ORIGINAL RESEARCH ARTICLE

Performance and emission characteristics of Baobab (Adansonia Digitata) bio-lubricant in four stroke spark ignition engine

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Abstract
Over the years, the growing interest for bio-based alternatives to mineral products (i.e. fuel and lubricant) to save energy and improve environmental friendliness has become one of the most researched topics. According to world meteorological organization (WMO), Concentration of carbon dioxide (CO_2) reached 420.23 parts per million in April, 2022. In this research, the extract from baobab nuts was purified, degummed and epoxidized to form Bio-lubricant. The physicochemical properties of the formed bio-lubricants were determined and are within the index of American Society for Testing and Materials (ASTM). The Fourier Transform Infrared (FTIR) at different temperatures and Gas Chromatography Mass Spectroscopy (GC-MS) with two different acids were conducted on the products. The results depicted minimal changes with repeated oxidation at higher temperature and different acids respectively. A four-stroke spark ignition engine at three different speeds was used to validate the bio-lubricant by compared with SAE40 performances. Four engine parameters considered: specific fuel consumption (SFC), brake thermal efficiency, brake power and brake mean effective pressure. The bio-lubricant maintained a low values trend for the four parameters at engine speeds of 2000rpm, 2500rpm and 3000rpm with exception of brake thermal efficiency that depicts high value of 56% at both 2000rpm and 3000rpm. The SI engine lubricated with SAE40 has higher CO, HC and CO2 emissions.

Keywords: *Baobab Bio-lubricant, Engine performance and exhaust emission*

INTRODUCTION
Petroleum based fossil fuels have been dominant transport fuels since the very beginning of mechanized mobility in nineteenth century. Predicted exhaustion of fossil fuels in foreseeable future, according to the analysis made by the British Petroleum (BP) in the year 2020, global oil proved reserve rose to 1732.4 billion barrels at the end of the year 2020 and was potentially adequate to meet supply in 53.5 years of the world oil production [1] and environmental pollution concerns provide motivation for search of renewable alternative fuel for the transport sector which would have relatively lesser harmful impact on the environment. According to world meteorological organization (WMO), Concentration of carbon dioxide (CO_2) reached 420.23 parts per million in April, 2022. There is need to developed new technological solutions that are less harmful to decrease environmental pollution brought by vehicles and machines.

Lubricants are among the largest drivers of global oil demand in the world. The negative environmental impacts resulting from the entry of direct mineral lubricants necessitates the application of bio-lubricants as an excellent alternative to mineral lubricants (Zainal *et al*., 2018). Bio-lubricants are lubricant derived from biological products or renewable materials that satisfy established biodegradability and toxicity criteria. Bio-lubricants are generally considered lubricant with high biodegradability as well as low human and environment toxicity [3] [4]. Many researchers have investigated the physicochemical properties and the performance of different plants oil extract such as palm oil, coconut oil, soybean, sunflower and other edible and non-edible plants extract. Bio-based lubricants are known to have good lubricity, high flash point, high viscosity index and good resistance to shear compared to mineral oils [5].

Krishna, *et al*. (2014), investigated the performance of palm oil as biolubricant in a compression ignition (CI) engine by substituting mineral lubricant with vegetable lubricant as a base stock for an environmental friendly lubricant without adding any additives. However, the Gas Chromatography Mass Spectroscopy (GC-MS) and Fourier Transformation Infrared (FTIR) of the palm oil was not studied. Kaisan *et al*., (2017), investigated the exhaust emission of binary and multi-blends of biodiesel from Jatropha; Neem and Cotton Seed Biodiesel. The Engine performance and emission of bio-lubricants were not exploited. Thapliyal & Thakre, (2017) investigated the correlation of physicochemical, rheological, and tribological parameters of mineral and synthetic commercial engine oils using four-ball tribotester. Attia *et al*., (2020) produced bio-lubricants from; sunflower, soybean, Jatropha and waste cooking oil by applying calcium oxide (CaO) as a heterogeneous base catalyst through trans-esterification of fatty acid methyl esters (FAMEs) and ethylene glycol. However, GC-MS; FTIR; peroxidation; Engine performance and emission of bio-lubricants were not presented in the research. Encinar *et al*., (2020) produced biolubricant through the trans-esterification of rapeseed and castor oil methyl ester with different alcohols and titanium iso-propoxide as catalyst. Gemsprim *et al*., (2020) carried out tribological evaluation of vegetable oil-based lubricant blend from Mahua & Sunflower to investigate the wear rate and coefficient of friction values using pin on disc wear tester. Girish & Shashidhara, (2021) studied performance and emission characteristics of four stroke gasoline engine under formulated Neem oil as base lubricant. Nomède-Martyr *et al*., (2021), studied Moringa with graphite additives as alternative to conventional petroleum-based lubricant. However, the GC-MS; FTIR, engine performance and emission of bio-lubricants were not explored by most of these reports.

Mineral oil reserve is declining and associated with it is enormous greenhouse gas emissions when used in heat engines. The problem of oil spillage during drilling or transporting mineral oil leaves the environment polluted causing harmful effects to living organism on land and water and the cost of remediating the damage is very high. Many biolubricant from other feedstock's as reported by other researchers produces higher brake specific fuel consumption when compared with mineral diesel, also most blends of biolubricants with mineral diesel show comparable performances between 20-50%/80-50% ratios. Thus, the need to explore other feedstock that could take high ratios.

