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Full Length Research Paper

Characterization and evaluation of African bush mango Nut (Dika nut) (*Irvingia gabonensis*) oil biodiesel as alternative fuel for diesel engines

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The African bush mangos (*Irvingia gabonensis*) were collected from the wild, dried and the kernels were split to release the nuts. The oil from the nuts was extracted in a soxhlet extractor that was operated at 60°C using normal hexane as solvent. It gave an oil content of 60% which was mainly triglyceride and was solid at room temperature. It was heated to 40°C to liquefy it and a methanol molar ratio of 6 to 1 was used along with 4 g/L of sodium hydroxide as catalyst during transesterification to biodiesel. Chromatography analysis of the biodiesel gave 59% linolenic fatty acid and tests show that the biodiesel has properties that are within the American society for tests and materials limits for biodiesel. Of particular significance is the cloud point of -14°C which allows it to be used in cold conditions and a flash point of 97°C that makes it a safe fuel during storage. The performance characteristic is similar to that of diesel fuel and the specific fuel consumption is 8% higher than diesel fuel which is consistent with the difference in their heating values. The oil will thus be a potential source of alternative fuel for diesel engine.

Key words: African bush mango (*Irvingia gabonensis*), fuel properties, biodiesel, transesterification.

INTRODUCTION

The diesel engine is predominantly used to power trucks, farm tractors, electrical power generating sets and earth moving equipment because of better fuel economy, longer engine life and higher maximum power output than petrol engines. It has however, created proportional increase in pollution from diesel engine that is having adverse effect on the environment hence the search for alternative fuels for diesel engines. The search has been focused on vegetable oils because of the similarity of their molecular structure to diesel fuel and its renewable source from agriculture and animal fats.

However, the relatively high viscosity of vegetable oils, the consequential poor fuel atomization characteristic and the associated fuel injector blockage and cold starting problems, have made vegetable oils unsuitable for such use in neat form thus creating the need for a method of conversion to vegetable oil esters which is commonly known as biodiesel (Mangech, 1999; Neihaus et al., 1985; Schlick et al., 1988; Peterson et al., 1981; Peterson, 1986; Chowhury, 1942; Pryor, 1982).

Biodiesel has been defined as a mono-alkyl ester of vegetable oils or animal fats (NBB, 1997; Walton, 1938; Knothe et al., 2005; Mittelbach and Remschmidt, 2004). It has very similar physical properties to diesel fuel which allows it to be used as substitute fuel in diesel engines without any modification. Since it is produced from renewable, domestically grown and sometimes under-utilized feed-stocks, it can reduce the demand for petroleum based fuels and possibly lower the overall cost of diesel fuel in the long term. It also contains no or very little sulfur and thus offers promise to reduce particulate and toxic emissions, which is one of the primary objections to diesel fuel.

Africa has a variety of trees and plants that grows in the wild and produce oil yielding seeds. One of such seeds is the African bush mango or Dika nut (*Irvingia gabonensis*), the yielding tree has a conical shape and grows mostly in the tropical rain forest. It can rise to a height 40 m and has a peculiar dense dark green foliage.

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The mangos are usually ripe for harvest in the month of December and they drop on their own to the ground when ripe except when plucked or disturbed by birds or bats. The African bush mango has great economic value and is traded widely. The fruit is usually collected from the wild, dried and the kernel is split to release the nut. The kernel is usually processed into press cake and added to soup in mashed form to thicken it, confer flavor, aroma and drawability. It contains mainly triglyceride and is thus a potential feedstock for biodiesel production. The aim of this work is to extract the oil, transesterify, characterize and test it as possible alternative fuel for use in diesel engines.

MATERIALS AND METHODS

The nuts were harvested from the wild, dried in the sun and the kernel remove by splitting the nut into two halves using a nut splitting tool. The kernels were dried in the sun to reduce moisture content. The oil was leached out using normal hexane solvent in a soxhlet extractor operated at 60°C. The oil extracted turned to solid at room temperature. The normal hexane and sodium hydroxide used were to analytical grade and were purchased from Finlab company in Akure, Nigeria. The experiments were carries out in the chemistry and engine laboratories of the Federal University of Technology, Akure, Nigeria.

