American Journal of Engineering and Applied Sciences

Original Research Paper

Experimental Study of Diesel Engine Generator Performance and Emission Characteristics Using a Mixture of Jatropha Oil and Rubber Seed Oil Biodiesels Along a Two-Step Transesterification

[1]Fana Gebremedhin Gebremichael and [2,3]Joao Fernando Chidamoio

[1]*Postgraduate Division, Faculty of Engineering, Eduardo Mondlane University, Maputo, Mozambique*
[2]*Center of Excellence on Studies in Oil and Gas Engineering and Technology, Maputo, Mozambique*
[3]*Center of Industrial Studies Safety and Environment, Eduardo Mondlane University, Maputo, Mozambique*

Article history
Received: 08-02-2024
Revised: 19-04-2024
Accepted: 25-04-2024

Corresponding Author:
Fana Gebremedhin Gebremichael
Postgraduate Division, Faculty of Engineering, Eduardo Mondlane University, Maputo, Mozambique
Email: fanagebremedhin6@gmail.com

Abstract: This study investigates the performance and emission properties of engine-generator powered using various dual biodiesel mixes prepared from two inedible feedstock jatropha and rubber. Jatropha and rubber oils had high acid values, which were 13.96 and 27.91 mg KOH/g, respectively. Therefore, a two-step transesterification process was conducted to lower the acid value to 0.28 and 0.42 mg KOH/g for jatropha and rubber, respectively. The various physicochemical properties of biodiesels were compared with standards and diesel. The engine generator performance and emissions of various mixed biodiesel-diesel blends (BC10, BC20, BC30, and BC40) were investigated at varying loads and constant speeds (3000 rpm) and compared with B0, BA20, and BB20 biodiesel blends. In general, a blend of jatropha and rubber biodiesel reduced density and viscosity when compared to rubber biodiesel and improved ignition quality when compared to jatropha biodiesel. Dual biodiesel blends reduced CO_2, CO, and HC emissions in comparison to diesel, while NOX emission was higher. The results of the experiments show that better engine-generator performance and fuel exhaust emissions were seen with the BC20 followed by BC40 and can be utilized as a substitute fuel in diesel engine generators without requiring any modifications.

Keywords: Biodiesel, Engine Generator, Performance, Two-Steps Trans-Esterification

Introduction

The rapid depletion of world fossil fuel resources and the pursuit of managing environmental degradation forces researchers to look for alternative renewable fuels. Biodiesel has been considered a sustainable substitute for conventional diesel because it has several advantages, its characteristics are similar to petroleum diesel, it is renewable and clean energy, reduces greenhouse gas and pollutant emissions, and increases energy security by providing a stable and cost-effective energy supply. Vegetable oil is a reliable starting material for renewable energy production because it is widely available in various sources. Several kinds of research have been done on vegetable oils such as Jatropha Curcas L and rubber seed that confirm the suitability of vegetable oils as a source of biodiesel production (Jaichandar and Annamalai, 2016; Liu *et al*., 2018; Ulfah *et al*., 2018).

Biodiesel is a mono-alkyl Fatty Acid Methyl Ester (FAME) derived from renewable lipid sources using the transesterification process, where vegetable oils and animal fats chemically react with suitable alcohol (methanol) in the presence of a catalyst under a controlled temperature for a given length of time forming glycerin as a by-product (Roschat *et al*., 2012). Various edible and inedible vegetable oils have been in use as raw materials for the production of biodiesel. The possibility of producing biodiesel from edible vegetable oils in commercial quantities is not certain such as palm oil, soybean, rapeseed, sunflower, sesame oil, and olive oil because these compete with the food supply, resulting in the food crisis and high price of biodiesel produced (Abdulkareem *et al*., 2011). To prevent the food-fuel crisis, non-edible vegetable oils that are easily available and not fit for human consumption could be the most suitable for biodiesel production and supplementation (Sabarish *et al*., 2016).

Jatropha and rubber seed, which are non-edible oil-bearing, can grow under a wide variety of climatic conditions and wastelands with high oil yield per hectare and were found to be a renewable alternative source of biodiesel production (Amalia Kartika *et al*., 2013; Ramadhas *et al*., 2005).

Liu *et al*. (2018) revealed that rubber seed oil biodiesel and its blends with petro-diesel provided excellent lubricity, acceptable flammability, and cold flow properties compared to neat petrol-diesel, although the Cetane Numbers (CN) and Cold Filter Plugging Points(CFPP) of biodiesel blends slightly decreased with increasing contents of petro-diesel. Ramadhas *et al*. (2005) revealed that biodiesel from non-edible rubber seed oil is quite suitable as an alternative to diesel.

Teoh *et al*. (2019), studied the effects of adding bioethanol as a fuel additive to a coconut biodiesel-diesel fuel blend in diesel engine characteristics. The author concluded that B20E10 (20% biodiesel +10% bioethanol) achieved the highest average reduction of 9.3 and 52% in smoke and CO emissions, respectively, as compared to the diesel and also the authors revealed that when the percentage of bioethanol in the blend increased, the minimum Brake Specific fuel Consumption (BSEC) was observed. This is due to the bioethanol's lower viscosity, which significantly improved the fuel atomization process.

Jaichandar and Annamalai (2016) conducted an experiment using Jatropha Oil Methyl Ester (JOME) and its blends of 20 and 50% with standard diesel as a source of fuel for a compression ignition engine. The authors concluded that the specific fuel consumption of JOME and its blends was higher than that of diesel due to the lower calorific value of JOME and a slight reduction of brake thermal efficiency was observed with JOME and its blends due to higher viscosity, lower volatility and lower calorific value of biodiesel fuel than that of conventional diesel. Also, the authors revealed that due to the higher O_2 content in the JOME, emissions of CO and Unburned Hydrocarbon (UBHC) decreased with an increase in the percentage of JOME in the blend. The calorific value, density, and kinematic viscosity of jatropha and rubber seed oil biodiesels are not comparable to conventional diesel (Jaichandar and Annamalai, 2016; Vashist and Ahmad, 2011). These properties influence the performance of biodiesel as a fluid in the feed tubes, in the injector (thus lowering the atomization quality and combustion quality and resulting in high levels of pollutant emissions), and in the efficiency of the engine generator. Thus to overcome these problems and obtain high-quality biodiesel, a two-step transesterification process and blending of the two different biodiesel can be carried out.

