Fuel and Physiochemical properties of Cashew (Anarcardium 1 Occidentale) Nut Oil, its Biodiesel and Blends with Diesel.

ABSTRACT

The aim of this study is to measure the fuel and physiochemical properties of cashew nut oil, its biodiesel and blends with diesel fuel. The oil was extracted by soxhlet extraction method and transesterified with methanol using sodium hydroxide as catalyst. The resulting biodiesel was washed, dried and blended 20% (B20) and 10% (B10) with diesel. They were characterized following the ASTM and EN protocols and the fatty acid profile was determined by chromatography analyzer. The result obtained shows that the properties of the biodiesel are close to those of diesel and can thus be used as alternative fuel for diesel engines.

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INTRODUCTION

Cashew nut is one of the possible feed stocks that can be commercially exploited in Nigeria as it has been ascertained by the Food and Agricultural Organisation of United Nations – Economic and Social Department (FAO, 2008), that Nigeria is the second largest cashew nut (with shell) producers in the world, producing 660 000 tonnes per year. It is extensively cultivation in south America, India and Africa, helped by the fact that cashew tree will tolerate a wide range of conditions including drought and poor soil. It cannot however, withstand cold frost but would quickly recover after a bush fire. Cashew nut yields two “oils”, one of them obtained, between the seed coat (or, pericarp) and the nuts called the Cashew Nut Shell Liquid (CNSL). CNSL is not a triglyceride hence cannot be converted to biodiesel but contains a high proportion of phenolic compound and can be polymerized in a variety of ways which makes it a versatile industrial raw material with diverse uses in friction linings, paints and varnishes, laminating and epoxy resins, foundry chemicals and as an intermediary of chemicals. It is however, toxic and corrosive to the skin.

The second product cashew nut oil (CNO) obtained from the nut contains triglyceride and therefore a potentials and abundant source of feedstock for the production of the biodiesel. It is also used for manufacturing wood preservatives, coatings and friction materials (Alexander, 2008).

cashew tree is high yielding in Nigeria and a five years old cashew tree can produce up to 500 nuts per annum. However, the full benefit of the tree is not exploited as on a typical plantation, the fruits are allowed to fall and decay to release the nut that are then picked up. Sometimes they are eaten fruits and nuts raw by cows and other animals. Some studies have been done on the uses of cashew nut oil (Achal, 2002, Akinhanmi et al., 2008, Akinwale,2000, Aremu et al., 2007, Frankel, 1991,Rosengarten, 1984,Gibbon and Pain, 1981,Winterhatter et al., 1991) but not much work has been done on the measurement of the physiochemical properties of Nigeria’s cashew nut oil hence the aim of this study is to characterize the fuel and physiochemical properties of cashew nut oil, its biodiesel and 10% (B10) and 20% (B20) blends with diesel fuel. Biodiesel has been defined as the mono alkyl ester of vegetable oils and animal fats [NBB, 1997]. It is biodegradable, nontoxic, environment friendly and has agricultural origin hence renewable (Ma and Hanna,

1999,Canakci and Van Gerpen, 1999, Darado et al., 2002, Van Gerpen et al., 2004, Canakci and Van Gerpen, 2001).

The fuel properties of biodiesels are to a large extent dependent on feed stocks, which vary not only with the species but also with place of production (Ramadhas et al., 2005). The fuel standards for biodiesel, which are evolved from fossil fuel standards, ensures quality assurance by limiting the amount of impurities in the fuel such as triglycerides, monoglycerides, diglycerides, water, free fatty acid, soap and residual alcohol. These impurities need to be limited in biodiesel because their presence can lead to fuel deterioration during storage which can cause significant operational problems. Presently Nigeria has a biodiesel policy and standards are being developed to ensure uniformity of properties.