Transesterification process

The extracted oil which was solid at room temperature was heated to 120°C for 1 h to remove any water content and then allowed to cool to 60°C. 4 g of sodium hydroxide was added to 1 L of methanol in a mixer and stirred at 500 rpm until it is completely dissolved to form sodium methoxide. The sodium methoxide was next mixed with the neat oil at different molar ratios in the reactor and stirred at 1000 rpm (Doranto et al., 2002) for 3 h at a constant temperature of 60°C. The mixture was then allowed to settle for 8 h to drive the reaction to completion and allow the mixture to separate into two layers of biodiesel and glycerol which is denser, at the bottom. Finally, the mixture was separated using a separating funnel.

Optimum condition for biodiesel yield

The amount of catalyst and molar ratio for optimum biodiesel yield by transesterification were not available in the literature and hence determined by an iterative experimental design. The catalyst amount was varied from 2.5 to 5 g/L in a step of 0.5 g. For each value, molar ratios of 1:1, 4:1, 6:1 were used which gave 18 test samples that were transesterified and the proportion of biodiesel in each sample was determined.

Purification process

The biodiesel was washed with distilled water to remove impurities such as diglycerine, monoglycerine, catalyst, soap and excess methanol. The washing was done by mixing with 20 vol. (%) distilled water and stirred gently for 30 min. It was allowed to settle and gave a two phase mixture from which the biodiesel was separated. The procedure was repeated three times (Doranto et al., 2002) to obtain a clear biodiesel. It was finally heated to 110°C to remove any water vapour still present.

Measurement of properties and fatty acid profile

The main properties of the oil and its biodiesel were measured using mainly the American society for testing and materials (ASTM) protocols for biodiesel fuels. The weight proportions of the composition of the saturated and unsaturated fatty acids in the oil were analyzed by a gas chromatography (GC) analyzer (GC-17A model Shimadzu inc., Japan) using HP 5/Bp 5-capillary column 30 m long, 0.25 mm diameter, 0.25 mm film and a spit/splitless injection port. The injector was maintained at 230°C and the detector temperature at 240°C. Nitrogen was the carrier gas at a flow rate of 45.0 ml/min and pressure of 2.0 psi. The oven temperature was set at 40°C, held for 1 min, programmed to 120°C at 20°C/min for 25 min and then to 230°C at 35°C/ min for 35 min. The total run time was 68.14 min. The fatty acid composition was expressed as the peak area of each acid divided by the total peak area of all the acids.

Engine testing

The test engine is a Lister 8/1 VA low speed single cylinder diesel engine that is connected to an electrical dynamometer.
The specification of the engine is:

Nominal power output: 6 kW @ 850 rev/min and 4.5 kW @ 650 rev /min.
Bore: 114.3 mm
Strok: 139.7 mm
Swept volume: 1.433 L.

The field is excited separately by current from the mains and adjusted by a rheostat. The engine is loaded by switching in the 8 electrical elements that are capable of absorbing the full output of the dynamometer and are selected by means of a selector switch. The generated current is fed to the load resistance in the generator circuit. The engine was operated at full throttle opening and the load was increased gradually by switching on the load elements one at a time until the speed was reduced to the minimum value at which the engine will just run smoothly. The plint fuel guage used to measure fuel consumption consists of a glass tube containing four knife-edged spacers, which are positioned to accurately calibrate the volume of fuel between them. The spring balance reading, the engine speed, revolution counter, quantity of fuel consumed and time were all recorded during each test run and used to compute the engine performance parameters. The test was done for B100 and diesel fuel for comparison.

RESULTS AND DISCUSSION

The oil extracted was solid at room temperature. The optimum catalyst amount and molar ratio required were determined by iterative experimental design and the results are shown in Figure 1. The best molar ratio from the economic point of view is 4 to 1.
The free fatty acid composition obtained from chromatography analysis is as shown in Table 1 and consists essentially of 59% linolenic fatty acid which is a polyunsaturated acid with three bonds. It has a total unsaturation of 95.28% which is similar to those of castor and safflower oils biodiesel and higher than those of jatropha and soya bean oils.

In view of the fact that the oil was solid at room temperature and had to be preheated to liquefy it and the

