Generator Engine Performance and Exhaust Gas Emissions, Using Biodiesel from Jatropha Curcas with Kerosene Blends

Alberto Julião Macamo, Carlos Lucas, Satoshi Kato, Yoshimitsu Kobashi, Jesse Armando Jaime Dombo

Abstract— The needs of various lighting systems and transport increasing every day in the world and in developing countries such as Mozambique, therefore, several motor vehicles increase, while the conventional fuels such as fossil diesel will getting scarcer gradually with time. In this case, there is a need to study alternatives that can cope with conventional fuels. The purpose of this experimental study is to evaluate the effect of the blend kerosene along with biodiesel from Jatropha Curcas in the single cylinder diesel engine generator coupled to lamps and small electric stoves. Experimental analysis was carried out to verify the performance and exhaust emissions of the diesel engine generator, using various blends of kerosene with biodiesel from Jatropha Curcas in proportions of 20% – 100% biodiesel and under the conditions of 0 – 3.75 kW of different loads. The results under various parameters were believed to the vicinity of fossil diesel. Different parameters of performance and emissions, such as thermal efficiency, specific fuel consumption, and energy of the exhaust emissions have been determined and compared with diesel fuel. Proportions of 60% and 80% in volume of biodiesel in blends with kerosene are ideal for use in diesel engines generators and emissions (HC, CO and smoke) decrease with the increase of engine load.

Keywords: diesel engine generator; Jatropha curcas L.; biodiesel; kerosene

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1 INTRODUCTION

The world demand for energy continues to increase, especially with the developing countries, and at the same time the related operation seems limited, given that 75% to 85% of the world's energy is supplied by fossil fuels [1]. As a way of mitigating external dependence on oil in some countries (like Mozambique) and minimize the effects of the greenhouse gases caused by the use of established fossils, has intensified the search for energy sources, among them sustainable Biofuels, which are fuels produced from biomass, whose use in diesel engines has been very widespread [2].

Biofuels may not, in practice, replace fossil fuels, because the area needed for production would imply a reduction in the agricultural area required for the production of food, with the aggravating factor that some plants used for purposes energy, such as soybeans are edible. Then the use is also made in addition to fossil fuels, such as kerosene (petroleum). Nowadays, many studies on the use of the mixture with the kerosene has been brought to cable in some countries such as Japan, [3], [4].

The properties of biodiesel are very close to diesel. But biodiesel has slightly lower energy content than diesel, and can be used pure or mixed with diesel without appreciable changes in the characteristics of the engine. Various efforts are made to use different types of fuel in diesel engines to extend mitigate scarcity of fossil diesel [5].

Biodiesel offers a number of advantages such as: biodegradable, higher combustion efficiency, less sulfur, whereas it has some disadvantages: the energy content of biodiesel is about 10-12% by mass which is less than conventional diesel engine; the higher viscosity, the incompressibility, the high price and increased engine wear [6], [7]. Also, have a chemical structure with about 76 – 77% of carbon, 10-12% oxygen and 11-12% hydrogen by mass. The carbon – hydrogen fraction of biodiesel is affected by fatty acid content, which means that there are differences in the characteristics of combustion injection, performance and emissions in a diesel engine [7], [8]. The several studies have reported that biodiesel usually causes the increase in emissions of nitrogen oxide (NOx), carbon monoxide (CO) and hydrocarbons (HC) compared to fossil diesel fuel, while the significant reduction in the emission of particulate matter (PM) can be achieved [9]–[11].

Jatropha is a plant inedible, that with discovery of its high potential for the production of vegetable oil became the target of research on the part of investors, NGOs and farmers and not only, which directed the use for the production of biodiesel in several countries, including Mozambique [12].

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The aim of this study was to evaluate the performance and exhaust emissions in a diesel engine generator fueled with biodiesel and blends of kerosene (oil of enlightenment), and the effect of physic-chemical properties of fuels on the thermal efficiency of the engine, to establish the possibility of production of biodiesel from Jatropha Curcas in Mozambique. Biodiesel has been processed from the Jatropha Curcas oil produced in Mozambique. Finally, the specific energy consumption and fuel were measured while applying different mixing fractions of fuel into a single cylinder diesel engine generator.

2 Material, experimental devices and procedures

2.1 Material

Biodiesel (B_{100}) was processed in the laboratory of PETROMOC – Petroleum of Mozambique SARL. Jatropha Curcas seeds are grown in Nacala district, Nampula province in the North of Mozambique and the kerosene purchased in the local service station fuel supply. Four mixtures of kerosene-biodiesel (with $K_{80}B_{20}$, $K_{60}B_{40}$, $K_{40}B_{60}$ and $K_{20}B_{80}$) were used in this experimental study. The various properties of biodiesel, kerosene and mixtures are presented in Table 2 and 3.