Based on the literature, a large number of investigations on the performance, emission, and combustion of the compression ignition engine utilizing different biodiesels have been executed. However, several experimental studies have focused on the utilization of single biodiesel and its blend with conventional diesel but the performance of the diesel engine is still low relative to diesel. Very few works, Balasubramanian and Srithar (2014) have been carried out using a mix of two different biodiesels blended with diesel and the researchers left numerous gaps in this field. This research aims to optimize the performance of diesel engine generators and reduce the level of exhaust emissions using mixtures of jatropha and rubber biodiesel. Therefore, the goal of this study is to extract and characterize the oils, conduct a 2-step trans-esterification process, evaluate the properties of the biodiesel compared with diesel fuel, and investigate the performance and exhaust emissions of a single-cylinder diesel engine generator fueled with dual biodiesels and its blends. The utilization of a blend of jatropha and rubber seed oil biodiesel as a fuel for diesel engines can keep the environment safe from sulfur produced by fossil fuels and make it more competitive with petrol-diesel and large-scale production of the Jatropha and rubber plants could bring economic profits to underdeveloped countries in Africa where the plant grows.

Materials and Methods

Materials

All reagents used in this study such as distilled water, citric acid, ethanol, phenolphthalein, diethyl ether, potassium dichromate $K_2Cr_2O_7$, acetone, benzoic acid, methanol, sulfuric acid, potassium hydroxide and anhydrous sodium sulfate (drying agent) were of analytical reagent grade. The experiments of this study were performed in the chemical engineering laboratory at the Department of Chemical Engineering and the post-harvest and Food Technology Laboratory at the Department of Rural Engineering, Eduardo Mondlane University, Maputo, Mozambique.

Seed Oil Extraction

The matured jatropha and rubber seed used in the present study for biodiesel production were purchased from Mozambique and Malawi respectively. The seeds were manually deshelled and the kernels were dried for the desired moisture content. Then, the kernels were ground in order to weaken and rupture the cell, which improves oil extraction. Oil from the seeds was obtained by a mechanical press operated hydraulically. The oil yield obtained was 30.48±0.073 wt% db. for jatropha while 20.49±0.068 wt.% db. for rubber kernel. The extracted oil was filtered using a vacuum filtration unit and then degummed with citric acid to obtain purified oil.

Biodiesel Production from the Extracted Seed Oil

The jatropha and rubber seed oil used in the study had an initial FFA level of 6.98% and 13.96%; the acid value and FFA of the oil were determined based on the technique established by the standard EN 14104. The FFA of the oils was beyond the limit so a reduction of FFA to <1% prior to the transesterification reaction is required for a better biodiesel yield and to avoid catalyst consumption in soap formation (Bouaid *et al*., 2012; Koh and Mohd Ghazi, 2011; Onoji *et al*., 2016). The physical and chemical characteristics of the oils are summarized in Table 1.

Acid Catalyst-Based Esterification of the Seed Oil

Acid esterification is used to reduce the FFA of oils. In this step, a conical flask was filled with oil after it was measured. The oil was preheated to 105°C for 10 min on a magnetic stirrer hot plate to remove moisture and volatile impurities. Then oil was cooled down to a temperature of 60°C. Then, the calculated amount of H_2SO_4 catalyst (i.e., 10% (weight relative to FFA) was mixed with methanol (the methanol-to-FFA molar ratio of 40:1) and stirred by heating at 50°C for 5 min and then added to the heated oil maintained at 60°C and the reaction continued for 1 h at a stirring rate of 600 rpm for the acid esterification to takes place (Bouaid *et al*., 2012). At the end of the reaction, the esterified oil was transferred into a separating funnel and allowed to settle for 2 h. The methanol-water fraction at the top layer was removed and the esterified oil separated at the bottom. Figure 1 shows the formation of two layers after the acid esterification. The % FFA of the pretreated oil was determined again in order to ensure it was less than 1% before the base-catalyzed transesterification of the oil.

Transesterification

Transesterification is the last step where biodiesel is produced. 200 g of the pretreated jatropha oil was poured into a 500 mL conical flask and heated at 60°C while pretreated rubber oil was heated at 55°C. For transesterification of pretreated oil, a measured quantity of KOH (i.e., catalyst concentration of 1.0%) was dissolved in methanol (i.e., the mole ratio of oil to methanol of 1:6). The prepared potassium methoxide solution was then poured into the heated oil (at 60°C of esterified Jatropha and 55°C of esterified Rubber oil) and stirred vigorously using a magnetic stirrer (maintained at 600 rpm for 60 min for jatropha and at 400 rpm for 67.5 min for rubber) (Ahmad *et al*., 2014; Syam *et al*., 2009). After completion of the reaction, the reaction was cooled and the mixture was transferred into a separating funnel for 24 h to separate the lower glycerol and other impurities layer from the upper biodiesel layer as shown in Fig. 2. The biodiesel was washed several times with warm distilled water (30% vv) at 50°C until the wash water drained out is clear to remove the residual catalyst, entrained glycerol and other impurities that remain in the funnel. The upper layer of clean biodiesel is collected as shown in Fig. 3. After washing, biodiesel was dried in the drying oven to evaporate the water and the excess methanol at a low temperature of 80°C. Finally, biodiesel was subsequently dried over anhydrous sodium sulfate Na_2SO_4 to remove the last traces of water, and dried biodiesel (Fig. 4) was centrifuged to remove sodium sulfate. The yield was determined on a weight basis and expressed as gram biodiesel per gram oil sample. In this research, different proportions of dual biodiesel blends, single biodiesel blends, and pure diesel (100%) were used to compare their properties. These are pure diesel (B0), BA20 (80% Diesel and 20% Jatropha biodiesel), BB20 (80% diesel and 20% rubber biodiesel), BC10 (90% diesel, 5% Jatropha biodiesel and 5% rubber biodiesel), BC20 (80% diesel, 10% Jatropha biodiesel and 10% rubber biodiesel), BC30 (70% diesel, 15% Jatropha biodiesel and 15% rubber biodiesel), BC40 (60% diesel, 20% Jatropha biodiesel and 20% rubber biodiesel). The blending of biodiesel with diesel fuel was prepared on a volumetric basis.