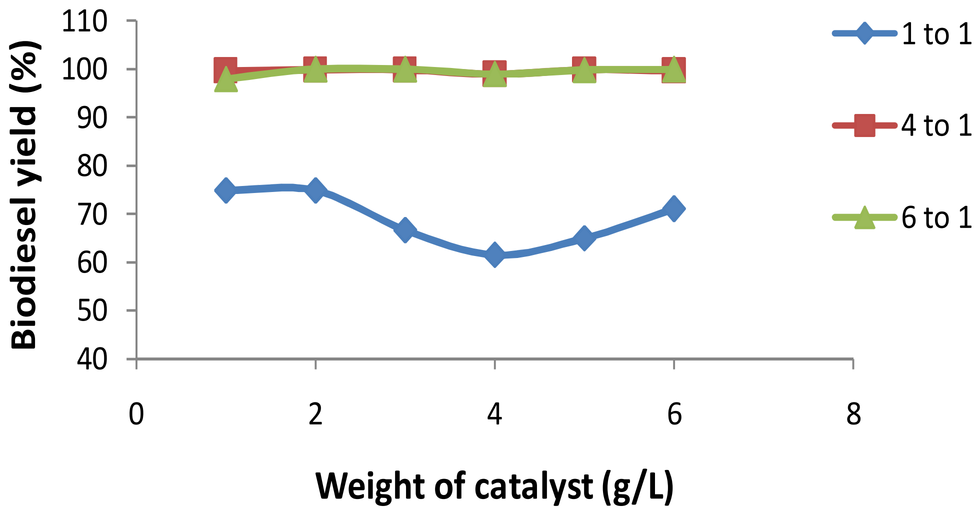

Figure 1. Variation of Dika oil biodiesel yield with catalyst amount and molar ratio.

Table 1. Composition of African bush mango nut and other oil biodiesels.

Fatty acid	Class	African bush mango	Jatropha[a]	Soyabean[b]	Safflower[b]	Castor oil[c]
Dihydroxystearic acid	C18:1	33.9	-	-	-	0.7
Eicosanoic acid	C18:0	0.31	-	-	-	0.3
Linolenic acid	C18:3	59.0	-	8.3	0.1	0.3
Linoleic acid	C18:2	2.2	48.18	54.1	75.5	4.2
Myristic	C14:0	-	-	0.1	-	-
Oleic acid	C18:1	-	28.46	22.5	14.4	3.0
Palmtic acid	C16:0	0.18	18.22	10.3	-	1.0
Stearic acid	C18:0	4.2	5.14	4.7	3.3	1.0
Ricinoleic acid	C18:1	-	-	-	-	89.5
Total saturated	-	4.50	23.36	15.10	10.00	2.00
Total unsaturated	-	95.28	76.64	84.90	90.00	98.00

a: (El-Diwani et al., 2009); b: (Allen et al., 1999); c: (Conceicao et al., 2007).

high unsaturation, a molar ratio of 6 to 1 and catalyst amount of 4 g/L of oil were used and it gave a biodiesel yield of 98%.

The properties of the oil, biodiesel and diesel fuel were measured and the results are shown in Table 2. The crude oil has a relative density of 0.93 at 60°C and reduced to 0.91 after transesterification that is still higher than 0.90 maximum for biodiesel but can be reduced further by blending with diesel fuel.

The cloud point is comparable to diesel fuel while the pour point of -6°C is higher than the -20°C for diesel fuel which limits its cold temperature and aviation applications. With a flash point of 125°C, the biodiesel can be classified as a non hazardous fuel. Safe for storage and handling.

The kinematic viscosity reduced from a high 250 mm^2/s at 40°C for the crude oil to 5.5 mm^2/s for the biodiesel which is within the ASTM limits for biodiesel. It can be seen from the chemical composition of the oil in Table 1 that it contains 59% linolenic fatty acid which has a molecular weight of 278.

Figure 2 shows the variation of torque developed with engine speeds. Although the torque developed is less than that when using diesel fuel, it has flat top like diesel fuel and most suitable for an engine working between 1200 and 1800 rpm. The torque spectrum is wider and is capable of keeping the engine running to a much lower speed. This means that the engine can operate at a much lower speed which is a good characteristic for an engine working in hilly market. The reason for the wide spectrum is the more complete combustion due, largely, to the oxygen content of the fuel.

Figure 3 shows the specific fuel consumption over a range of speeds. The specific fuel consumption for dika

Table 2. Properties of African bush mango nut, its biodiesel and diesel fuel.

