Production of Biodiesel from Jatropha Curcas L., and Engine Performance with Blends Fuels

Alberto Julião Macamo, Carlos Lucas, Salvador Mate, Satoshi Kato, Yoshimitsu Kobashi

Abstract— Consumption of the fossil fuel increases in proportion to energy demands all over the world as well as in the Republic of Mozambique. The Biofuels produced from Jatropha seeds attracts attention as alternative fuel compared to fossil fuel. Production of Jatropha in Mozambique started in 2007 with the government promoting the agricultural process but with little efforts as for the technology development for processing the seeds produced. In this paper, the issues of producing vegetable oil from Jatropha Curcas seeds, using both mechanical extraction methods are addressed. Studies of the biodiesel production, the engine performance and exhaust emission with Jatropha extracted oil used as the fuel for diesel engine were conducted. Jatropha seeds preheated at temperature range of 80 – 90 ºC produced high percentage of oil extracted (22.5%) with low acid value (21.38 mg KOH/g). The extracted oil was submitted to the process of degumming, neutralization and transesterification with conversation rates of 96%, 80.1% and 90%, respectively. This has led to yield of 66% of biodiesel. A direct injection diesel engine generator (YDL 4200, 4.5 kW, 3000 rpm) was used as the test engine. The biodiesel was used as the test fuel and was mixed with diesel fuel for different mixture ratio of 5 – 100%. The desirable mixture ratio of biodiesel 5 – 20% was obtained from the point view of the better exhaust emissions which was lower compared to diesel fuel. There is no change of the thermal efficiency with the mixture ratio of 5 – 20%, but it decreases within the range of 40 – 100%. The specific fuel consumption and energy consumption in all mixtures decreases with increased engine load. However, the NOx emission increases with increased engine load. There is no change of HC concentration with mixture ratio in the range of 10 – 80%, but it increases at the ratio of 5% and of 100%, which is compared with diesel fuel.

Keywords: Jatropha Curcas L.; biodiesel; transesterification

1 Introduction

Mozambique is one of the world's countries dependent on fossil oil-derived fuels for their energy needs, and has a potential agriculture and forestry desirable and tempting for investors in sustainable development projects in Biofuels. It is estimated that the country has a production capacity of 40 million liters of biodiesel and a medium minimum on average consumes Mozambique about 1600 liters of diesel for a year [1], [2].

Petromoc and the Mozambican economic reports show that the country remains in extreme dependence on imports: in 2006 the trade deficit was about 6.5 percent of GDP, compared with 14.5% in 2000, while the volume fractions of petroleum diesel fuel showed imports of around 700 million dollars, against 2.4 billion dollars of exports in 2006 [3]. Although until then, Mozambique mattered about of 570 million liters of fossil energies, of which diesel fuel occupies 66%., the production of Biofuels could contribute to partial reduction of imports of liquid fuels. Besides, biodiesel is an alternative fuel for diesel engines [4], and biodiesel is considered as a renewable energy source bio-degradable and friend of environment, with features similar to petroleum diesel fuel, consisting of a mixture of methyl esters or fatty acid esters, obtained in the transesterification reaction subsequent to a triglyceride with a alcohol, methanol or ethanol, as shown in Figure 1 [5], [6].

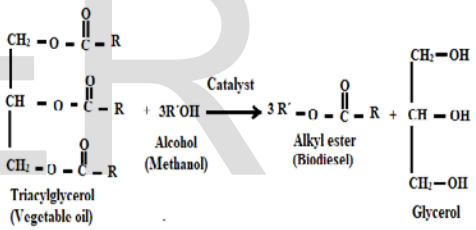

Figure 1: Triacylglycerol reaction with methanol

Where R and R ´ are long chains of hydrocarbons called fatty acid chains.

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 [4], [7].

Biodiesel contains 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].

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Most of the studies have evaluated biodiesel derived from edible vegetable oils and animal fat [9], that potentially increases the price of food and worse the quality of life. To achieve the sustainable production of biodiesel, the use of non-edible source and the improvement of the economics of biodiesel production are required.

Jatropha Curcas L. (Figure 2) is one of the candidates for the production of biodiesel as the seeds are non-edible. Due to the resistance to long periods of drought, the adaptabilities to soils and weather conditions, Jatropha Curcas L. is possible to grow with a very wide geographic distribution in Mozambique. In addition, from the point of the view of economic potential, it is recommended as the seeds are rich in the oil content [10], [11].