Table 1: Physico-chemical properties of Jatropha and rubber seed oil

Parameters	Jatropha oil	Rubber oil	Ref. RSO[b]	Ref. JSO[c]
Density at 25°C (g/mL)	0.9140	0.9188	0.910-0.922	0.917±1
Specific gravity at 15	0.9189	0.9236	0.91-0.9200	0.912-0.9186
°API gravity at 15 °C	22.4800	21.7100	NS22.81±0.16500	
Kinematic viscosity at 40 °C (mm^2/s)	42.4200	42.6600	11.22-66.2	35.98±.3-50.73
Acid value (mg_{KOH}/g_{oil})	13.9600	27.9100	1.68-34	1-38.20
% FFA	6.9800	13.9600	0.84-17	0.5-19.10
Oxidative stability (h)	0.2267	0.2433	NS[a]NS[a]	

[a]Not applicable; [b]Aravind *et al*. (2015); Reshad *et al*. (2015); Widayat *et al*. (2013); Asuquo *et al*. (2012); [c](Agarwal and Agarwal, 2007; Folaranmi, 2013)

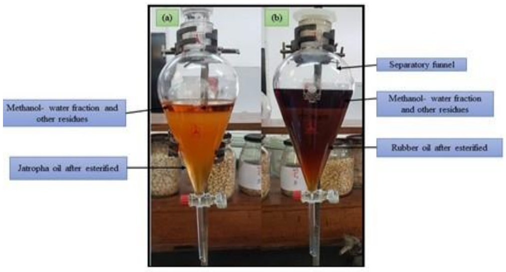

Fig. 1: Formation of two layers after the acid esterification; (a) Jatropha and (b) Rubber

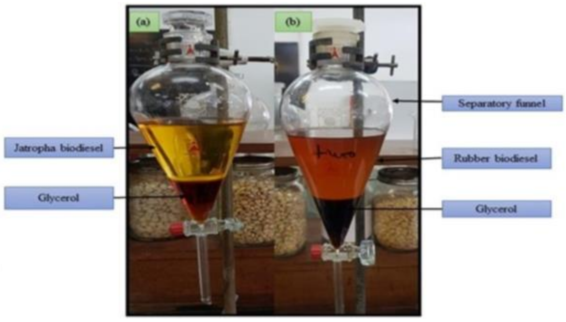

Fig. 2: Gravity settling of biodiesel and glycerol phases; (a) Jatropha and (b) Rubber

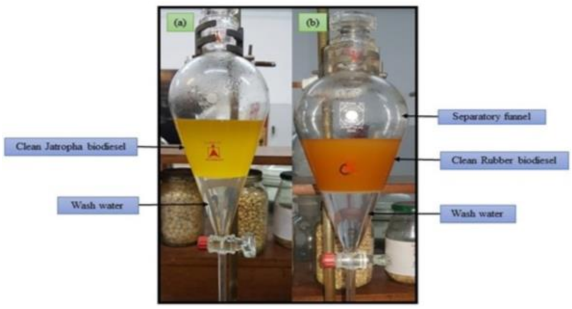

Fig. 3: Separation of clean biodiesel from water; (a) Jatropha and (b) Rubber

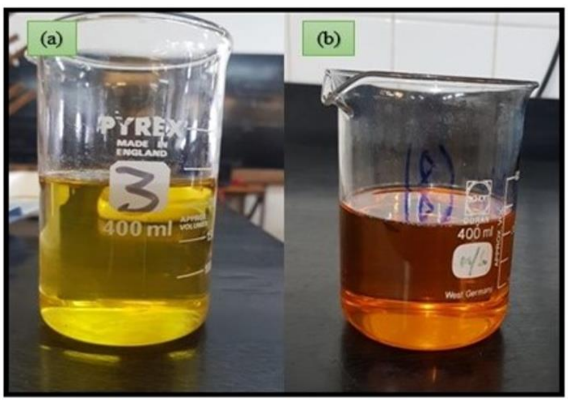

Fig. 4: Methyl ester (Biodiesel); (a) Jatropha and (b) Rubber

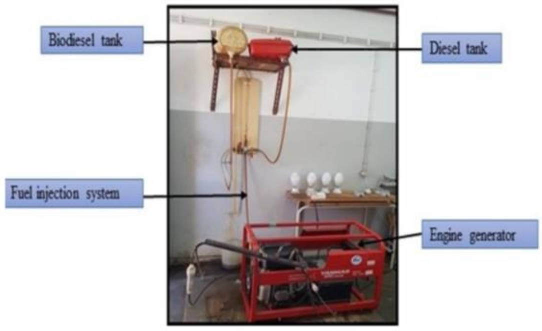

Fig. 5: Pictorial view of the engine generator with the fuel supply system

Table 2: Engine and generator specifications

	Items	Specifications
Engine	Type	4 Stroke, vertical cylinder, air-cooled diesel engine
	Diameter × stroke (mm)	78×67
	Displacement (L)	0.32
	Maximum power at 3000 rpm(kW)	4.5
	Starting system	Electrical and or manual
	Fuel oil	Diesel oil
	Fuel oil tank capacity (L)	13.5
	Dimensions (L × W × H)	378×422×453
Generator	Type	Self-excited 2 poles
	Frequency (Hz)	50 at 3000 rpm
	Voltage (V)	220
	Maximum power (kW)	4

Experimental Setup for Engine Generator Testing

The experiment was carried out on a single-cylinder, four-stroke, direct injection, and air-cooled, YANMAR brand (Model: YDL 4200) diesel engine that was equipped with a generator as shown in Fig. 5. The Generator was coupled with 250 W lamps and a 1000 W electric stove to provide a load to the engine. The performance and emission analysis were conducted with diesel, single biodiesel blends with diesel, and dual biodiesel blends with diesel at varying loads of 0, 25, 50, 75, and 100% while engine speed was kept constant at a rated speed of 3000 rpm. Table 2 displays all of the test engine and generator technical details.

diesel fuel, the engine was started and it warmed up for 15 min to ensure parameters were being analyzed at a steady state and then it switched over to the fuel samples. Once the engine reaches a steady state, the emission and fuel consumption readings are taken. The same procedure was performed from zero to full load condition. During the emission analysis, a Horiba automotive emission analyzer (model: MEXA-84L) illustrated in Fig. 6a was used to measure the emissions of CO, $CO_{2,}$ and hydrocarbons in the exhaust of the engine. The air-fuel ratio (A/F), % $O_{2,}$ and NOX were determined with a Horiba NOX analyzer (model: MEXA-720 NOx).

