport, residential, power generation, and street lighting. The transport sector is the largest consumer of petroleum products followed by the manufacturing sector and other sectors such as agriculture, tourism, and power generation [1]. Demand for energy has continued to increase at an alarming rate. This has been necessitated by the world population growth with life expectancy increasing due to improved health care. For example population growth in Kenya is estimated at 2.7 % per annum [8]. As shown in Figure 2.1, there has been a steady increase of population. The population living in urban areas is also increasing and it is estimated that by the year 2027, the population living in urban areas will exceed that living in rural areas [9]. This will be due to the fact that many new urban centers will be created, which means more energy will be required. This poses a challenge if no measures are put in place to supply the required energy, now and in the future.

![Figure 2.1: Population projection in Kenya 1999 - 2032 [1]](image1)

In Kenya, energy is composed of commercial and non-commercial resources. Commercial energy mainly comprises of petroleum products and electricity, while non-commercial comprises of biomass, and to a lesser extent solar energy, wind power and biogas. From the National Energy Matrix, total final energy consumption in Kenya in 2009 was 14 million tonnes of oil equivalent [1, 10].

As shown in Figure 2.2, petroleum fuel accounts for about 29 % of the total final energy consumption while electricity and combustible renewables account for about 3 % and 68 % of the total final energy consumption respectively. Assuming a 2.45 kg CO\textsubscript{2} emission per litre of petroleum fuel, 14 million tonnes of oil leads to about 10,250 thousand tonnes of CO\textsubscript{2} [1]. Biomass sources (charcoal, fuel wood etc.) may not support the demand for long due to the pressure on the limited land whose quality is deteriorating due to climate change.

![Figure 2.2: Energy consumption preference in Kenya [1].](image2)

By the year 2010, connectivity to electricity in Kenya varied greatly across provinces with Nairobi province having the highest connection rate of 53.47 % while Western province had the least connection rate of 14.5 %. The national connection rate was estimated to be 28.9 %. This shows that a good portion of the population uses either fossil fuels or biomass for cooking and lighting. The usage of fuel wood, charcoal and kerosene in rural areas is higher compared to urban areas. Figure 2.3 shows the popularity of various fuels in Kenya both in urban and rural areas. Kerosene is the most popular (80 %), followed by charcoal (60%), fuel wood (55 %), electricity (37 %) and LPG (21 %) in that order [1]. The usage of fuel types by various income categories reveals that the use of material residue, kerosene and fuel wood declines with rise in income. The key determinants for kerosene choice at the household were occupation, total energy expenditure, household size, fuel wood price, education level and price of LPG [1]. The use of biomass for cooking and lighting together with kerosene usage has led to adverse health implications. These health implications include respiratory infections such as asthma, bronchitis, obstructive lung diseases, adverse pregnancy outcome and lung cancer. These have been responsible for 2.7 % of the global disease burden and nearly 1.6 million deaths per year [2].
A. Pollutant Emissions

Increased energy demand has led to gas pollutant emissions such as CO, CO$_2$, SOx etc. which have contributed to global warming, climate change and adverse effects to the environment. Due to these effects, a lot of efforts are being directed towards curbing these emissions as well as reducing the concentration of these gases already in the atmosphere.

As shown in Table 2.1, CO emission is high in China (8,8867.3x 1000 metric tonnes) while Palau has very low emissions (negligible) indicating that it is possible to put up strategies to curb emissions [12]. Table 2.2, shows the anthropogenic sulphur dioxide emission from combustion of fossil fuel which contains 1-2% sulfur content by weight. Sulphur dioxide combines with moisture in the atmosphere to form sulfate acid. These sulfate acid depositions are detrimental to ecosystems [11]. Combustion of fossil fuels has greatly increased sulfur emissions into the atmosphere with the anthropogenic emissions now greater than natural emissions [3].