Figure 2: Plant and the fruit of Jatropha Curcas L.

This paper treats a comprehensive study on the biodiesel fuel made from Jatropha Curcas L., including the production process, the properties of the oils and the biodiesel fuel, and the effect of the fuel properties on the engine performance and emissions, to investigate the possibility of the biodiesel production in Mozambique and to learn the features of the biodiesel fuel made from Jatropha Curcas L. The oils were extracted from the Jatropha seeds cultivated in Mozambique by an oil press machine. The yield and the physical properties of the oils in the biodiesel production processes were highlighted. Finally, the fuel consumption and the emissions were measured while applying different mixing fractions of fossil diesel fuel and biodiesel fuel into a single-cylinder diesel engine.

2 Material, experimental devices and procedures

2.1 Material

The biodiesel was produced from the seeds of Jatropha curcas L. cultivated in the province of Nampula-Nacala in the northern region of Mozambique. The oil was extracted by an oil press machine, and it was converted into biodiesel by a transesterification method. The flowchart of the biodiesel production is shown in Figure 3 and the details are described in the following sections.

2.2 Experimental set –up and procedures for biodiesel production

2.2.1 Oil extraction

Figure 4 shows pictures of the pre-heater and the oil extraction system. As the initial step of the extraction process, the seeds were preheated at the temperature of 80 – 90 °C for 20 minutes by the pre-heater which can heat up about 50 kg of seeds at one time. Firewood and charcoal were used as biomass energy fuel at the preheated. The preheated is equipped with a rotary kiln to allow the homogeneous distribution of the heat inside the tank. The roasted seeds were immediately transferred to the oil press machine which has the ability to extract 100 kg/h, and the oil was extracted while keeping the temperature of 160 °C with electrical resistors fed by 340 volts.

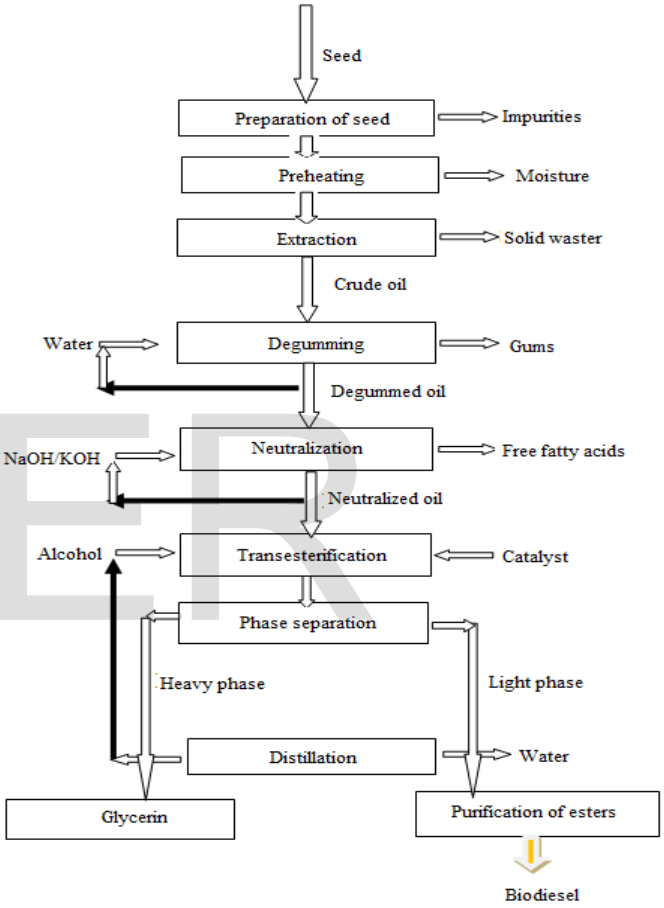

Figure 3: Biodiesel production flowchart

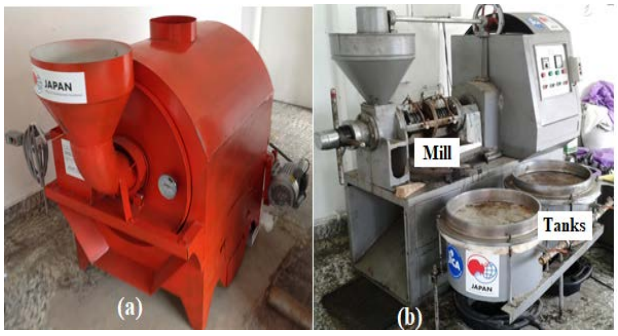

Figure 4: (a) Rotary pre-heater and (b) Oil press machine

The extracted oil was collected by the tanks at which solid

wastes were filtered. After filtering the oil was kept in containers to proceed with subsequent phases of degumming, neutralization and transesterification.