METHODOLOGY

Experimental setup

The baobab oil was extracted from baobab nuts part of the baobab tree. The extracted baobab oil used for the experiment was purchased from a vendor at Kano. The extracted baobab oil was degummed and purified by adding 200ml of water with 10% phosphoric acid mixed with 2L of baobab oil in a beaker, heated at 90°C for one hour. Afterwards, the mixture was kept overnight to allow separation of oil and gum. The purified baobab oil was epoxidized and the epoxidation method reported by [13] was adopted. The required amount of KOH was placed in the contractor. The calculated amounts of acetic acid and sulfuric acid were added to baobab oil and stirred for 30 min. Then 17g of 30% aqueous hydrogen peroxide was added drop wise over 30 min. The reaction mixture was continuously stirred to avoid zones of high peroxide concentration that could lead to explosive mixtures. The ring-opening reaction reported by [14] was adopted. The reaction consists of mixture of epoxidized baobab oil and an alcohol. The reaction mixture at 70℃ was agitated by a motor-powered stirrer for 15 min at a speed of 1000 rpm and 1.5% w/w of catalyst was added to initiate the reaction and obtain the products. The physico-chemical properties of the baobab lubricant such as density, cloud point, pour point, acid value, iodine value, saponification value, octane number, FTIR and GC-MS were determined according to ASTM Standard methods for lubricant. Table 3.1 depicts the values of the determined physico-chemical properties of baobab lubricant.

Engine performance test was carried out on the bio-lubricant product and compared with SAE40 standard fossil-based lubricant using a four-stroke spark ignition stationary engine. Four engine parameters were considered at three different speeds (2000rpm, 2500rpm and 3000rpm). The bio-lubricant was used as the engine lubricant and the engine runs till no further changes on the four engine parameters then the biolubricant was drained and replace with SAE40. Similarly, the fossil lube undergoes the same test and the result were used for further analysis.

The NHA-506EN emission analyzer was use to analyzed the exhaust emission of the Baobab bio-lubricant emission and compared with the SAE40 fossil lube. For the emission analysis, the engine torque was also varied adding to the speed variation at 2Nm, 4Nm and 6Nm.

Table 2.1: Physico-Chemical Properties of Bio-lubricant from Baobab

PROPERTIES	BOABAB LUBE	ASTM MINIMUM
Specific Gravity (g/cm^3)	0.89	0.88
Viscosity @ 100℃	14	12.5-16.3
Cloud point (℃)	-8.1	-9
Flash Point(℃)	223	220
Pour Point (℃)	20	(-10) – (-65)
Total Base Number(KOH/g)	8	7-10

Engine Performance Test

The produced bio-lubricant from baobab oil was evaluated on stationary four stroke spark ignition engine. Furthermore, the exhaust gases were analyzed. Tables 3.2 and 3.3 depict the four stroke SI engine and the gas analyzer specifications respectively.

Table 2.2: Four stroke SI engine Specification

Engine Parameters	Specification for SI engine
Engine type	Four -stroke single- cylinder
Weight	51kg
Engine Capacity	406cc
Net power	6.3kw @ 3600
Speed	36600rpm

Table 2.3: Gas Emission Analyzer Specification

Equipment	Measured Variables	Range	Uncertainties
NHA-506EN emission analyzer	HC	0-9999ppm	
	NOx	0	0
	CO	0-10vol%	±0.06vol%
	O_2	0-25vol%	±0.1vol%
	CO_2	0-18vol%	±0.1vol%

RESULTS

The FTIR analysis of the bio-lubricant produced from baobab oil was carried out at different temperature epoxidation. Figure 3.1 depicts the FTIR result before epoxidation while figure 3.2 depicts the FTIR results at temperature of 30℃ and table 3.1 summarized FTIR results of the different temperatures at 30℃ increment.