2.2 Equipments and procedures to measure properties of biodiesel and kerosene

The density was measured by a pycnometer. The measurements were carried out three times for each sample to find the average then the density was corrected to standard density measured at constant temperature of 15 °C.

The viscosity was measured by the Redwood viscometer. The sample was introduced into the viscometer where the temperature was controlled by the surrounding heated water at 40 °C. The time for 50 mL of the sample falling down from a hole made in the center of the viscometer was measured, and it was converted to the viscosity by use of the calibration curve. The measurements were repeated five times to find the average.

The oxidation stability was tested using Rancimat (Model 743, Metrohm). The 3 g sample was placed in a sealed reaction tube, and it was exposed to an air flow of 10 L/h at a constant temperature of 110 °C. In this equipment, highly volatile oxidation products formed are transferred into the measuring vessel with the air flow where they are mixed into the water, while increasing the conductivity. Since the conductivity of the water is continuously recorded, it is possible to determine the oxidation stability as the induction time when the conductivity reaches 200 µS/cm.

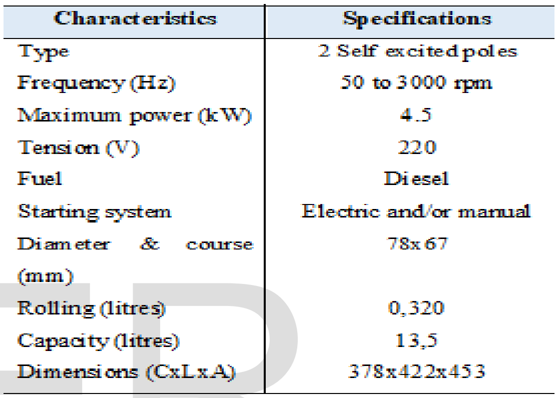
To assess the acid value of the samples, a 0.1 mol/L solution of potassium hydroxide was made by dissolving 5.61 g of KOH in a liter of ethanol.

The calorific value was measured with a calorimeter (Model C200, IKA). Combustion was carried out in the calorimeter. The 0.5 g sample was put into the vessel where pure oxygen was filled at a pressure of 10 bar to optimize the combustion process. The higher calorific value of the sample was calculated according to the correlation with the weight of the sample, the heat capacity of the calorimeter system, the temperature increase, and the correlation values from other burning aids.

2.3 Engine generator testing system

Engine tests were implemented to evaluate the engine performance and the emissions when using the biodiesel. A single cylinder diesel engine (Yanmar, model YDL 4200) equipped with a generator was used. The specifications of the engine are shown in Table 1. The engine is cooled by air. The rated output of the engine was 4.5 kW at the speed of 3000 rpm. The engine load was adjusted by changing the numbers of lamps (0.25 kW) and heaters (1.0 kW), which are coupled to the generator.

TABLE 1: SPECIFIC FEATURES OF THE ENGINE GENERATOR



Characteristics	Specifications
Type	2 Self excited poles
Frequency (Hz)	50 to 3000 rpm
Maximum power (kW)	4.5
Tension (V)	220
Fuel	Diesel
Starting system	Electric and/or manual
Diameter & course (mm)	78x67
Rolling (litres)	0,320
Capacity (litres)	13,5
Dimensions (CxLxA)	378x422x453

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The engine was operated for 15 min with fossil diesel to be warmed up, and then the fuel line was connected to a fuel tank in which the tested fuel was reserved. The eight kinds of the mixed fuels consisting of fossil diesel and biodiesel were tested for the net engine load from 0 to 3.75 kW at a constant rotation speed of 3000 rpm.

The exhaust gas compositions were measured by sampling the gas from the exhaust pipe. The air/fuel ratio and NO_x were measured with a λ sensor (HORIBA, MEXA-730-λ) and a NO_x sensor (HORIBA, MEXA-720-NO_x), respectively. The concentrations of total hydrocarbons (HC) and CO were evaluated with an exhaust gas analyzer (HORIBA, MEXA584L). Smoke was collected on a paper with a probe connected to the exhaust pipe, and the smoke level was determined by comparing blackness on a reference paper.