Fig. 6: Exhaust gas analyzers: MEXA-584L; (a) and MEXA-720NO × (b)

Results and Discussion

Biodiesel Conversion

The initial acid value of the oils (13.96 and 27.91 mg KOH/g oil for jatropha and rubber) has been reduced to 1.12 and 0.56 mg KOH/g oil for jatropha and rubber respectively by the first step of the acid esterification process. The percentage yield of biodiesels from jatropha and rubber oil was 96.05±0.15 and 95.93±0.14, respectively. It was observed a high yield of biodiesel; was due to the low content of FFA in the refined oils thus enhancing their biodiesel conversion.

Determination of Engine-Generator Performance and Emissions

The engine fuel system was adjusted by using two different tanks with 25 mL burette systems to the main fuel supply line as shown in Fig. 5. With conventional diesel fuel, the engine was started and it warmed up for 15 min to ensure parameters were being analyzed at a steady state and then it switched over to the fuel samples. Once the engine reaches a steady state, the emission and fuel consumption readings are taken. The same procedure was performed from zero to full load condition. During the emission analysis, a Horiba automotive emission analyzer (Model: MEXA-84L) illustrated in Fig. 6a was used to measure the emissions of CO, CO_2, and hydrocarbons in the exhaust of the engine. The air-fuel ratio (A/F), % O_2, and NO_X were determined with a Horiba NOX analyzer (Model: MEXA-720 NOx).

Characterization of Produced Biodiesel

The fuel properties of jatropha and rubber biodiesel, the mixture of jatropha and rubber biodiesel were compared with biodiesel standards and diesel in order to evaluate their quality. The results obtained are demonstrated in Table 3. The rubber biodiesel had a little higher kinematic viscosity and density as compared to that of the jatropha biodiesel. In this study, the blend of jatropha biodiesel and rubber biodiesel showed a reduction in density (0.8838 g/mL) and viscosity (5.85 mm^2/s) compared to rubber biodiesel. The flashpoint is one of the most important properties of the fuel. As can be seen from Table 3, the flashpoint obtained for Jatropha and Rubber biodiesel was 178°C and 176°C respectively, and were quite high compared to that of the diesel (57°C). However, rubber methyl ester had slightly a lower flashpoint when compared to jatropha methyl ester, but the blend of jatropha and rubber biodiesel brought a little increment in the flashpoint (177°C). Since the flashpoints of the biodiesels are considerably high this makes them extremely safe for handling and storage. The physicochemical analysis result showed that the quality of jatropha, rubber, and blends of the two biodiesel produced met the detailed requirements established by the EN14214 and ASTM D6751 standards

Performance and Emissions Analysis of Test Engine Generator

The performance and emissions of the engine generator were analyzed with BC10, BC20, BC30, and BC40 and compared results with BA20, BB20, and diesel fuel.

Specific Fuel Consumption (SFC)

Specific fuel consumption assesses how effectively an engine uses the fuel supplied to generate power (Adaileh and AlQdah, 2012). Figure 7 shows the variation of SFC with load for all fuels tested. It has been observed that the specific fuel consumption value of all fuels tested decreased with an increase in engine generator load. The lowest SFC was observed with the BC20 blend followed by BC40 among the dual biodiesel blends. The SFC for BA20 and BC20 was close to that of diesel. The SFC of BC20 was found 1.43% lower than BB20 and nearly similar to BA20. This can be attributed to the addition of jatropha biodiesel in rubber biodiesel improved the density and viscosity of the dual biodiesel blend (BC20) compared with BB20.

The air-fuel ratio of the mixture influences the combustion phenomenon, the completeness of combustion, and the emission characteristics of diesel engines (Teoh *et al*., 2014). Figure 8 depicts the variation of air/fuel ratio with load for all fuels tested. It is observed from the figure that the air-fuel ratio at low load conditions was higher than at high load conditions, regardless of the fuel used. This condition is due to the requirement for more fuel for the given airflow rate while the load was increased. It was found that the A/F for BB20 was slightly lower than the same percentages of the jatropha-rubber mixed biodiesel blend and jatropha biodiesel blend. This is due to the higher fuel consumption owing to the high viscosity and density of rubber biodiesel. Among all tested fuels, it is observed that BC40 had the best air/fuel ratio.

DOI: 10.3844/ajeassp.2024.126.135

Table 3: Fuel properties of biodiesel produced from Jatropha and rubber seed oil and its mixture in comparison with the standards and diesel

					Biodiesel standards	
Properties	Diesel	JME[d]	RME[e]	JRME[f]	EN14214	ASTM D6751
Density at 15	0.83090	0.8816	0.8849	0.8838	0.86-0.9	ns
Density at 25	0.82250	0.8773	0.8795	0.8774	ns[g]	ns
Specific gravity at 15	0.83170	0.8823	0.8857	0.8846	ns[g]	ns
API gravity at 15	38.63000	28.8700	28.2600	28.4500	ns[g]	ns[g]
Kinematic viscosity at 40	3.16000	5.7400	5.9800	5.8500	0.5 max	0.8 max
acid value (mg KOH/g oil	ns	0.2800	0.4200	ns	3.5-5	1.9-6
Flashpoint	57	178.0000	176.0000	177.0000	120 min	93 min
Cloud point	-8	1.0000	1.0000	1.0000	ns[g]	ns
Pour point	-24	3.0000	3.0000	3.0000	ns[g]	ns[g]
Oxidation stability	38.3600	5.8300	5.6800	5.4500	≥ 6	≥ 3