2.2.2 Degumming, neutralization and transesterification

The main steps of the biodiesel production consisted of the degumming, the neutralization and the transesterification processes. Figure 5a) shows the degumming oil unit. The degumming was implemented to remove the suspended impurities. The oil was heated in the reactor up to 80 °C, and 20% (v/v) of the hot water was mixed at 80 °C. Immediately after the mixture was transferred to the separator, 15% (v/v) of the hot water was mixed at 80 °C, and the mixture was left for the phase separation. Once this process was completed, the mixture was transferred to the vacuum dryer to remove the water remaining in the oil.

The next step was the neutralization which used the unit same as the degumming process. Once the acidity of the degummed oil was determined by the titration method, a proper amount of the NaOH-water solution was mixed into the oil which was heated up to 70 °C. This process produced the soap. After removing the soap content, the citric acid-water solution was mixed with oil, and the water layer with the remaining soap content was separated. Once this process was completed, the mixture was transferred to the vacuum dryer to remove the water remaining in the oil.

Finally, the transesterification was implemented to convert the oil into the biodiesel in the unit shown in Figure 5b). NaOH was dissolved in methanol to obtain a homogeneous mixture of sodium methoxide, and it was mixed into the neutralized oil while keeping the oil temperature around 55-67 °C. After this process, the oil was moved to the other oil separator for the phase separation, and then the yielded methyl ester was washed up by the hot water with 80 °C. At the end of this process, the methyl ester was transferred to the vacuum dryer to remove the water remaining.

The change in the weight of the oils was measured at every step of the processes. Figure 6 shows the pictures of the crude oil, the degummed oil, the neutralized oil, and the biodiesel.

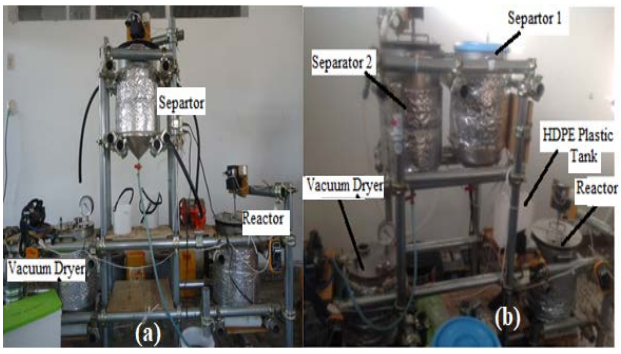

Figure 5: (a) Degumming and neutralization unit, (b) Transesterification unit

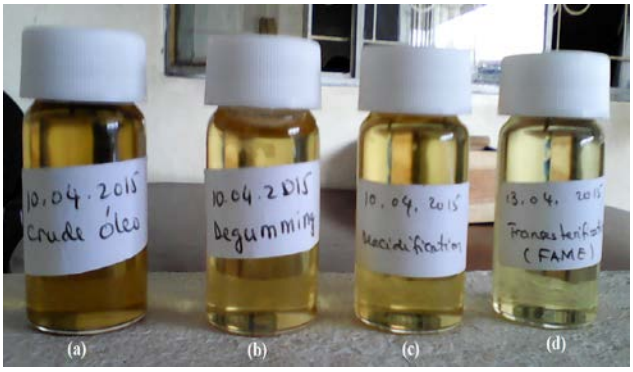

Figure 6: Samples of oils from Jatropha Curcas L. (a) crude oil, (b) degummed oil, (c) neutralized oil and (d) biodiesel

2.3 Equipment and procedures to measure oil and fuel properties

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 sample of oil was introduced in the viscometer container, controlling the transferring into the flask until a volume of 50 mL was reached. The process was repeated five times to find the average. Finally the viscosity was determined by use of the calibration curve.