3 RESULTS AND DISCUSSIONS

3.1 Physic-chemical properties of biodiesel and of their blends with kerosene

Table 2 lists properties biodiesel transesterified and kerosene, compared with the standards of diesel, (EN 14214, DIN 51605, ASTM D 6751 and ASTM 2382). In this part, the biodiesel properties are compared with that of the literatures to show the characteristics of the biodiesel from Jatropha Curcas produced in Mozambique. The kinematic viscosity and density have impacts on fuel injection systems and spray combustion characteristics in engines. Biodiesel density is within the range of EN14214 and kinematic viscosity of ASTM D6751. The low oxidative stability of biodiesel prevents the long-term storage. In the present study, the oxidative stability of biodiesel was bottom, and instability has been accelerated by the transesterification process. The increasing instability was due to the long duration and high ambient temperature during transport and storage, as was noted by [13]. The acid value of biodiesel tested in this study were within the range of DIN 51605 and higher to the literature [14] of 0.05 mg KOH/g. The calorific value of biodiesel is higher in the literature [4], [15] of 32.43 MJ/kg and 38.5 MJ/kg respectively.

TABLE 2: PHYSIC-CHEMICAL PROPERTIES OF FUELS AND STANDARD PATTERNS

	Fuels			Standard		
Properties	Diesel	Kerosene	Biodiesel	EN14214	DIN 51605	ASTM D6751
Density (kg/m^3)	832	769	874	860 - 900	890 - 920	-
Kinematic viscosity at 40 °C (cSt)	4.10	0.98	5.89	3.5 - 5.0	36	1.9 – 6.0
Oxidative stability (h)	24.6	29.6	1.15	6.0	6.0	3.0
Acid value (mg KOH / g)	0.02	0.23	1.14	0.5	1.9 -2.0	0.5
Calorific value (MJ /kg)	44.4	48.9	39.5	-	-	39.51 (ASTM 2382)

Table 3 shows the physic – chemical properties of kerosene and their mixtures with biodiesel, comparable to EN14214 and EN 590 standards. The kinematic viscosity and density increase in relation with the increase in the fractions of biodiesel in the blend. The density and kinematic viscosity was within the range of diesel EN 590 to the biodiesel fraction of 60% and lower to the literature [14] which are 851.8 kg/m3 and 4.21cSt, respectively. The oxidative stability was degraded by increasing the fraction of biodiesel in the blend, and the acid value comparable to EN14214 the mix of 40%, and increased with the fraction of biodiesel above. It is expected that the blends of 60% and 80% are ideal for use in diesel engines generators, according to the physical characteristics of the density and kinematic viscosity.

TABLE 3: PHYSIC-CHEMICAL PROPERTIES OF KEROSENE AND THEIR BLENDS WITH BIODIESEL

	Fuel						Standard	
Properties	Kerosene	$K_{80}B_{20}$	$K_{60}B_{40}$	$K_{40}B_{60}$	$K_{20}B_{80}$	B_{100}	EN14214	EN 590
Density at 15 °C (kg/m^3)	769	789	810	832	853	874	860 - 900	820 - 845
Kinematic viscosity at 40 °C (cSt)	0.98	1.57	2.0	3.17	4.57	5.89	3.5 - 5.0	2 - 4.5
Oxidative stability (h)	29.6	5.26	2.72	2.11	1.29	1.15	6.0	
Acid value (mg KOH/g)	0.23	0.32	0.57	0.8	1.05	1.14	0.5	-
Calorific value (MJ/kg)	48.9	47.0	45.1	43.3	41.4	39.5	-	-

3.2 Engine performance and emissions

The change in the net thermal efficiency with the blend kerosene and biodiesel is shown in Figure 1. The thermal efficiency increased with the increase of the engine load and it slightly increased with the fraction of biodiesel in the blends. The increase of the engine load increases thermal efficiency as the cooling loss becomes relatively low. The test system used in this study is unable to evaluate the in-cylinder combustion process, so that was difficult to explore the specific reason for improving the thermal efficiency of the blend fuels. Presumably, the biodiesel derived from Jatropha and kerosene has a lead time of ignition [16], [17], thus, the ignition time advanced has improved the level of constant volume fraction. This positive behavior was remarkable in the case of the present study in high speed engine generator. The maximum thermal efficiency observed was 30.2% and 30.3% in $K_{80}B_{20}$ and $K_{40}B_{60}$, respectively, comparable with the maximum thermal efficiency to 24.6% in diesel at 3.75 kW engine load. Results of the thermal efficiency in this study are comparable with the results of the literature [18], [19] ranging from 26.09% and 24.36% in 3.078 kW of engine load and 33.69% to 20% biodiesel blends in 3.84 kW of diesel engine load.