Table 2.1: Carbon monoxide emissions from selected countries in the world [12]

<table>
<thead>
<tr>
<th>Country</th>
<th>Abb</th>
<th>CO Emissions x 1000 Metric tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>CHN</td>
<td>88,867.3</td>
</tr>
<tr>
<td>United States</td>
<td>USA</td>
<td>77,706.7</td>
</tr>
<tr>
<td>India</td>
<td>IND</td>
<td>63,843.8</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>RUS</td>
<td>27,893.6</td>
</tr>
<tr>
<td>Tanzania</td>
<td>TZA</td>
<td>17,841.5</td>
</tr>
<tr>
<td>South Africa</td>
<td>ZAF</td>
<td>10,065.3</td>
</tr>
<tr>
<td>Uganda</td>
<td>UGA</td>
<td>4,321.9</td>
</tr>
<tr>
<td>Kenya</td>
<td>KEN</td>
<td>3,788.8</td>
</tr>
<tr>
<td>Nine</td>
<td>Niu</td>
<td>0.1</td>
</tr>
<tr>
<td>Palau</td>
<td>PELW</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 2.2 shows that sulphur emissions are growing and there is need to curb the emissions.

The IPCC report notes that emissions from developing countries need to deviate as soon as possible from what the IPCC estimates as baseline emissions, even if developed countries make substantial reductions [13].

Figure 2.4: Comparative carbon dioxide emissions between atmospheric and anthropogenic sources [7].

Figure 2.4 shows CO$_2$ emissions scenario in the world from atmospheric and anthropogenic sources. It shows that the CO$_2$ emissions from anthropogenic sources in the world are growing. This calls for a means of stopping the increase.

This growth is brought about by the increased energy demand [7]. If the trend continues, the energy supply to meet the needs of the world economy is too vulnerable to failure arising from under-investment, environmental catastrophe or sudden supply interruption. This has been emphasized in the recent years by world leaders who endorsed that judgment and made a political commitment to change. They asked the International Energy Agency (IEA) to map a new energy future [7]. The road-map to energy future is to embrace sustainable development. Stabilizing greenhouse gases at 450 parts per
million (ppm) CO₂ requires a reduction of developed country emissions by 25-40 percent below 1990 levels by 2020. If this goal is not met, steeper reductions would be required over subsequent decades [2].

B. Performance of Kerosene Lamps

Figure 2.5 shows the common kerosene lamps in Kenya [14]. The small tin lamp is common with the rural poor and the urban poor living in informal settlements. The small and large lantern is mainly used by the middle income earners in rural areas where there is no electricity. The pressure lamp is used in large rooms both in rural and urban areas. It is more common in large gatherings in rural areas and to light up rooms in urban areas when there is a power outage.

Tin lamps operate by having a wick (cloth material, mostly cotton), immersed in a container. Kerosene is put into the container from which the wick takes up the fuel by capillary action. The wick is then lit to produce light. Lantern lamps are improvement of the tin lamps. A glass chimney is incorporated to shield the burning wick. A provision is also made to raise or lower the wick to control the amount of light. Pressure lamps have a fuel container which can be pressurized by using a plunger. The fuel is pressurized to control light output.

The figure shows that pressurized kerosene lamp gives the highest light intensity of about 180lux. Simple kerosene wick lamps, which are very common with the rural poor, give the poorest light of about 1lux. Hurricane lamps, which are common among the average rural dwellers, produce about 5lux light output [14]. Although pressure lamps give the highest light intensity, there is need to study their performance in totality to consider not only the light output, but also emission.

C. Straight Vegetable Oil Application in Lamps

Experiments on particulate emissions rate of simple kerosene lamps was conducted by Stuarte et al. [15]. It was found that the mean particulate emission rates in these lamps were substantially lower than those found for open biomass cooking fires, which range from 2-20 g/h [16]. The lower end of this range, however, just overlapped with the high emission rate found for the traditional tin/can lamp [15]. These figures show that tin/can kerosene lamps produce more emissions than lantern lamps. It also shows that emissions from tin lamps are comparable to that of open biomass cooking fire. No available literature was found on emission from pressure lamps.

Tami [22], has shown that Smoke emitted by simple wick lamps, similar to the one shown in Figure 2.7, was found to be significant but previously overlooked source of global black carbon. These lamps are used by hundreds of millions of households, and can be replaced by cleaner, affordable alternatives.