[d]Jatropha methyl ester; [e]Rubber methyl ester; [f] Blend of jatropha and rubber methyl ester; [g]Not specified

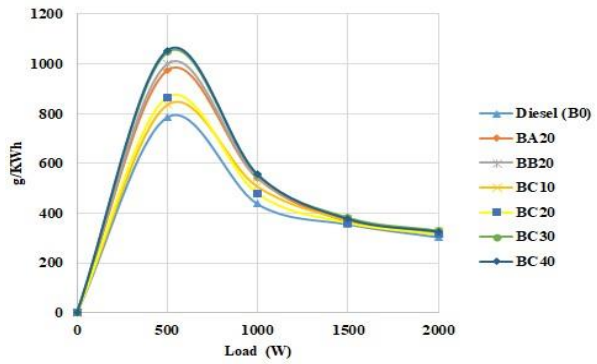

Fig. 7: Variation of specific fuel consumption with load for different fuels

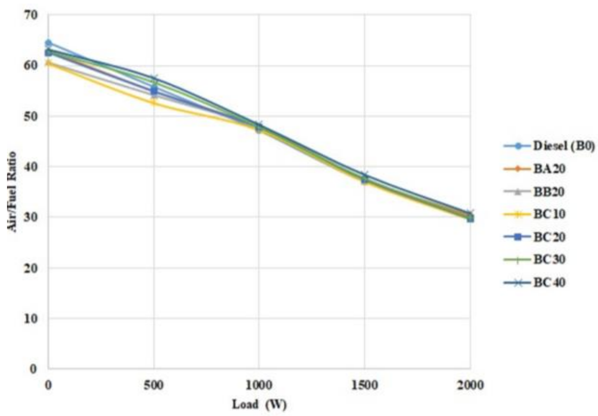

Fig. 8: Variation of air/fuel ratio with load for different fuels

Oxygen O_2 Emission

The percentage of O_2 content left in the exhaust gas against loads for diesel and different blends is indicated in Fig. 9. The O_2 emission of the engine generator running on biodiesel was slightly higher than diesel fuel due to the O_2 level of the biodiesel (the bound O_2 in the fuel) as reported by other researchers (Silva *et al*., 2019). BC20 gave the lowest % O_2 than the other biodiesel blended fuel. From the O_2 emission for single biodiesel blends, it was observed that BA20 and BB20 produced 3.42% and around 1% higher O_2 compared to the same percentages of jatropha-rubber mixed biodiesel blends (BC20) respectively. In contrast, it was observed that the mixing of jatropha and rubber effect resulted in a significant improvement in O_2 emission reduction.

Carbon Dioxide CO_2 Emission

Figure 10 compares the CO_2 emission of various fuel blends tested in the diesel engine generator at different loads. It was shown that the CO_2 emission values were lower when biodiesel blended fuel was being used. A decrease in CO_2 emissions is observed as the percentage of dual biodiesel increases in the blend over the entire range of engine load, which is due to a lower elemental carbon to hydrogen ratio in the biodiesel. A lower carbon-to-hydrogen ratio results in fewer CO_2 emissions than diesel during complete combustion (Xue *et al*., 2011). These results agree with those that other studies have reported (Emaish *et al*., 2021; Karmakar *et al*., 2018).