2.0 MATERIALS AND METHODS

2.1 Oil extraction

Cashew nut was planted in the backyard garden in 2010 and it yielded fruits after 15 months. 2 kg of the nuts was harvested and dried in the sun for five days at 35°C to reduce moisture content to about 7% (Ebewere et al., 2010) and decorticated manually to remove the kernel from the shell. The nuts which measured 5 mm diameter on the average, were milled to reduce diameter to about 1.16 mm and expose more area for higher oil extraction (Goodrum and Kilgo,1986,Sayyar et al., 2008). Analytical grade methanol, n-hexane and sodium hydroxide were procured from Finlab laboratory in Akure Nigeria. The oil was extracted in a soxhlet extractor with the n-hexane as the solvent. The oil was leached for 8 hours at 60°C and the hexane in the mixture was removed by using a rotary vacuum evaporator operating at 75°C. The oil obtained was weighed and the percentage oil yield was calculated by equation 1.

$$\%\ Oil\ yield = \frac{Weight\ of\ oil\ extracted}{Total\ weight\ of\ cashew\ nuts\ used} x100 \qquad 1.$$

2.2 Characterization of the oil.

The properties of the oil were first measured to determine if pretreatment was necessary or not before alkaline transesterification. It was found that the free fatty acid value (FFA) of the oil was 23.68 mg KOH/g which is high for direct alkaline transesterification as it can react with the catalyst to form soap which can inhibit methyl ester yield (Van Gerpen et al., 2004). The water content was 10% which is a little bit too high for uninhibited transesterification hence the oil was heated to 110°C and held constant for 30 minutes to allow some of the water to evaporate.

2.3 Transesterification procedure

Transesterification was carried out using a laboratory scale biodiesel processor in chemistry laboratory of the Federal University of Technology, Akure, Nigeria. Methanol was used as the reagent because it is a low cost and short-chain alcohol that reacts fast. The oil was first pretreated using sulfuric acid as catalyst to convert some of the fatty acids to ester before alkaline transesterification using anhydrous methanol at a molar ratio of 6 to 1 and 3g/litre of sodium hydroxide as catalyst. The processor was stirred at 600 rpm. at a temperature of 60 ^{o}C for 2 hours, after which the mixture was poured into a decanter and allowed to settle for 12 hours so that the reaction can be driven to completion and for the mixture to separate into two layers of biodiesel and glycerol which was at the bottom. The glycerol was drained off by gravity and the excess methanol in the biodiesel was removed in a flash evaporator. To remove any impurity, the biodiesel was washed in distilled and deionized water of volume

ratio 3 to 1 three times. Finally, the washed biodiesel was dried by passing it through anhydrous sodium sulphate (Na_2SO_4)(Schinas et al., 2009). The biodiesel produced and the glycerol was weighed and percentage yield calculated using equation 2.

$$Biodiesel\ \ yield\ \% = \frac{Weight\ of\ biodiesel}{Weight\ of biodiesel + weight\ of\ glycerol} \qquad 2$$

2.4 Fatty acid profile

The fatty acid compositions of the cashew seed oil, the methyl ester and blends with diesel (B10 and B20) and the standard sample of free fatty acid were determined by chromatography analyzer following the modified AOAC 965.49 and AOAC 996.06 official methods. The fatty acid methyl esters were separated using HP 6890 Gas Chromatography analyzer powered by HP ChemStation Rev A 09.11 [1206] software and equipped with a Flame Ionization Detector (FID) and HP INNOwax column (30 m x 0.25 cm x 0.20 µm film thickness). The carrier gas was nitrogen and the oven initial temperature then was at 60 ^{o}C. The first ramping was at 10 ^{o} C/min for 20 min and maintained for 4 minutes. The second ramping was at 15 ^{o} C/min for 4 minutes and maintained for 10 minutes. The detector temperature was 320 ^{o}C while hydrogen and compressed air pressures were 22 and 35 psi respectively. The proportion of the various fatty acids is shown in Table 1.

2.5 Determination of fuel and physiochemical properties

The fuel and physiochemical properties of the cashew seed oil, the biodiesel and blends we determined following ASTM, EN and AOCS methods and undertaken in McDonald laboratory in Warri, Delta state and the chemistry laboratory of the Federal University of Technology, Akure. Nigeria. The biodiesel and diesel were blended using a rotary blender in the ratio10% and 20% (vol/vol).

2.6 Density and relative density The density and relative density were measured using hydrometer to IP-160/ASTM D-1298. The measurements were made three times and then averaged.

2.7 Cold flow properties In measuring the Pour point, a 45 ml sample initially at 45°C was cooled in Herzog HCP852 at specified rate and examined at interval of 3°C to check if the sample is still flowing.