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 evaluate the acid value of the samples, a 0.1 mol/L solution of potassium hydroxide was made by dissolving KOH in 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 test 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

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 Yields in the biodiesel production process

Table 2 shows the amounts of crude oil extracted and the conversion rates in the biodiesel production processes (degumming, neutralization and transesterification). The crude oil was extracted from 50 kg of the Jatropha seeds while preheating at 80 – 90 °C and the 22.5% in mass was obtained. This yield is similar to the literature [12] of 21.19%, in which the preheating temperature of 80 °C.

The conversion rate of 96.0% in the degumming process revealed that the extracted oil consisted of less impurity, while the impurities removed were the gums and other wastes. In the neutralization process, 19.9% of the soap was removed and 80.1% of the oil was remained. The transesterification process achieved the conversion rate of 90.0% which is close to that obtained in the literature [13], in which the oil temperature was maintained 80 – 90 °C during the process, while 10.0% of the glycerin was removed. As a result, the yield of the biodiesel was 66.0%.

TABLE 2: VOLUME FRACTION OF OIL EXTRACTED AND PROCESSED FROM JATROPHA CURCAS

Pre-heating temperature (80 – 90 °C)	Volume (liter)	Conversion rate (%)
Crude oil	12.64	-
Degumming	12.14	96.0
Neutralization	9.72	80.1
Transesterification (biodiesel)	8.75	90.0

3.2 Properties of oil and biodiesel

Table 3 lists properties of oils and biodiesel transesterified, compared with the standards of biodiesel and vegetable oils (EN 14214, DIN 51605, and ASTM D 6751).

TABLE 3: PHYSIC-CHEMICAL PROPERTIES OF OIL AND STANDARD PATTERNS

	Oil				Standard		
Properties	Crude	Deg.	Neut.	Trans	EN14214	DIN 51605	ASTM D6751
Density (kg/m^3)	894	896	903	875	860 - 900	890 - 920	-
Kinematic viscosity at 40 °C (cSt)	36.39	38.35	38.07	6.1	3.5 - 5.0	36	1.9 – 6.0
Oxidative stability (h)	9.68	4.5	1.59	1.54	6.0	6.0	3.0
Acid value (mg KOH/g)	21.38	20.52	1.69	1.08	0.5	1.9 -2.0	0.5
Calorific value (MJ/kg)	42.6	42.1	41.6	39.5	-	-	43.5 (D4529)

Degummed (Deg.); Neutralized (Neut.) and Transesterified (Trans.)

Here in this part, the crude oil properties are compared with that of the literatures to show the characteristics of the Jatropha oil cultivated in the Nacala district of Nampula Province in Mozambique.

Density and kinematic viscosity have impacts on fuel injection systems and spray combustion characteristics in engines. No remarkable change in the density was made by the biodiesel production processes, and the density of the oils was within the range of DIN51605. The transesterification was only the process which reduced the density, and that of the biodiesel was in the range of EN14214. The kinematic viscosity dramatically was reduced with the transesterification process, as triglyceride which has a high kinematic viscosity was decomposed into methyl ester.

The low oxidation stability of oils and biodiesels hinders the long-term storage. In the present study, the oxidation stability of the crude oil was highest, and the instability was accelerated as undergoing the biodiesel production process. The increase of the instability was due to the long storage duration and the high room temperature during the storage [14], [15].

Oils with high acid value produce gum, soap, and glycerin, and reduce the yields of biodiesel. The acid value of the crude oil tested in the present study is higher than that in the literature [16], [17] which ranges from 8.4 to 17.2 mg KOH/g. The neutralization remarkably reduced the acid value, and the acid value obtained after the transesterification was still higher

than that in the biodiesel standards (EN14214 and ASTM D6751) and in the literature [15] .

Table 4 shows the properties of the diesel fuel, biodiesel, and their mixtures, together with the standards of biodiesel (EN14214) and diesel fuel (EN590).