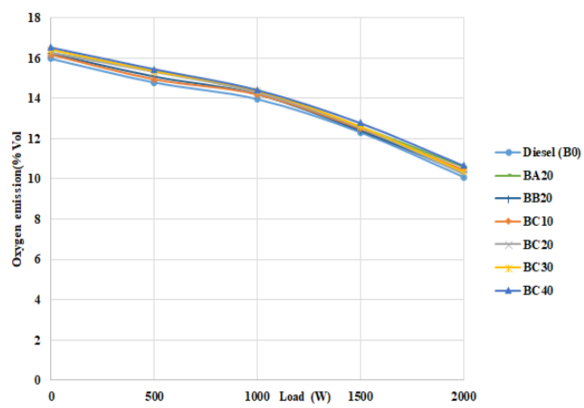

Fig. 9: Variation of O_2 emission with load for different fuels

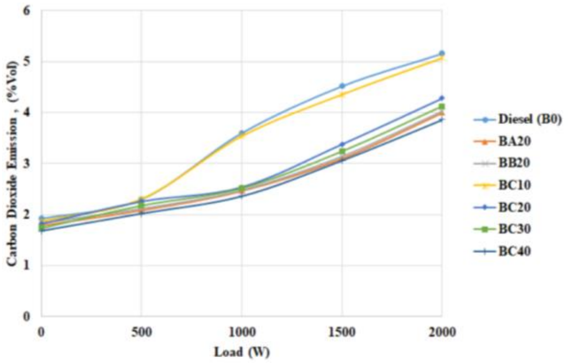

Fig. 10: Variation of CO_2 emission with load for different fuels

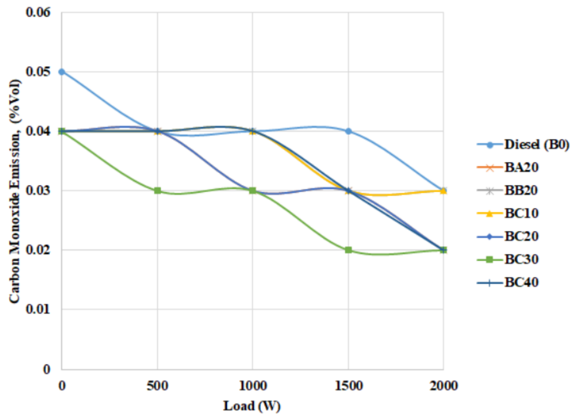

Fig. 11: Variation of CO emission with load for different fuels

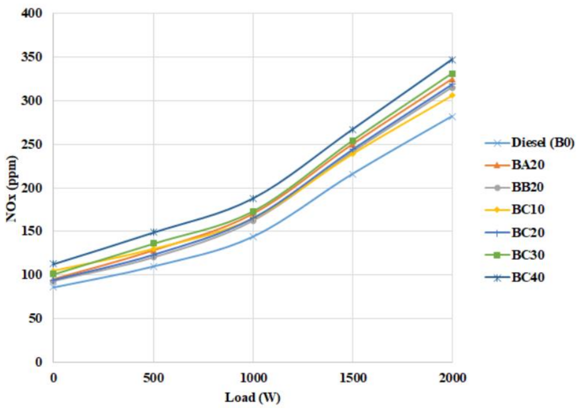

Fig. 12: Variation of NOx Emission with load for different fuels

Carbon Monoxide CO Emission

CO is formed during the incomplete combustion of fuel that contains no O_2 in its molecular structure. Figure 11 presents the variation of CO emission for all tested fuels and plotted against different engine generator loads. CO emission decreased with increasing engine load for all tested fuels. This could be attributed to the higher air ratio, the better air-fuel mixing process, and the increases in the temperature with the increases in engine load. The CO emission for BB20 was 50% higher than that of BA20. This is due to its high viscosity resulted in poor fuel atomization and vaporization during the combustion process, which increased exhaust CO. It was observed that BC20 produced 33.33% lower CO gas emission compared to the same percentage of (BB20) and the CO emission value of BC20 and BA20 was the same. This is due to the fact that the mixing of jatropha and rubber biodiesel enabled the complete burning of fuels due to the higher O_2 content in the biodiesel, which resulted in a significant improvement in CO emission reduction. It was observed that the engine generator emits more CO using diesel as compared to that of biodiesel blends except for BC10 and 20% rubber biodiesel blend (BB20), for which the values of CO emissions were the same as diesel at maximum load.

Emission of Nitrogen Oxides (NOx)

The variation of NOx emissions of different fuel samples with load is presented in Fig. 12. The NOx emissions for all fuels were increased when the engine generator load increased, due to enhanced combustion and higher temperature. As per the results, all biodiesel blends produced more NOx due to the presence of O_2 in the biodiesel and higher cylinder temperature compared to diesel fuel and BC40 exhibited higher values than other blends. Among the same percentage of biodiesel blends, the BA20 blend showed the highest NOx emission, which was 3.17 and 1.88% higher than BB20 and BC20 respectively, this can be due to its high CN. Thus NOx emission decreased for dual biodiesel blend (BC20) than that of BA20 fuel. The reason for the decrease in NOx can be explained by the mixing of jatropha and rubber biodiesel reduced adiabatic flame temperature. Moreover, it was observed that the NOx emissions for dual biodiesel blends increased with an increase in dual biodiesel percentage. This was due to reduced ignition delay by the increasing biodiesel percentage in the fuel blends. Generally, the formation of NOx was favored by higher combustion temperatures availability of O2en, and the longer residence time. The results of the present study are in full agreement with the findings of the other researchers (Labeckas and Slavinskas, 2006; Murillo *et al*., 2007; Godiganur *et al*., 2009).

Hydrocarbons Emissions

Figure 13 shows the effect of engine load on hydrocarbon emissions for different fuel blends and compared to diesel oil. At maximum load, all blends had lower values of hydrocarbon emission than diesel due to the oxygenated fuel of biodiesel, which leads to more complete combustion. This result is supported by the literature (Ozsezen and Canakci, 2010). It was seen that the HC emission reduced up to a load of 1000 W and subsequently marginally increased with an increase in load for all the fuel samples except for BC40, where the HC emission decreased up to a load of 1500 W and then increased after 1500 W load to full load.

DOI: 10.3844/ajeassp.2024.126.135

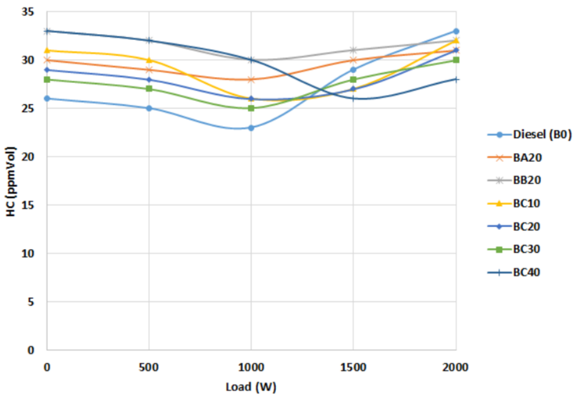

Fig. 13: Variation of hydrocarbon emission with load for different fuels

This is due to more injected fuel and lower air-fuel ratios. At maximum load, the HC emission of dual biodiesel blend (BC20) showed a 3.13% decrease in comparison with BB20 and it was similar to BA20. This is due to the fact that the mixing of jatropha and rubber biodiesel enabled better fuel atomization and vaporization in the combustion chamber, which resulted in a significant improvement in HC emission reduction. For dual biodiesel blends, increased dual biodiesel percentages in the blended fuel samples resulted in decreased HC emissions. This shows that unburned hydrocarbon emissions are likely to decrease as the fuel's O_2 content rises, which leads to cracking and faster burning.