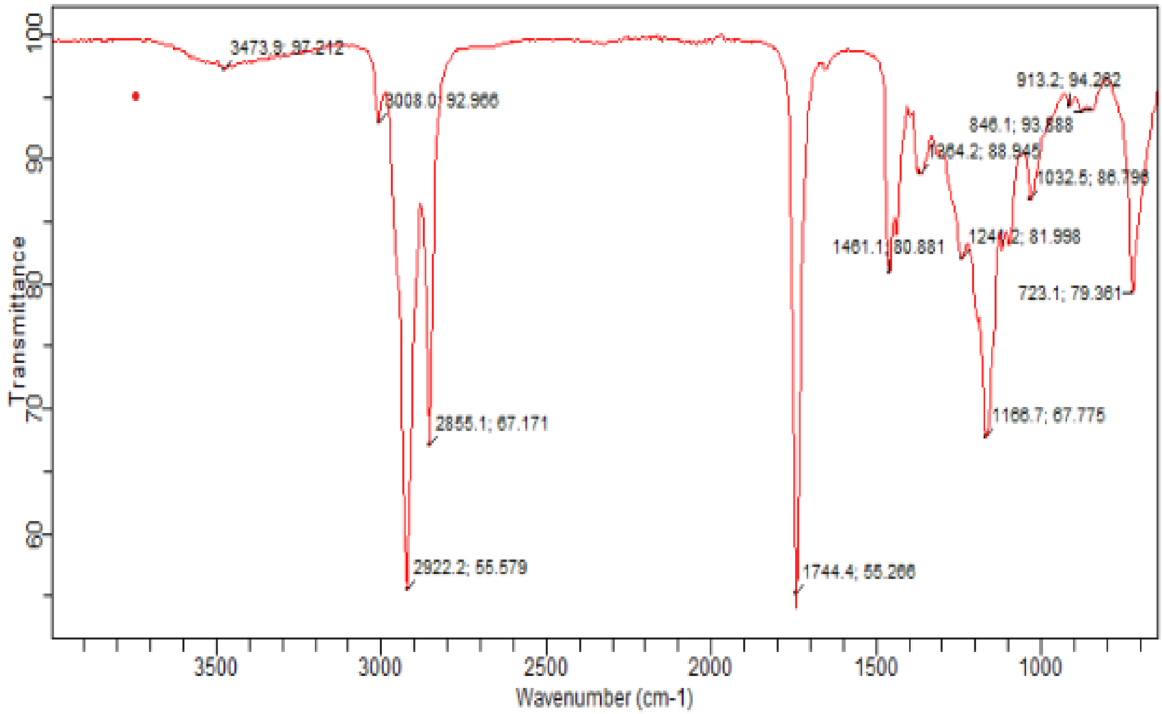

Figure 3.1 – FTIR Result for Baobab Oil before Epoxidation

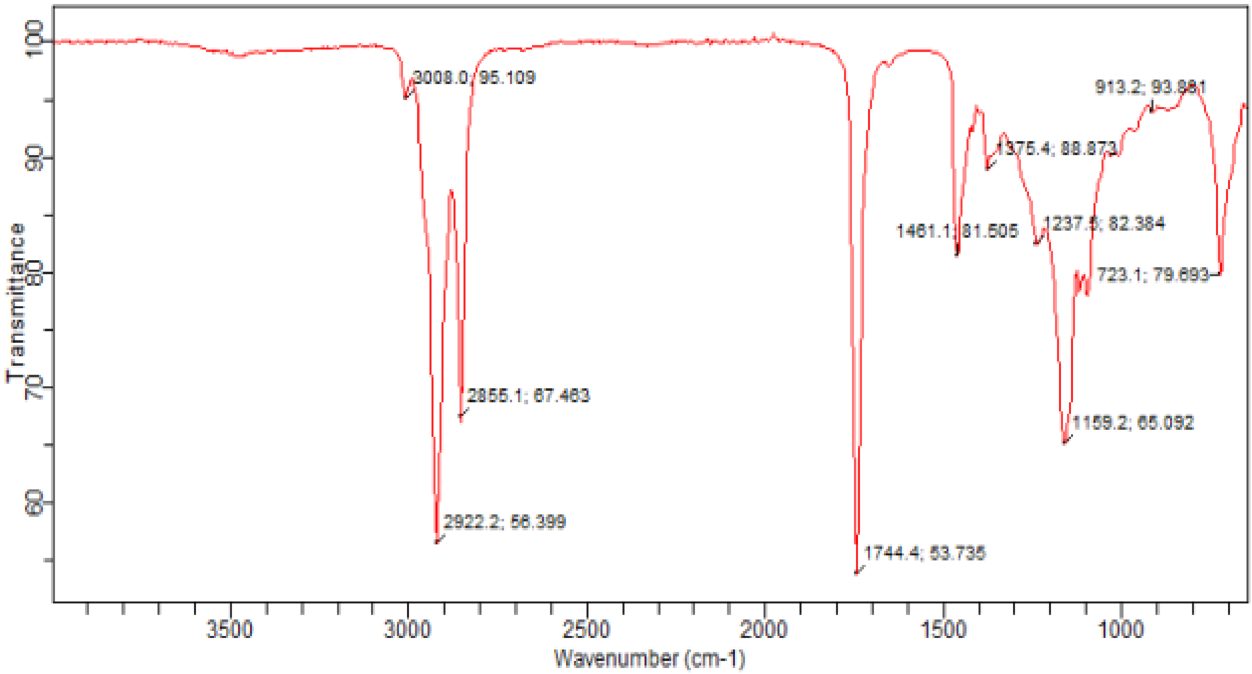

Figure 3.2 – FTIR Baobab Oil at 30℃ Epoxidation

Table 3.1 Summary of FTIR Spectroscopy at different Temperatures

Epoxidation							
	Before	**After**					
Temperature (℃)	Room	30	60	90	120	150	180
Wavenumber (cm-1)	1750/2900	1750/2900	1800/2950	1800/3000	1800/3000	1850/3050	1850/3050
Bond	C=O/ C-H	C=O/ C-H	C=O/ C-H	C=O/ C-H	C=O/ C-H	C=O/ C-H	C=O/ C-H
Functional Compound	Alkanes, Alkenes / Aldehydes, Carboxylic acids,	Alkanes, Alkenes / Aldehydes, Carboxylic acids,	Alkanes, Alkenes / Aldehydes, Carboxylic acids,	Alkanes, Alkenes / Aldehydes, Carboxylic acids,	Alkanes, Alkenes / Aldehydes, Carboxylic acids,	Alkanes, Alkenes / Aldehydes, Carboxylic acids,	Alkanes, Alkenes / Aldehydes, Carboxylic acids,

After epoxidation of the baobab oil, the GC-MS analysis was carried out on the epoxidized bio-lubricant product. Figure 3.3- 3.6 depicts the MS and Spectrum results with octadecadienoic acid methyl ester and hexadecadienoic acid methyl ester.