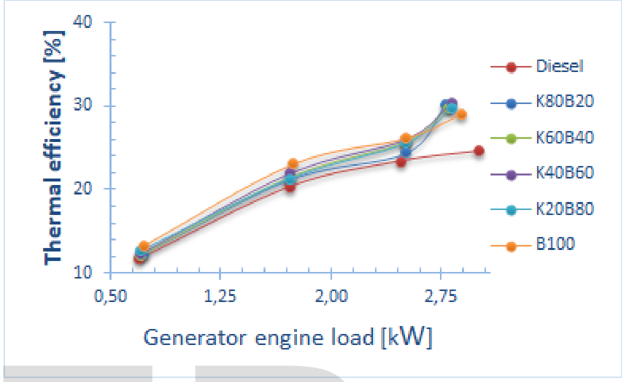

Figure 1: Variation of net thermal efficiency with engine load

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Figure 2 shows the variation of the specific consumptions of fuel (SCF) and energy (SCE). As shown in Table 3, the calorific values decrease with the increase of the biodiesel fraction, so that the large quantity of the blend fuels is required to obtain the same engine load as the diesel fuel achieved. The maximum energy consumption was 40% fuel blends in 30J/kWh to 0.704 kW engine load and minimum fuel consumption was 20% to 60% fuel at 253.9 g/kWh to 274.22 g/kWh higher values compared to the literature [10] ranging from 223.4 g/kWh to 220.1 g/kWh for fractions of 20% to 60% of fuel, respectively. However, there is a similarity to the thermal performance, low specific energy consumption and fuel can be achieved with the blend fuels.

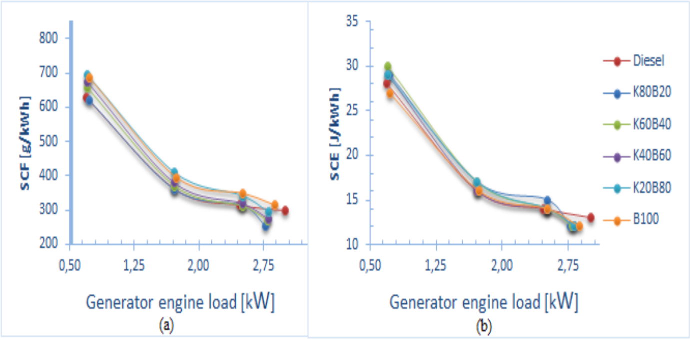

Figure 2: Variation of specific consumptions of fuel and energy with engine load

Figure 3 shows the variation of hydrocarbons (HC) and carbon monoxide (CO) in the exhaust gases, which are the indicators of the combustion incompleteness. Hydrocarbons are related to the boiling points of the fuels as the unevaporated fuel impinging on the combustion chamber wall yield HC. The concentration of HC remain relatively low level despite the engine load generator and the fuel increase, this implies that the boiling point of biodiesel has no significant impact on the walls of the chamber in the cylinder with fuel. Carbon monoxide has a strong dependence on the in-cylinder gas temperature, so that it decreases with the increase of the generator engine load. Additionally, CO is related to the concentration of fuel-air mixture and both are too – rich, and poorer mixtures produce carbon monoxide. However, there does not appear to be significant differences of CO between the fuels, this implies that changing the properties of the fuels shown in Table 3 has less impact on the mixture preparation in the combustion chamber.

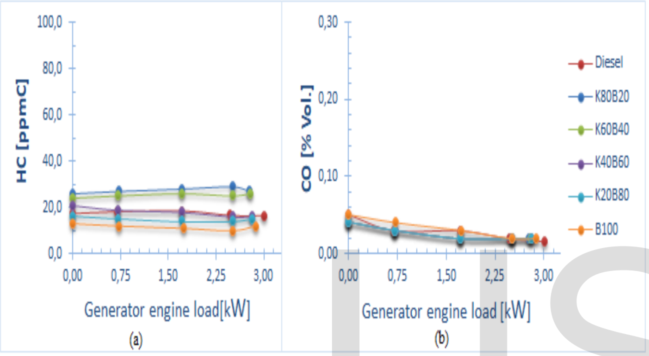

Figure 3: Variation of HC and CO with engine load

Figure 4 shows the concentration of carbon dioxide (CO2). The concentration of CO_2 may be due to volumetric fuel consumption increase and also the absence of oxygen in biodiesel from Jatropha Curcas. The use of biodiesel from vegetable oils in diesel engines, CO_2 emissions increase in mixed with fossil diesel [10], [11]. The absence of oxygen and high viscosity in biodiesel and mixtures thereof may lead to creation of an incomplete combustion and carbon dioxide increase from 3.5% to 4.2% with increased engine load. However, as shown in Figure 4 the results of this study do not show a significant difference between the CO_2 fuels.