TABLE 4: PHYSIC-CHEMICAL PROPERTIES OF DIESEL FUEL AND THEIR BLENDS WITH BIODIESEL

Properties	Fuel								Standard	
	Diesel	B_5	B_{10}	B_{20}	B_{40}	B_{60}	B_{80}	B_{100}	EN14214	EN 590
Density (kg/m^3)	832	840	842	843	845	853	864	875	860 - 900	820 - 845
Kinematic viscosity at 40 °C (cSt)	4.10	4.49	4.96	5.01	5.47	5.49	5.60	6.10	3.5 - 5.0	2 - 4.5
Oxidative stability (h)	24.6	8.09	7.61	4.36	3.16	2.12	1.64	1.54	6.0	
Acid value (mg KOH/g)	0.02	0.03	0.06	0.09	0.67	0.83	0.93	1.08	0.5	-
Calorific value (MJ/kg)	44.4	44.3	44.1	43.8	42.3	41.4	40.1	39.5	-	-

The density and the kinematic viscosity linearly increase with the increase of the biodiesel fraction. The density was within the range of diesel fuel (EN590) for the biodiesel fraction less than 40% while the kinematic viscosity was within the range of biodiesel (EN14214) for the biodiesel fraction less than 20%. The oxidation stability was degraded with the small fraction of the biodiesel, and the acid value increases by mixing the biodiesel more than 40%. It is expected that the blends of 5 – 20% biodiesel are ideal for use in diesel engines.

3.3 Engine performance and emissions

The change in the net thermal efficiency with the blend fuels is shown in Figure 7. The thermal efficiency increased with the increase of the engine load and it slightly increased with the proportion 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 the present study is unable to evaluate the in-cylinder combustion process so that it is difficult to explore the specific reason for the better thermal efficiencies of the blend fuels. One possible explanation is that Jatropha-derived biodiesel advances the ignition timing [18], [19] and thus the advanced ignition timing improved the degree of constant volume. This positive effect may be remarkable in high-speed diesel engine like the present study.

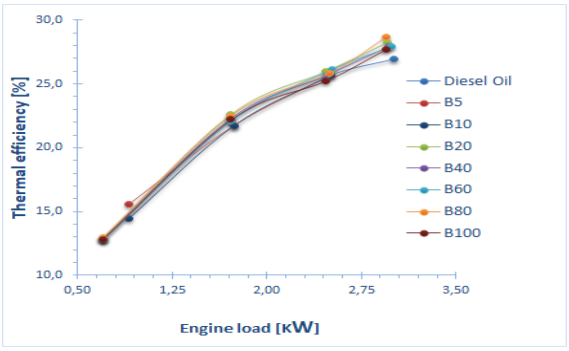

Figure 7: Variation of net thermal efficiency with engine load and biodiesel fractions in fuels

Figure 8 shows the variation of the specific consumptions of energy and fuel. As shown in Table 4, the calorific value decreases 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. Meanwhile, similar to the thermal efficiency, the low specific energy consumption can be achieved with the blend fuels.

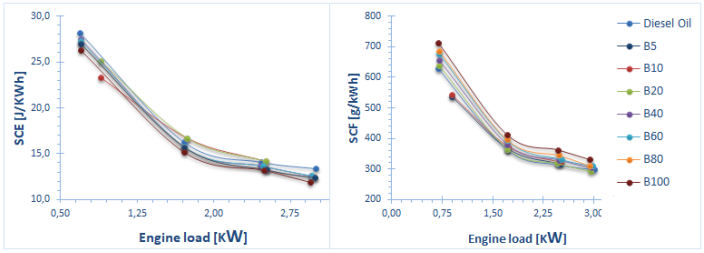

Figure 8: Variation of specific consumptions of energy and fuel with engine load and biodiesel fractions in fuels

Figure 9 shows the variation of carbon monoxide (CO) and hydrocarbons (HC) in the exhaust gas, which are the indicators of the combustion incompleteness. CO has a strong dependence on the in-cylinder gas temperature, so that it decreases with the increase of the engine load. Besides, CO is related to the state of fuel-air mixture concentration and both of the too-rich and the too-lean mixtures yield CO. There seems to be no significant difference in the CO between the fuels, implying that the change of the fuel properties shown in Table 4 has less impact on the mixture preparation in the combustion chamber. HC is related to the boiling points of the fuels as the un-evaporated fuel impinging on the combustion chamber wall yield HC. The HC concentrations maintain the low level despite the loads and the fuels, implying that the boiling point of the biodiesel has no significant impact Wall-wetting by the fuel.