Conclusion

This study investigated the two-step trans-esterification process for producing biodiesels from non-edible jatropha and rubber seed oils. The use of non-edible vegetable oils as biodiesel raw materials is significant because it allows biodiesel to be produced from sources that do not compete with food crops, potentially lowering the impact of biodiesel production on food prices and availability while also utilizing waste products. Due to the high-value FFA of jatropha and rubber seed oil two-step transesterification process was selected for maximum yield of biodiesel. The performance and emissions of the engine generator were analyzed with various mixes of jatropha and rubber biodiesel with diesel in different proportions (BC10 to BC40) and compared with B0 (pure diesel), BA20 (20% jatropha biodiesel, 80% diesel), and BB20 (20% rubber biodiesel, 80% diesel). The engine generator functioned smoothly and without issues across all biodiesel blends, indicating the engine’s good compatibility with biodiesel. SFC is a measure of the engine’s fuel efficiency; lower values indicate higher efficiency. The study discovered that at maximum load (2000 W), the SFC for BA20 and BC20 blends was comparable to standard diesel fuel, implying that these blends have equivalent fuel efficiency to diesel. BB20 had a slightly higher SFC (1.78%) than BA20, indicating marginally lower fuel efficiency. BC20 showed a 1.43% lower SFC than BB20, indicating a little but notable improvement in efficiency. The finding that certain biodiesel blends can achieve similar fuel efficiency (in terms of SFC) compared to diesel fuel is crucial for the adoption of biodiesel in practical applications. It proves that switching to biodiesel does not necessarily mean sacrificing engine performance. The highest A/F value was found for BC40 among all tested fuels at maximum load. A higher A/F ratio indicates that the fuel is burned more fully, which can enhance efficiency but may affect emissions. It was observed that emissions of CO_2 and HC were reduced for all the biodiesel blended fuels as compared to diesel fuel, suggesting that biodiesel combustion results in more complete burning and cleaner engine operation. This is beneficial for environmental sustainability. In general, the CO_2 and HC emissions decreased with the increasing dual biodiesel blend ratio. However, the study also found increased Oxygen (O_2) and Nitrogen oxide (NOx) emissions for all biodiesel blends compared to diesel due to their higher O_2 contents and higher cylinder temperature and pressure. The use of biodiesel has been proven to increase NOx emissions, necessitating further technological or chemical adjustments to mitigate this issue. BC20 exhibited the lowest percentage of O_2 emissions among the biodiesel blends tested, which could indicate a more complete combustion process. Overall, the study indicates that the BC20 blend followed by BC40, showed the best performance and emission characteristics, highlighting these mixed biodiesels as promising alternative fuels. Additionally, these biodiesel blends can be utilized in diesel engine generators without any modification, offering a sustainable and more environmentally friendly option for energy generation.

Acknowledgment

The authors acknowledge the financial support from the World Bank funds under the Inter-University Council for East Africa (IUCEA) project, in which the Center of Studies in Oil and Gas Engineering and Technology (CS-OGET) of the Eduardo Mondlane University is a beneficiary.

Funding Information

The authors have not received any financial support or funding to report.

Author’s Contributions

Fana Gebremedhin Gebremichael: Designed the study, participated in all experiments, coordinated the data analysis and contributed to the writing of the manuscript.

Joao Fernando Chidamoio: Made considerable contributions to conception and design and/or acquisition of data and analysis and interpretation of data. Contributed to drafted the article and reviewed it critically for significant intellectual content and gave the final approval of the version to be submitted and any revised version.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

References

Abdulkareem, A. S., Uthman, H., Afolabi, A. S., & Awenebe, O. L. (2011). Extraction and Optimization of Oil from Moringa Oleifera Seed as an Alternative Feedstock for the Production of Biodiesel. In M. Nayeripour & M. Kheshti (Eds.), *Sustainable Growth and Applications in Renewable Energy Sources*. IntechOpen. https://doi.org/10.5772/25855

Adaileh, W. M., & AlQdah, K. S. (2012). Performance of Diesel Engine Fuelled by a Biodiesel Extracted from a Waste Cocking Oil. *Energy Procedia*, *18*, 1317-1334. https://doi.org/10.1016/j.egypro.2012.05.149

Agarwal, D., & Agarwal, A. K. (2007). Performance and emissions characteristics of Jatropha oil (preheated and blends) in a direct injection compression ignition engine. *Applied Thermal Engineering*, *27*(13), 2314-2323. https://doi.org/10.1016/j.applthermaleng.2007.01.009

Ahmad, J., Yusup, S., Bokhari, A., & Kamil, R. N. M. (2014). Study of fuel properties of rubber seed oil based biodiesel. *Energy Conversion and Management*, *78*, 266-275. https://doi.org/10.1016/j.enconman.2013.10.056

Amalia Kartika, I., Yani, M., Ariono, D., Evon, Ph., & Rigal, L. (2013). Biodiesel production from jatropha seeds: Solvent extraction and in situ transesterification in a single step. *Fuel*, *106*, 111-117. https://doi.org/10.1016/j.fuel.2013.01.021

Aravind, A., Joy, M. L., & Nair, K. P. (2015). Lubricant properties of biodegradable rubber tree seed (*Hevea brasiliensis Muell. Arg*) oil. *Industrial Crops and Products*, *74*, 14-19. https://doi.org/10.1016/j.indcrop.2015.04.014

Asuquo, J., Anusiem, A., & Etim, E. (2012). Extraction and characterization of rubber seed oil. *International Journal of Modern Chemistry*, *1*(3), 109-115. https://www.semanticscholar.org/paper/Extraction-and-Characterization-of-Rubber-Seed-Oil-Asuquo-Anusiem/a2722790d13b6d928ac8b8c41a823f8b642bb7d5

Balasubramanian, K. A., & Srithar, K. (2014). Multiple biodiesel mixtures in diesel engine-performance and emission analysis. *Energy Education Science and Technology Part A: Energy Science and Research*, *32*(1), 13-24.

Bouaid, A., El Boulifi, N., Martinez, M., & Aracil, J. (2012). Optimization of a two-step process for biodiesel production from Jatropha curcas crude oil. *International Journal of Low-Carbon Technologies*, *7*(4), 331-337. https://doi.org/10.1093/ijlct/ctr047

Emaish, H., Abualnaja, K. M., Kandil, E. E., & Abdelsalam, N. R. (2021). Evaluation of the performance and gas emissions of a tractor diesel engine using blended fuel diesel and biodiesel to determine the best loading stages. *Scientific Reports*, *11*, 9811. https://doi.org/10.1038/s41598-021-89287-0

Folaranmi, J. (2013). Production of Biodiesel (B100) from Jatropha Oil Using Sodium Hydroxide as Catalyst. *Journal of Petroleum Engineering*, *2013*, 956479. https://doi.org/10.1155/2013/956479