The cloud point was determined by a cloud point meter which comprises of a waveguide sensor of a total-reflection type, the wave guide sensor including a wave guide having an incidence channel, an emergency channel and a detection surface all formed on a substrate, the incidence and emergency channels intersecting along the detection surface, an incidence optical fiber connected to the entrance of the incidence channel, and an emergency optical fiber connected to the exit of the emergence channel; and a cooling/heating means in contact with the waveguide sensor for cooling/heating the waveguide sensor within a desired temperature range.

The cold filter plug apparatus model MC840 with 0.7 micron filter `was used to test 60 ml of each sample. It involves chilling the biodiesel to a predetermined point and then reheating to room temperature. The chilling and reheating process resulted into the formation of mushy crystal like material called sterols which does not blend with the biodiesel and can clog the fuel filter.

2.8 Kinematic and dynamic viscosities: The kinematic viscosity was determined with a Herzog GmbH MP-480 that involves measuring the time for a fixed volume of the fuel to flow under gravity through a capillary at temperature of 40°C.

Kinematic viscosity = Calibration constant (mm^2/s) x mean time of flow (s). The Brookfield viscometer model LV-DV11 was used to measure the dynamic viscosity at a temperature of 40°C.

2.9 Flash point Flash point measurements were done according to method ASTM D6751 using Kehler Model K-16270 (Pensky-Martens Closed Flash Tester).

2.10 Higher and lower heating values The lower heating value was obtained using the oxygen bomb calorimeter (Parr Instrument Company, US.) following the ASTM D240 method.

2.11 Calculated cetane index The cetane number of the biodiesel was calculated using equation 3 (Willard, 1976).

$$CI = -420.34 + 0.016G^2 + 0.192G(\log T_{50}) + 65.01(\log T_{50})^2 - 0.0001809T^2_{50} \qquad 3$$

where G is the API (American Petroleum Institute) specific gravity and T_{50} is the distillation temperature as 50 vol.% fuel sample distilled and condensed in a unit of ℉.

2.12 Iodine and peroxide values The iodine and peroxide values were analyzed, based on the methods of the American Oil Chemists' Society (AOCS cd8, 1980) by titrating with 0.01 N sodium thiosulfate for the mixture of tested fuel and chemical reagents until they were light blue and light yellow, respectively. The iodine value and peroxide value were then calculated by equations (2) and (3).

$$Iodine\ value = \frac{(B-T)xCx0.001269}{Y} \qquad 4.$$

$$Peroxide\ value = \frac{(T-B)xCx1000}{Y} \qquad 5.$$

where B and T are denoted as the amounts (in mL) of sodium thiosulfate titrated for the blank sample and tested sample, respectively. C is the molar concentration (in mol/L) of sodium thiosulfate and Y is the weight (in g) of the tested sample.

2.13 Acidic number The acid number, which is the amount of KOH required to neutralize 1 g of fat and expressed as mg KOH/g, was determined by titrating with 0.01 N potassium hydroxide for the mixture of tested fuel and chemical reagents until the appearance of the color pink.

2.14 Oxidative stability A glass ware apparatus for ASTM D 2274 was used for the oxidation stability test. The fuel was made to degrade by heating and oxygenating the sample in a shorter period of induction time. Oxygen was bubbled for 16 hours while the fuel was held at 95 ^{o}C. Thereafter, the fuel sample was filtered to measure the amount of any insoluble that was formed. Finally, the amount of time that the fuel could be stored before deterioration by forming acids was then estimated.

2.15 Soap content

For soap content measurement of the oil, the AOCS method cc 17-79, (soap in oil) was used. 5 g of each sample was titrated with 0.1N solution of HCL acid to the phenolphthalein end point. 1 ml of bromophenol blue indicator was added and the titration was continued until the bromophenol changed from blue to yellow.

2.16 Saponification value

This was determined using equation 6.

$$Saponification\ value = \frac{(B-T)x28.5}{Weight\ of\ sample} \qquad 6$$

2.17 Moisture content

The moisture content was measured by Karl-Fisher Method (ASTM D 6304) 831 KF Coulometer (Metrohm Company, Switzerland) using 5 ml of the samples.

2.18 Water and sediment Water and sediment content were obtained by centrifuge model HNS II by Thermo Electron Corp, US. 100 ml of each sample was poured into a centrifuge tube and spun at 800 rev/min for 10 minutes. After centrifuging, the volume of water and sediment which settled into the tip of the centrifuge tube was read to the nearest 0.005 ml and recorded as the volumetric percentage water and sediment. by centrifuge.