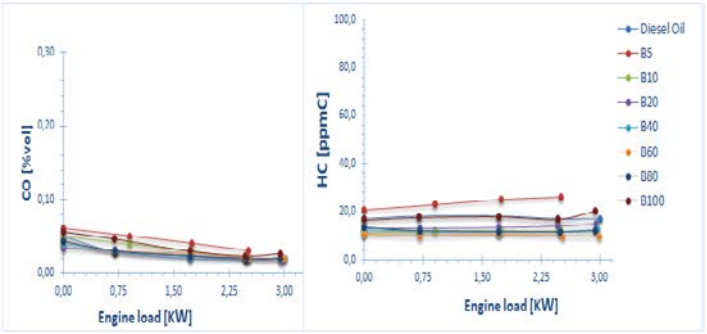

Figure 9: Variation of CO and HC with engine load and biodiesel fractions in fuels

The variation of NO_x emission with the engine load and the biodiesel fractions in the fuels is shown in Figure 10. 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 [9], [20], the present result show no significant difference in the NO_x emission between the blend fuels. The temperature in diesel spray flame depends on the local

equivalence ratio and the combustion phasing. Although the Jatropha-derived biodiesel consists of oxygen atoms and may advance the ignition timing, that is the typical biodiesel characteristics, the high rotation speed of 3000 rpm in the present study tends to delay the combustion phasing and shorten the time-based combustion period. It is likely that the high rotation speed made the difference of NO_x less sensitive to the kinds of the fuels.

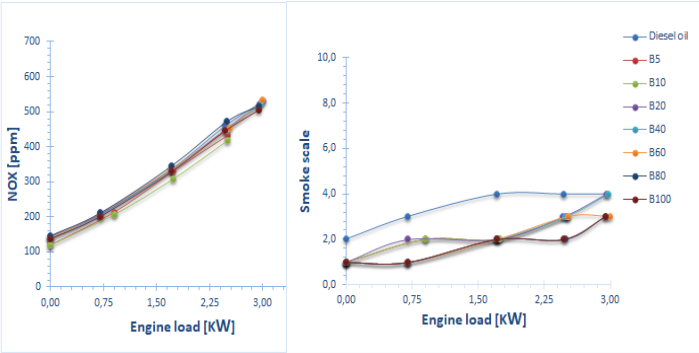

Figure 10: Variation of NOx and smoke emission with engine load and biodiesel fractions in fuels

The variation of smoke with the engine load and the biodiesel fractions in the fuels is shown in Figure 10. Smoke is generated in a rich air-fuel mixture in which equivalence ratio is higher than 2.0 [21]. The smoke increases as the engine load increases, because the large fuel quantity forms the richer mixture. The increase of the biodiesel fraction clearly reduced the smoke. As conjectured in Figure 9, mixing biodiesel into diesel fuel has less impact on the mixture preparation. The reduction of the smoke is related to the chemical property of the biodiesel. It seems that the oxygen atoms in the biodiesel suppressed the formation of the smoke.

4 Conclusion

The study treated a comprehensive study on the production and the use of the biodiesel derived from Jtropha Curcas L. cultivated in the province of Nampula – Nacala in the northen region of Mozambique. The oil extraction was performed by use of a batch – type biodiesel production system. The physical properties of the extracted oils and the biodiesel – blended fuel were measured, and the performance and the emissions of the biodiesel – blended fuels were examined in diesel engine. The conclusions are as follows:

1. The oil content and the conversion rate are within the range of other studies, and the yield of the biodiesel fuel was 66.0%.
2. The density of the produced biodiesel is only the properties that satisfies the biodiesel standard EN14214. The oxidation stability is low and acid value is high due to the long storage duration and the high room temperature during the storage.
3. According to the physical properties of the blend fuels, the blends of 5 – 20% biodiesel are ideal for use in diesel engines.
4. Despite the above physical properties of the produced biodiesel, smoke emission decreases with the increase of the biodiesel fractions mixed into diesel fuel while maintaining similar NOx and thermal efficiency.

Acknowledgment

Thanks to JICA (Japan International Cooperation Agency) by the scholarship granted for training and improvement of laboratory techniques in higher education institutions in Japan. KIT (Kanazawa Institute of technology) for the reception and training in its laboratories of mechanical engineering and chemical engineering and BDF project plant technical-scientific support Mozambique and material and other members of the working group.

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