Godiganur, S., Suryanarayana Murthy, C. H., & Reddy, R. P. (2009). 6BTA 5.9 G2-1 Cummins engine performance and emission tests using methyl ester mahua (*Madhuca indica*) oil/diesel blends. *Renewable Energy*, *34*(10), 2172-2177. https://doi.org/10.1016/j.renene.2008.12.035

Jaichandar, S., & Annamalai, K. (2016). Jatropha oil methyl ester as diesel engine fuel - an experimental investigation. *International Journal of Automotive and Mechanical Engineering*, *13*(1), 3248-3261. https://doi.org/10.15282/ijame.13.1.2016.11.0271

Karmakar, R., Kundu, K., & Rajor, A. (2018). Fuel properties and emission characteristics of biodiesel produced from unused algae grown in India. *Petroleum Science*, *15*, 385-395. https://doi.org/10.1007/s12182-017-0209-7

Koh, M. Y., & Mohd Ghazi, T. I. (2011). A review of biodiesel production from Jatropha curcas L. oil. *Renewable and Sustainable Energy Reviews*, *15*(5), 2240-2251. https://doi.org/10.1016/j.rser.2011.02.013

Labeckas, G., & Slavinskas, S. (2006). The effect of rapeseed oil methyl ester on direct injection Diesel engine performance and exhaust emissions. *Energy Conversion and Management*, *47*(13-14), 1954-1967. https://doi.org/10.1016/j.enconman.2005.09.003

Liu, P., Qin, M., Wu, J., & Chen, B. S. (2018). Performance characteristics of rubber seed oil biodiesel. *IOP Conference Series: Materials Science and Engineering*, *292*, 012073. https://doi.org/10.1088/1757-899x/292/1/012073

Murillo, S., Míguez, J. L., Porteiro, J., Granada, E., & Morán, J. C. (2007). Performance and exhaust emissions in the use of biodiesel in outboard diesel engines. *Fuel*, *86*(12-13), 1765-1771. https://doi.org/10.1016/j.fuel.2006.11.031

Onoji, S. E., Iyuke, S. E., Igbafe, A. I., & Nkazi, D. B. (2016). Rubber seed oil: A potential renewable source of biodiesel for sustainable development in sub-Saharan Africa. *Energy Conversion and Management*, *110*, 125-134. https://doi.org/10.1016/j.enconman.2015.12.002

Ozsezen, A. N., & Canakci, M. (2010). The emission analysis of an IDI diesel engine fueled with methyl ester of waste frying palm oil and its blends. *Biomass and Bioenergy*, *34*(12), 1870-1878. https://doi.org/10.1016/j.biombioe.2010.07.024

Ramadhas, A., Jayaraj, S., & Muraleedharan, C. (2005). Biodiesel production from high FFA rubber seed oil. *Fuel*, *84*(4), 335-340. https://doi.org/10.1016/j.fuel.2004.09.016

Reshad, A. S., Tiwari, P., & Goud, V. V. (2015). Extraction of oil from rubber seeds for biodiesel application: Optimization of parameters. *Fuel*, *150*, 636–644. https://doi.org/10.1016/j.fuel.2015.02.058

Roschat, W., Kacha, M., Yoosuk, B., Sudyoadsuk, T., & Promarak, V. (2012). Biodiesel production based on heterogeneous process catalyzed by solid waste coral fragment. *Fuel*, *98*, 194-202. https://doi.org/10.1016/j.fuel.2012.04.009

Sabarish, C. S., Sebastian, J., & Muraleedharan, C. (2016). Extraction of Oil from Rubber Seed through Hydraulic Press and Kinetic Study of Acid Esterification of Rubber Seed Oil. *Procedia Technology*, *25*, 1006-1013. https://doi.org/10.1016/j.protcy.2016.08.200

Silva, F. C. da, Aranha, F. N., Angelkorte, G. B., Guardiola, J. F. H., Teixeira, L. P., & Correia, R. C. de B. (2019). Quantification and qualification of exhaust gases in agricultural diesel engine operating with biodiesel mixtures. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *23*(10), 794-799. https://doi.org/10.1590/1807-1929/agriambi.v23n10p794-799

Syam, A. M., Yunus, R., Ghazi, T. I. M., & Yaw, T. C. S. (2009). Methanolysis of Jatropha Oil in the Presence of Potassium Hydroxide Catalyst. *Journal of Applied Sciences*, *9*(17), 3161-3165. https://doi.org/10.3923/jas.2009.3161.3165

Teoh, Y. H., Masjuki, H. H., Kalam, M. A., Amalina, M. A., & How, H. G. (2014). Effects of Jatropha biodiesel on the performance, emissions, and combustion of a converted common-rail diesel engine. *RSC Adv.*, *4*(92), 50739-50751. https://doi.org/10.1039/c4ra08464k

Teoh, Y. H., Yu, K. H., How, H. G., & Nguyen, H.-T. (2019). Experimental Investigation of Performance, Emission and Combustion Characteristics of a Common-Rail Diesel Engine Fuelled with Bioethanol as a Fuel Additive in Coconut Oil Biodiesel Blends. *Energies*, *12*(10), 1954. https://doi.org/10.3390/en12101954

Ulfah, M., Mulyazmi, Burmawi, Praputri, E., Sundari, E., & Firdaus. (2018). Biodiesel production methods of rubber seed oil: A review. *IOP Conference Series: Materials Science and Engineering*, *334*, 012006. https://doi.org/10.1088/1757-899x/334/1/012006

Vashist, D., & Ahmad, M. (2011). A comparative study of castor and jatropha oil source and its methyl ester test on the diesel engine. *International Journal of Engineering Science and Technology*, *3*, 4765–4773.

Widayat, W., Satriadi, H., Yuariski, O., & Murwono, D. (2013). Biodiesel Production from Bulk Frying Oil with Ultrasound Assisted. *Research Journal of Applied Sciences*, *Engineering and Technology*, *6*(10), 1732-1739. https://doi.org/10.19026/rjaset.6.3896

Xue, J., Grift, T. E., & Hansen, A. C. (2011). Effect of biodiesel on engine performances and emissions. *Renewable and Sustainable Energy Reviews*, *15*(2), 1098-1116. https://doi.org/10.1016/j.rser.2010.11.016