Property	ASTM code	ASTM limits	African bush mango nut oil	African bush mango nut oil biodiesel	Diesel fuel
Relative density	D1298	-	0.93	0.91	0.85
Pour point (℃)	D2500	-	28	-6	-20
Cloud point (℃)	D2500	-	23	-14	-12
Flash point (℃)	D93	130 min	300	140	55
Kinematic viscosity (mm^2/s at 60℃)	D445	1.99 to 6	45	3.2	2.8
Heating value (MJ/kg)	D240	-	28	39	42.7
Carbon residue (%)	D4530	0.05	0.10	0.05	0.05
Acid number (mg KOH/g oil)	-	0.80 max	1.2	.01	-

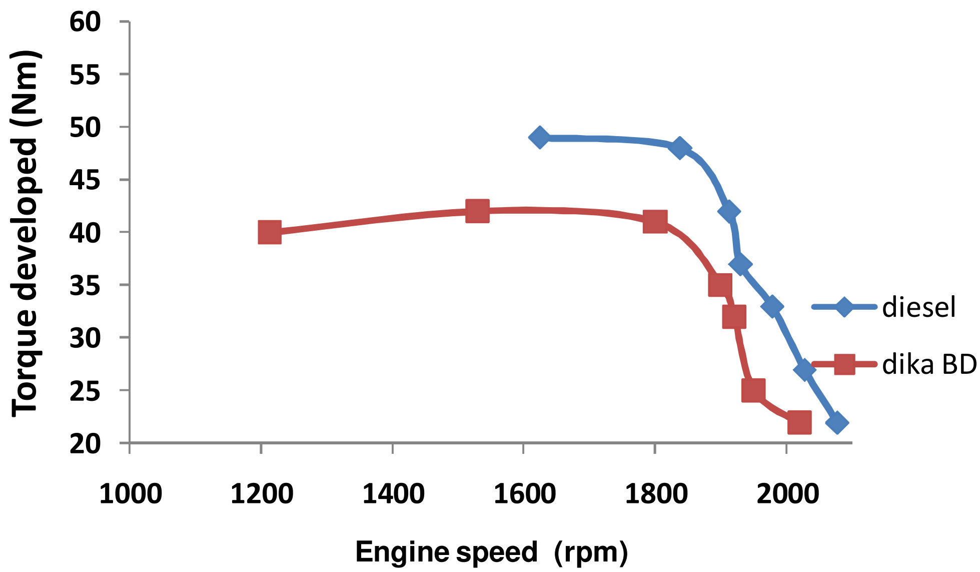

Figure 2. Variation of torque with engine speed of African bush mango nut oil biodiesel.

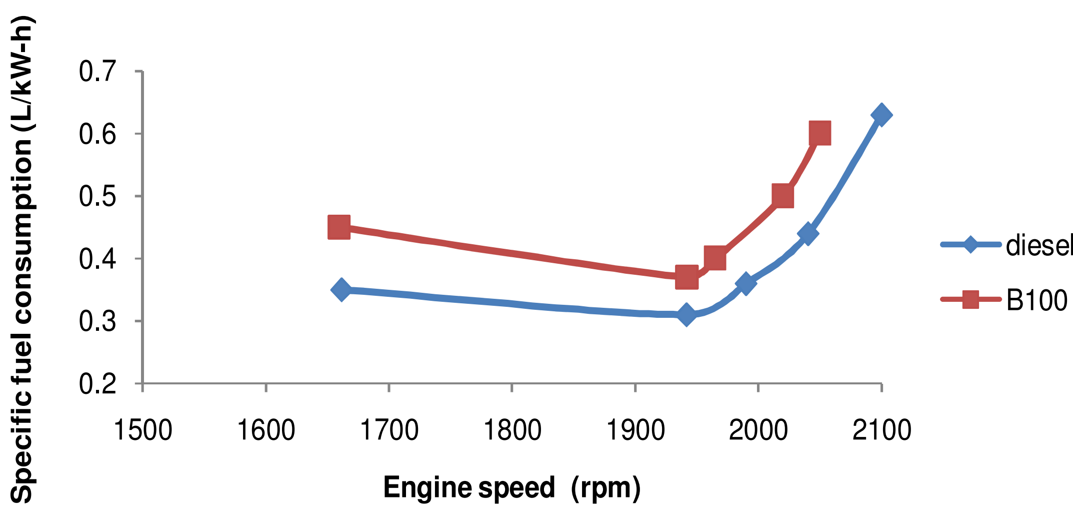

Figure 3. Variation of specific fuel consumption with engine speed of African bush mango nut oil biodiesel.

oil biodiesel is about 8% lower than that of diesel fuel and consistent with the difference in their heating values. The minimum specific fuel consumption occurred at 1950 rpm

Conclusion

African mango nut oil biodiesel has similar properties to diesel fuel and superior cold flow properties.

The flash point is also much higher than that of diesel fuel, which makes it a suitable alternative fuel for diesel engines. Dika oil is solid at ambient temperature of 25℃. Its wild source, high oil content and high conversion rate would make it a competitive fuel to diesel and other biodiesel fuels.

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