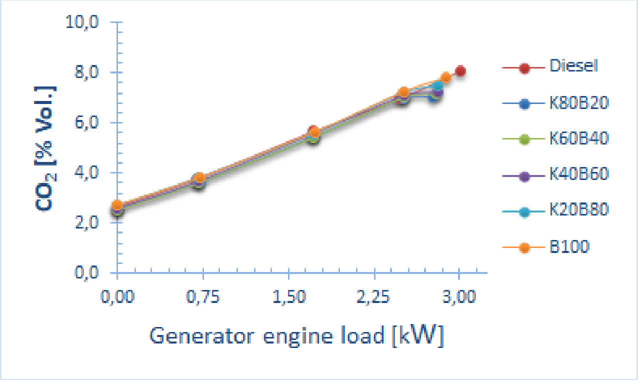

Figure 4: Variation of CO_2 with engine

The variation of NO_x emission with the engine load and the biodiesel fractions in the fuels is shown in Figure 5. The smoke are produced in a rich fuel-air mixture in which the equivalence ratio is greater than 2.0 [20]. The smoke increases as the engine load increases, because the large fuel quantity forms the richer blend. With the increase in the fraction of biodiesel has reduced the smoke in this study. Biodiesel blends in kerosene had less impact on the preparation of mixtures. The reduction of the smoke is related to the physic – chemical properties of the biodiesel. It seems that the oxygen atoms in the biodiesel suppressed the formation of the smoke. This trend of significant reduction of smoke was observed in many studies of using biodiesel in diesel engines to the literature [9], [10], [21], [22].

The NOx increases with increased engine load generator and the fraction biodiesel mixture in kerosene. This trend of increased NOx diesel engine load is comparable to the literatures [9], [10], [19], [23]–[25]. NOx formation depends on the temperature, which due to high activation energy and required for the reactions involved in the process and these reactions are determined by the equivalence relation, oxygen concentration and also the combustion temperature [6]. This formation of NO_x formation in diesel engines is dominated by the Zeldovich mechanism, and thus is an exponential function of combustion temperature. NO_x emission increases with the increase of the engine load due to the higher combustion temperature. Despite the fact that it is known that the use of biodiesel increases NO_x emission [23], [26], the results of this study did not show a significant difference in the NO_x emission between the blend fuels. The temperature in diesel spray flame depends on the relationship of local equivalence and the combustion phase. Even though biodiesel is derived from Jatropha consists of oxygen atoms and can advance the ignition timing, which is the typical characteristic of oils, high rotation speed of 3000 rpm in this study tends to delay the progressive combustion and shorten the time based combustion period.

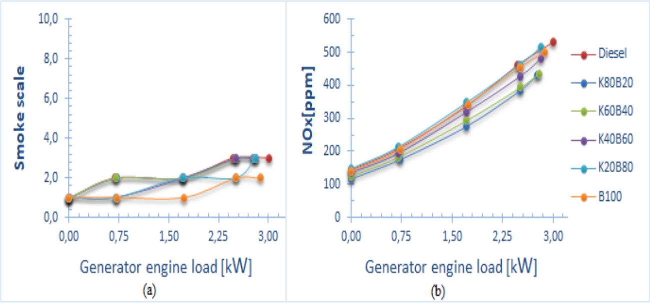

Figure 5: Variation of smoke emission and NOx with engine load

4 CONCLUSION

This study approach to the use of biodiesel from Jatropha Curcas L. cultivated in Nacala district, Nampula province in the North of Mozambique. Biodiesel has been processed in the laboratory of PETROMOC – petroleum of Mozambique SARL and the kerosene purchased local service station. The physic – chemical properties of biodiesel and its mixtures with kerosene were measured and the thermal efficiency and the emissions were assessed in the diesel generator engine. The conclusions are as follows:

1. The density of biodiesel produced from Jatropha Curcas oil meets the standard EN14214. The kinematic viscosity and acid value meets the ASTM D6751 and DIN 51605, respectively.

2. As the physic – chemical properties of biodiesel blends with kerosene, blends of 60% and 80% of biodiesel are ideal for use in engines, because the density and viscosity meets the standards EN 590 and EN 14214, successively.

3. Although the densities are below in relation to the established in the standards, the fractions of 20% and 40% of biodiesel presented acid value that meets the standards EN 14214 and EN590, relatively.

4. Smoke emissions increase with increasing fractions of biodiesel in kerosene and CO_2, NOx and thermal efficiency similar.

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