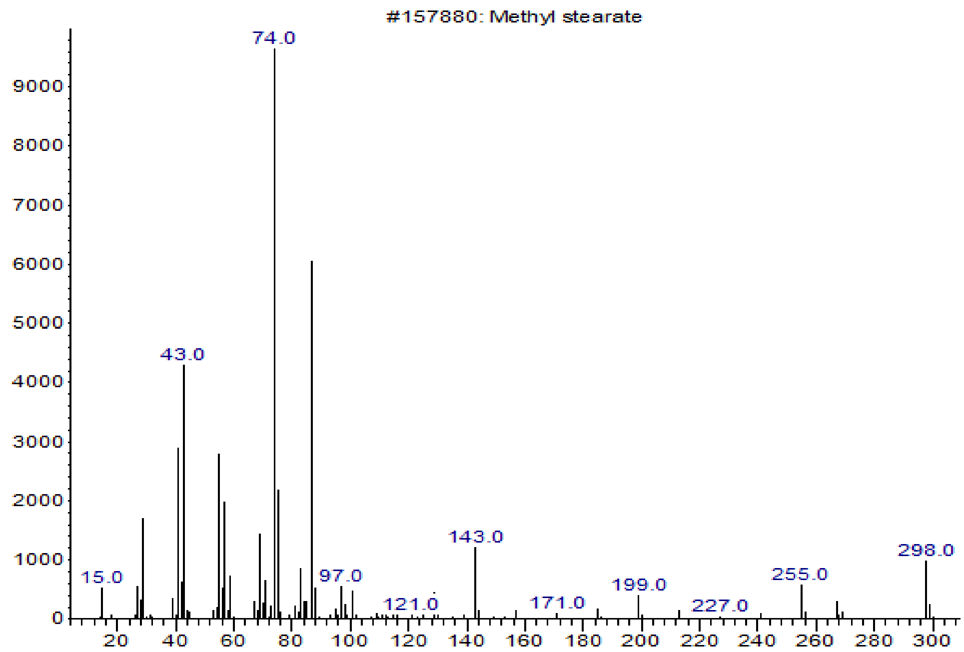

Figure 3.3 – MS Results with 77.7 % Octadecadienoic acid, methyl ester

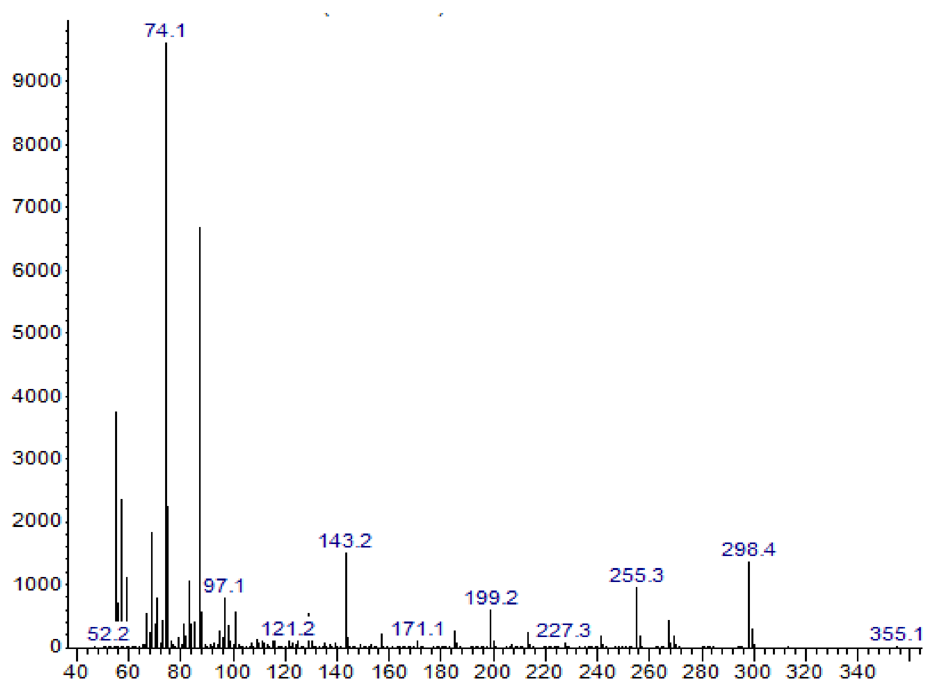

Figure 3.4 – Spectrum Results with 77.7 % Octadecadienoic acid, methyl ester

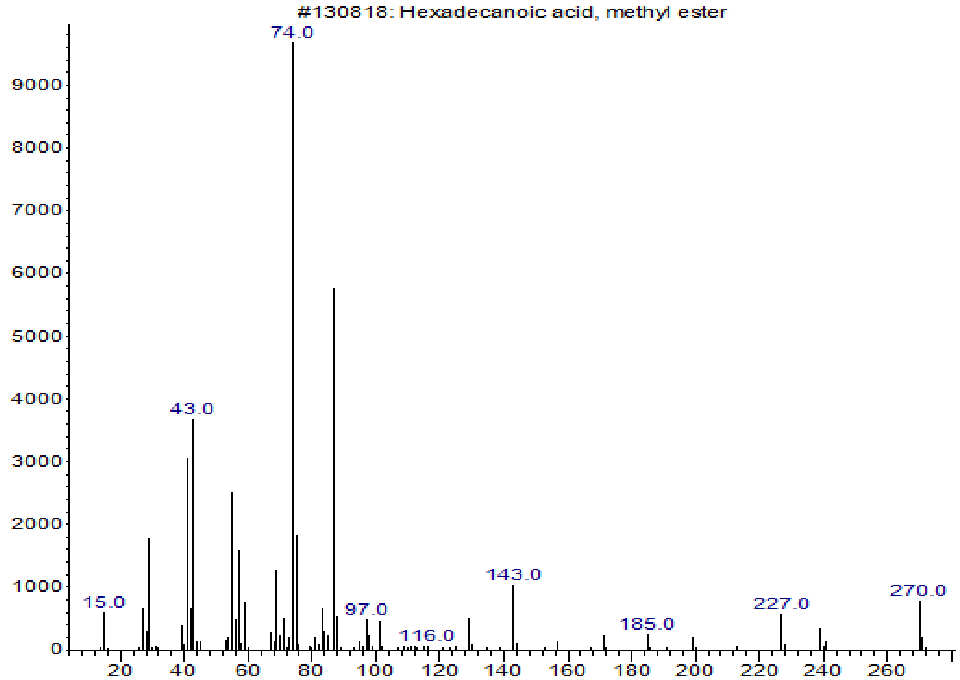

Figure 3.5 – MS Results with 77.7 % Hexadecadienoic acid, methyl ester

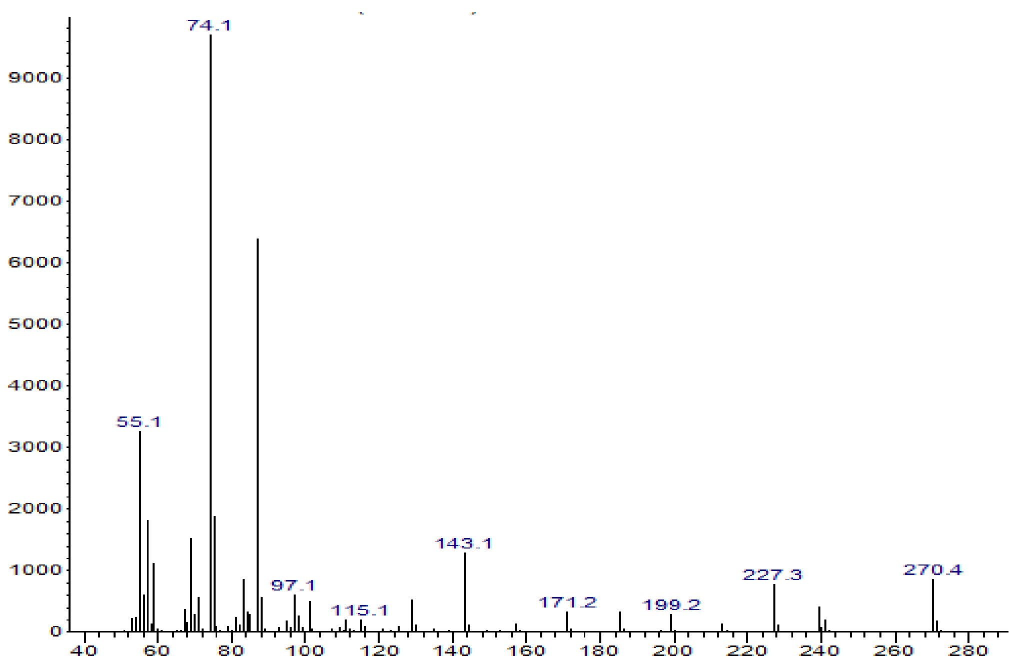

Figure 3.6 – Spectrum Results with 77.7 % Hexadecadienoic acid, methyl ester

For the engine performance analyses, the specific fuel consumption, Brake thermal efficiency, Brake power and Brake mean effective pressure were the engine parameters considered for the validation of the propose baobab biolubricant. Figure 3.7 – 3.10 depicts the engine test performance of bio-lubricant product and SAE40 fossil base lube based on the four engine parameters.