2.19 Carbon residue Carbon residue was determined by heating a sample to 500 ^{o}C in nitrogen filled chamber at controlled rate to ensure that the sample cokes and does not combust. The formed volatile compounds were flushed from the chamber by nitrogen, and the mass of the remaining coke determined. The test is to simulate the formation of carbon deposits in the engine by the fuel.

2.20 Sulfated ash Isotemp muffle furnace was used for ash analysis. The residue was allowed to cool down and thereafter treated with sulfuric acid and heated to 750 ^{o}C until oxidation of carbon was complete. The ash was then cooled, retreated with sulfuric acid and heated to 750 ^{o}C to constant weight. To obtain the sulfated ash content of the samples, the final weight was divided by the initial weight and then multiplied by 100 to express as percentage.

2.21 Glycerine content The wet Chemical AOCS method for determining glycerol, methanol, AOCS Official method Ca 14-56 entitled “Total, free and combined glycerol Iodometric-periodic Acid method as well as methanol Content was used. It is similar to the method prescribed in the ASTM standard but easier to perform. It was also used for the determination of monoglycerides, diglycerides and triglycerides

2.22 Copper Strip corrosion test Copper strip corrosion test was conducted according to ASTM D130 protocol. A polish copper strip was immersed in 50 ml sample of the oil and methyl ester for 3 hours at 50°C. At the expiration of the duration each strip was washed in a standard solvent and the result were compared with standard description of tarnished and corrosion.

2.23 Distillation temperatures During the vacuum distillation test, the system pressure was set at between 1 kpa and 83 kPa. and were made to correspond to 5 to 95 vol % in a step of 5 vol % of the liquid fuel distilled and condensed.

2.24 Metal analysis For metal analysis 50 ml of samples were prepared by diluting 1:10 with kerosine. The dilution was to eliminate possible viscosity effect that may affect accuracy. The Teledyne fuelpro biodiesel metal analyzer was calibrated with standards prepared by diluting plasma pure biodiesel stock standards. The standard concentrations were 0.00, 10.00, 20.00, 30.00, 40.00 ppm of Na, K, Ca, Mg, P and S.

2.24 Colour The colours of the oil, biodiesel and blends were observed visually.

3.0 RESULTS AND DISCUSSION

The Oil yield was 32% and biodiesel yield 87%.

Table 1 shows that the fatty acid profile of CNO is 63% unsaturated consisting mainly of 20.97% linolenic acid with triple bond, 34.48% oleic acid with single bond and 28.87% palmitic saturated fatty acid. Many properties vary with chain length, number of bonds and degree of unsaturation (Laza and Bereczky, 2010). It was reported that methyl esters of saturated acids have a higher cloud point, cetane number and better stability (Knothe, 2005). The results obtained for the fuel and physiochemical properties are shown in Tables 2 to 5.
There are significant differences in the fatty acid profile of B100, B20 and B10 compared with CNO because transesterification chemically breaks down the molecules of the vegetable oil during which the glycerol from the triglycerides are removed and replaced with radicals from the alcohol used which changes the structure and hence the properties of transesterified oils (Bello, et al., 2011).

Table 1. Fatty acid profile of cashew nut oil and its biodiesel.

Fatty Acid	Form	Oil	B100
Capric	C10:0	1.37	2.23
Lauric	C12:0	1.83	2.98
Myristic	C14:0	0.59	0.96
Palmitic	C16:0	28.87	23.13
Palmitoleic	C16:1	3.16	5.16
Stearic	C18:0	4.06	5.57
Oleic	C18:1	34.48	31.65
Linoleic	C18:2	4.67	7.62
Linolenic	C18:3	20.97	20.71
Total Saturation %		36.71	34.87
Total unsaturation %		63.28	65.13

3.1 Density and relative density

The density of biodiesel is generally higher than those of fossil diesel fuel and the value depend on their fatty acid composition as well as on its purity. CNO density of 902 kg/m^3 reduced to 874, 856 and 854 for the B100, B20 and B10 respectively. The relative density of CNOME is within the limits for biodiesel and higher than diesel except for B20.