Agatha et al. [17], of Kenyatta University, has demonstrated that a Chinese wick cook stove shown in Figure 2.8 can run on straight vegetable oil. They found out that the heating value of the straight vegetable oils were higher than those of conventional kerosene. The emissions from the stoves were less than those from kerosene stoves. The stove burned with less unpleasant odour.
Kimpea et al. [18] analysed the oil used in ancient Roman oil lamp found at the archaeological site of Sagalassos by gas chromatography (GC) coupled to mass spectrometry (MS). The identification of plant sterols and long chain alcohols suggested that a vegetable oil was used in these lamps. The lipid sample was also analysed with reversed-phase liquid chromatography (LC) coupled to MS with atmospheric pressure chemical ionization (APCI). It was shown that predominantly olive oil was used as a fuel for the antique oil lamps. The presence of large quantities of unsaturated triacylglycerol (TAG) and traces of saturated TAG indicated that also other oils and animal fat were added.

D. Biofuel Application in IC Engines

Rudolf Diesel [19] demonstrated the first use of vegetable oil in compression ignition engine in 1898 at the World Fair in Paris France. It was powered by peanut oil which had not been transesterified.

Farhad Ghafarzade [20] successfully modified a diesel Mercedes Benz to run on waste vegetable oil. The oil had to be filtered before it was used. The car had two separate fuel tanks to hold fossil diesel and vegetable oil. Old engines, manufactured before 1980, were preferred for modification because they had fewer moving parts. Emission from the modified engine showed a 70% CO₂ reduction.

Kleinova et al. [21] did research on the use of straight vegetable oils and animal fats applicable as fuels in standard diesel engines after having adapted the fuel system for electronically controlled dual fuel regime oil/fat-fossil diesel. The performance and emission characteristics of the engines running on rapeseed oil, lard, or chicken fat were obtained and compared to those of fossil diesel and fatty acid methyl esters. The results of engine tests of these fuels showed a decrease in maximum power and maximum torque in comparison to fossil diesel due to a lower energy content of triacylglycerols. The level of both controlled and uncontrolled emissions was low for all tested biofuels and was also low for the reference fossil diesel. The results of performance and emission tests for rapeseed oil containing 3 and 6 vol. % of anhydrous ethanol were comparable to those obtained for pure oil.

III. RESULTS AND DISCUSSION

About a third of the world population lives without electricity. This makes them to rely on other energy sources for cooking and illumination. 80% of the Kenyan population use kerosene for cooking and lighting. There is an increased demand for fossil fuel both in the developed and developing countries, which has led to escalating oil prices. Increased fossil fuel use leads to green house gas emissions with associated health problems. Kerosene lamps are common with low and middle income earners. Tin kerosene produces the least amount of light of about 11ux, glass lantern lamps produce about 5lux while pressure lamps produce about 180lux.

Emission from tin kerosene lamps produces high black carbon. 7%-9% of the fuel in these lamps is converted to black carbon. This is a very high emission factor considering the millions of these lamps which are used worldwide. Particulate emissions from kerosene lamps are lower than those from biomass burning although the lower limit of biomass burning coincides with the upper limit of that from kerosene lantern lamp.

Chinese wick stove, which work by capillary, similar to kerosene tin and lantern lamp can operate on straight vegetable oil producing less particulate and gaseous emissions compared to kerosene wick stove. Early Roman lamps used straight vegetable oil, predominantly olive oil. Early diesel engines were designed to run on straight vegetable oil. Modern engines can run on straight vegetable oil with no or minor modification.

IV. CONCLUSIONS

The pressure exerted on fossil fuels can be lowered by fuel diversification to renewable fuels such as straight vegetable oil. Pollutant emissions from biofuels are lower than those from fossil fuels. Kerosene lamps, which previously were considered insignificant to global degradation, emit dangerous emissions to the environment. Kerosene lamps can be modified to run on vegetable oil to reduce dangerous emissions. Global degradation can be reduced if fuel switching to cleaner renewable energy is embraced.

ACKNOWLEDGEMENT

The authors wish to acknowledge the financial support from National Council for Science and Technology (NCST) for the grant advanced towards this research. They also wish to thank Jomo Kenyatta University of Agriculture and Technology (JKUAT) for supporting this work through provision of laboratory space and equipment. The authors also wish to thank Dr. Kithinji, University of Nairobi, Chemistry Department, for facilitating emission measurements. All those who supported this work directly and indirectly are greatly acknowledged.

REFERENCES

[1] KENYA INSTITUTE FOR PUBLIC POLICY RESEARCH AND ANALYSIS,(KIPRA), "A COMPREHENSIVE STUDY AND ANALYSIS ON