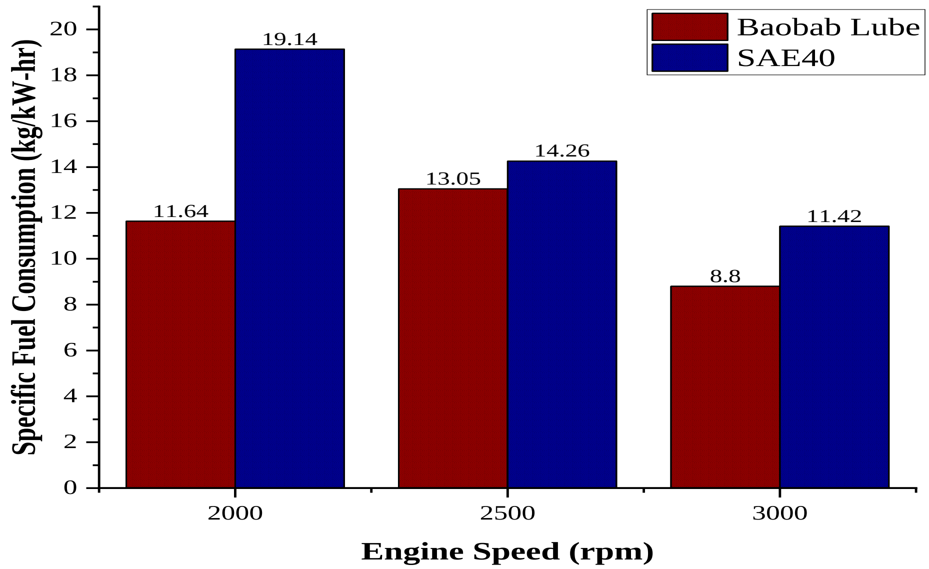

Figure 3.7 – Specific fuel Consumption

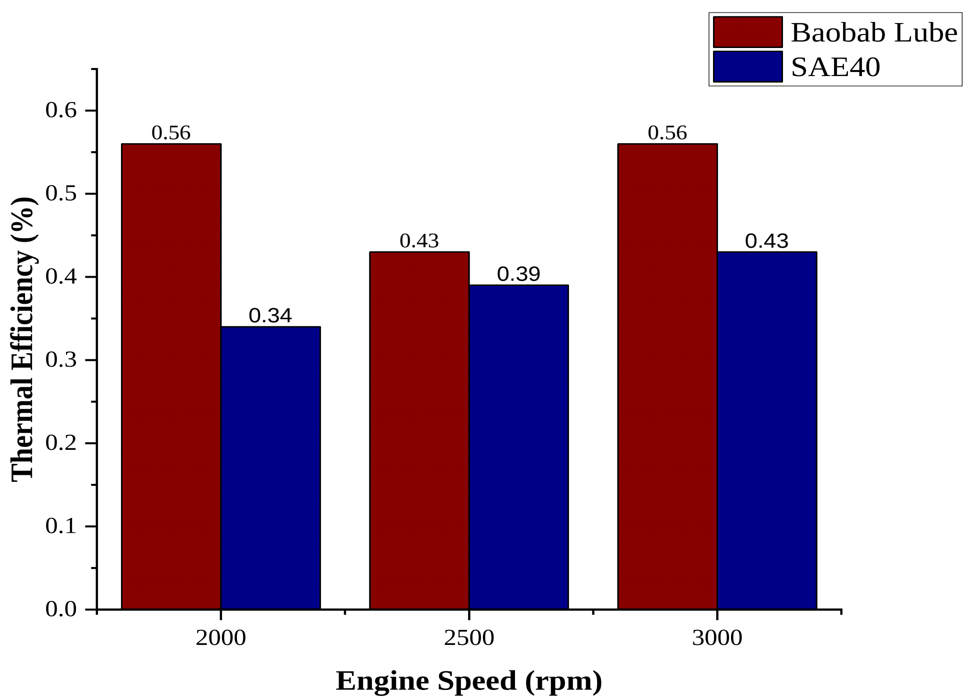

Figure 3.8 – Brake thermal Efficiency

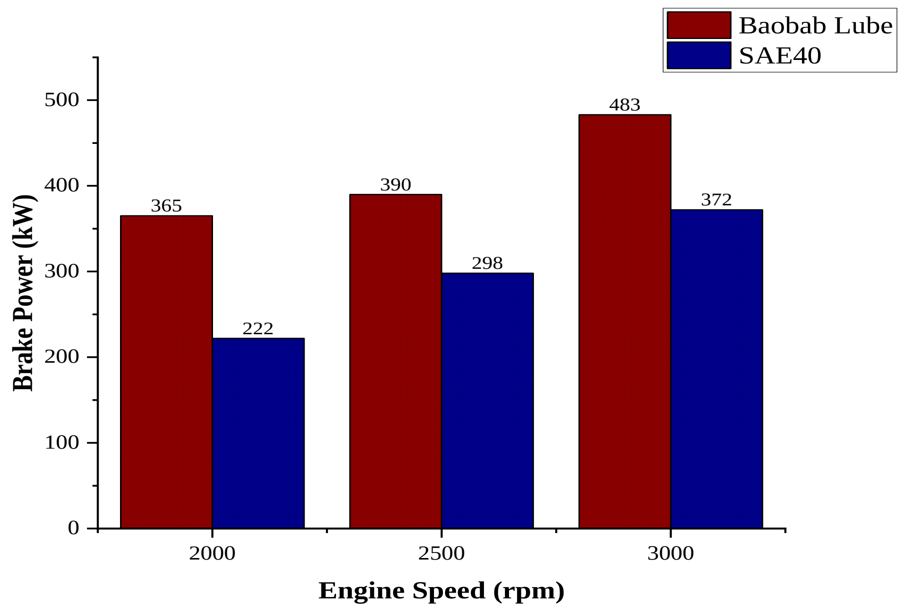

Figure 3.9 – Brake Power

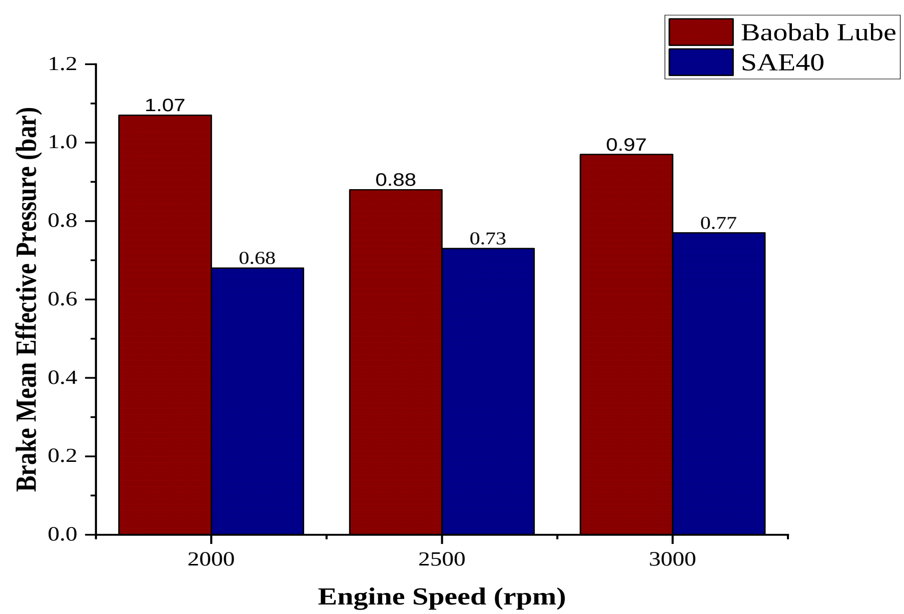

Figure 3.10 – Brake Mean Effective Pressure

Figures 3.11 – 3.16 depicts the results of different gas emission for both biolubricant and fossil lubricant (SAE40).

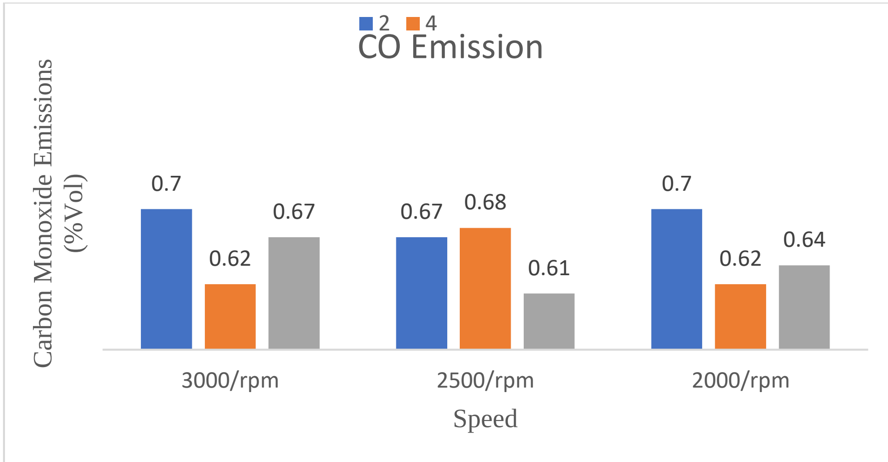

Figure 3.11 – CO emissions at various speeds for Baobab lube oil

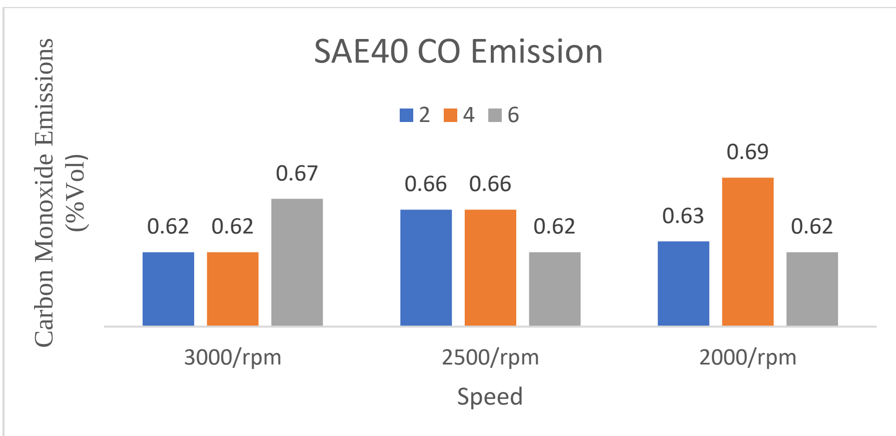

Figure 3.12 – CO emissions at various speeds for SAE40 lube oil

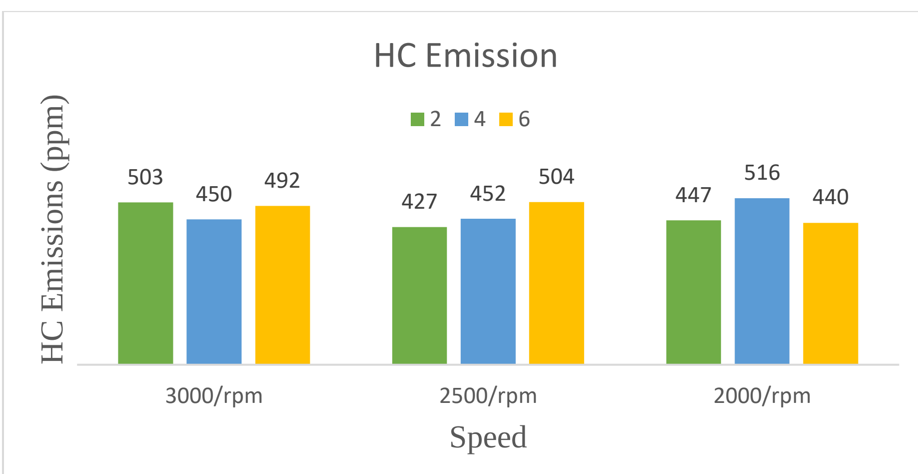

Figure 3.13 – HC emissions at various speeds for Baobab lube oil

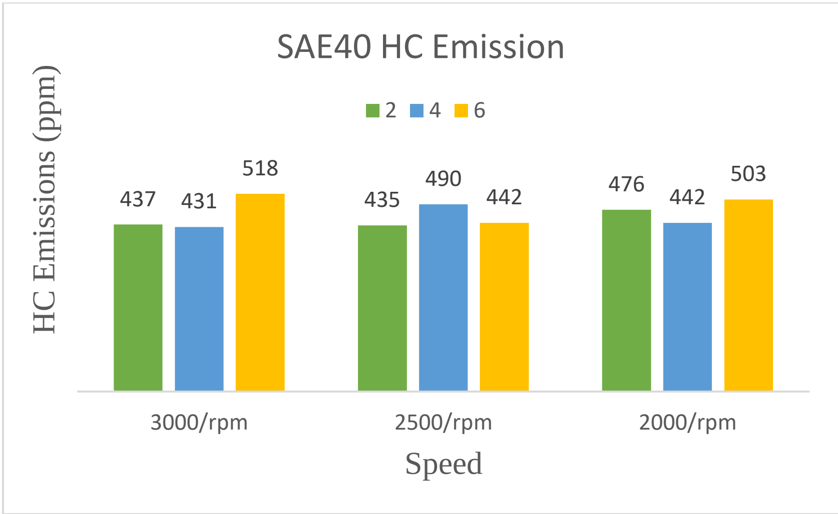

Figure 3.14 – HC emissions at various speeds for SAE40 lube oil

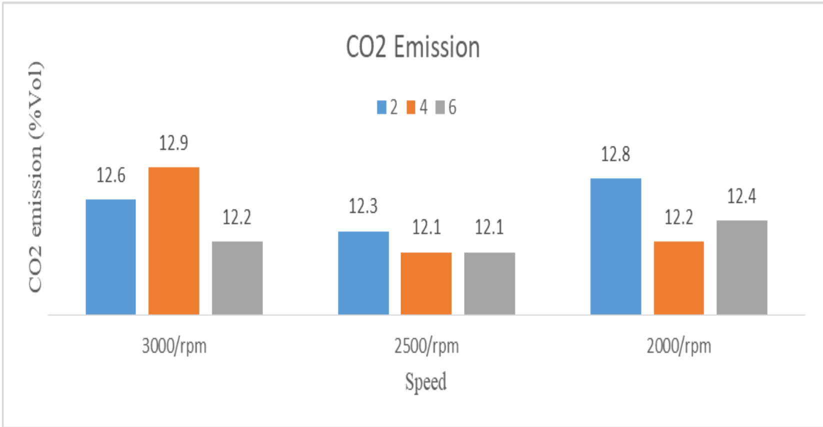

Figure 3.15 – CO_2 emissions at various speeds for Baobab lube oil

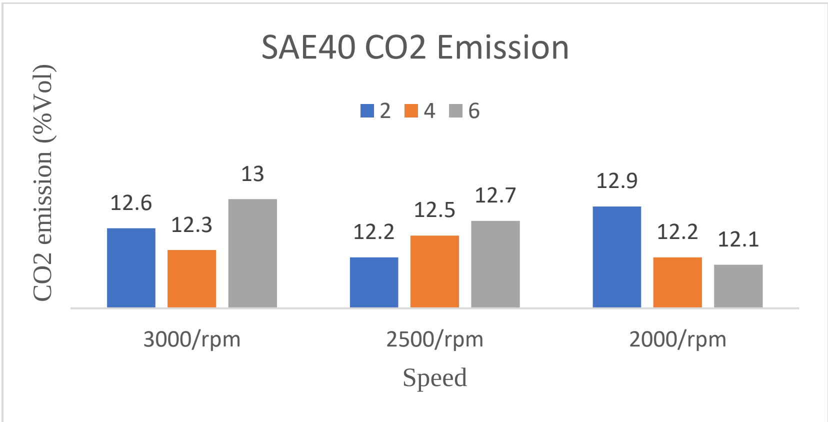

Figure 3.16 – CO_2 emissions at various speeds for SAE40 lube oil

DISCUSSION

The finger print region (<1500cm^{-1} of the FTIR results has little changes after repeated oxidation at higher temperatures, let alone the functional group region (>1500cm^{-1}). As shown in Fig 3.1, the finger print region for the FTIR depicted three spikes at wave numbers of 723, 1167 and 1461. The result indicates presence of Chloroalkane, Alcohols and Alkenes compounds respectively. However, the presence of C=C double bond and hydrocarbon are assured. This functional compound corresponds to the functional compounds fossil lubricant; hence, the product is suitable for use as lubricant. The GC-MS analysis standard as confirmatory test on the substance present in the biolubricant. The engine performance result for the four engine parameters depicts less difference between the bio-lubricant and SAE40 fossil lubricant at speed of 2500rpm. As shown in fig 3.7, the bio-lubricant has low SFC compared to the SAE40 which depicts that the bio-lubricant is more efficient than the SAE40. However, the remaining three parameters depicted lower values compared to the SAE40 lubricant. The higher the thermal efficiency and the brake power, the lower the SFC which leads to increase in friction and inertia of moving parts due to high speed. The emission characteristics of baobab bio-lubricant and SAE40 lube oil in a four-stroke spark ignition engine at operating speeds of 2000, 2500 and 3000 rpm under loads of 2, 4 and 6 kg has been presented. It was observed that for both lube oils the CO, HC, and CO2 emissions were comparable with little differences showing on both sides. It was established that for baobab lube oil, at lower load of 2kg for all speeds the CO emissions is higher compared to the standard lube oil, also at 2000rpm, it can be seen that CO emission at 4kg for standard lube oil is higher than that of the baobab lube oil, however, this trend is not consistent for all load. It was also established that at 3000rpm HC emission from baobab lube oil at 2kg, 4kg is 15.1% and 4.4% respectively higher than standard lube oil but at 6kg opposite is the trend with a corresponding 5.3% decrease in HC emission. It was shown from the results that at 3000rpm and 2kg load for both lube oils, there is no difference in CO2 emission, while for 4kg load there is a 4.9% increase for baobab lube oil emission but for 6kg load, there is a 6.6% increase for standard lube oil. Similar trend is reported at other speeds. However, the outcome from both lubes are comparable with little differences which can be attributed to the additives that comes with the standard lube oil (SAE40) which are absent in the baobab lube oil.

CONCLUSION

Epoxidation of baobab oil gives 90.7% methyl-ester which can be used as bio-based lubricants in four stroke single cylinder spark ignition engine without engine modification.

The profile of bio-lubricants produced and the physico-chemical properties indicated that they are viable replacement for SAE 40 conventionally used for SI engines in conformity with ASTM Standards.

The use of baobab lubricant as engine oil confirms that the lube is suitable for engine lubrication. The lowest Specific fuel consumption was depicted by baobab lubricated engine at low; medium and high engine speeds of 2000 rpm, 2500 rpm and 3000 rpm correspondingly. This trend was maintained by the brake thermal efficiency and the brake power as well as the brake mean effective pressure. The highest brake thermal efficiency values were given by baobab at 56% both at 2000 rpm and 3000 rpm

Bio-lubricants produces exceptional emissions properties and generates less greenhouse gases emissions. The SI engine lubricated with normal fossil-based lubricant (SAE 40) has higher CO and HC emission as well as CO2 emissions. However, adding additives could increase the performance of baobab bio-lubricant and reduce the emission characteristics of the exhaust gasses.

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