3.2 Cloud and pour points

Cold temperature behaviour of biodiesel is an important quality criterion, as frozen fuel may cause blockage of the fuel lines and filters and starve the engine of fuel. The two most important criteria are the cloud and pour points. The cloud, pour and cold filter plugging points are all a little bit above zero which limits their application in cold regions.

3.3 Flash point

The flash point of pure biodiesels is usually higher than the ASTM limits, but fall rapidly with increasing amount of methanol. CNO has a flash point of 167 ^{o}C, the value for CNOME is 136°C while the values for B10 and B20 are 82 ^{o}C and 89 ^{o}C respectively and which although are below the minimum for biodiesel, are higher than that for diesel fuel. High flash point can prevent auto ignition and reduced fire hazards at high temperatures during transportation and storage periods. It is hence a measure of flammability of fuels and an important safety criterion.

3.4 Viscosity

Kinematic velocity is the dynamic viscosity/relative density. The dynamic and kinematic viscosities of the CNO are 49.62 cts and 54.92 mm^2/s respectively. Those of CNOME and the blends are within the limits for biodiesel. Viscosity is an important property of biodiesel since it affects the operation of fuel injection equipment, particularly at low temperatures when the increase in viscosity affects the fluidity of the fuel or leakage at high temperature when too thin. Dynamic viscosity is of interest in relation to the settling rates of contaminants, and kinematic velocity in respect of pumping and atomization.

3.5 Higher and lower heating values

Heating value is the enthalpy released after the complete combustion reaction of fuel at a constant pressure or volume. Fuels having higher the heating value, will consumption lower fuel to obtain the same engine power output. Monyem and Van Gerpen (2001) found that a biodiesel had a heating value lower than that of ASTM No. 2D diesel by about 12.7–14.7%. The higher and lower heating values for CNO are 40 MJ/kg and 37.30 MJ/kg, 44.00 MJ/kg and 37.20 MJ/kg for CNOME respectively and are slightly less than that of diesel fuel which is consistent with the trend for biodiesel. The heating values increases after transesterification because the glycerol removed from the oil has lower heating values and it also increases with the amount of diesel in the blend because diesel has higher heating values.

3.6 Calculated cetane Index

Biodiesel has a higher cetane index than diesel fuel because of its oxygen content (Knothe, 2005) and also because the fatty acids present in the fuel have very high cetane index. Cetane index increases with increasing length of both fatty acid chain and ester groups, while it is inversely related to the number of double bonds. The calculated cetane index of the CNO of 49.28 increased to 60.83 for the CNOME 47.75 and 46.22 for B20 and B10 respectively. That of CNOME is above the minimum limit for biodiesel but reduces with blending because diesel has lower cetane number.

3.7 Water content and sediment

CNO contains 10% water by volume. This falls drastically after transesterification. The moisture content was 3420 and reduced to 221 after transesterification. Free water promotes microbial growth in the oil leading to sludge and slime formation, which can cause blockage of fuel filters and fuel lines. Moreover, high water contents are also associated with hydrolysis reactions, partly converting biodiesel to free fatty acids.

3.8 Cold soak filtration

This is a measure of the time in seconds it takes for cold soaked biodiesel to pass through two 0.8 micron filters. It an indicator of the amount of particulate matter collected on the filter. The test is to prevent the precipitation of solid materials in inferior biodiesel during cold weather. The cold soak filtration is 310 for CNO and falls to 230, 77 and 95 for the CNOME and the B10 and B20 blends respectively.

3.9 Iodine values

Iodine number is a measure of the total unsaturation within a mixture of fatty acids, and is expressed in grams of iodine which react with 100 grams of biodiesel. Unsaturation can lead to deposit formation and storage stability problems with biodiesel. Fuels with higher iodine number tend to polymerize and form deposits on injector nozzles and piston when heated. The iodine values for the CNO, CNOME, B10 and B20 are below the maximum for biodiesel. The value for CNOME is 85.28 and 82.75 for CNOME The iodine values are all

below the maximum for biodiesel and reduces further with blending. Iodine value is an indication of the drying quality of the oil.

3.10 Peroxide value

Peroxide value is generally used to determine the extent of fuel oxidation. It is an indicator of oil auto ignition and high value is an indication of high degree of rancidity. The peroxide value of an oil increases with its oxidization level. Cherng-Yuan and Rong-Ji, (2009) shows that marine fish-oil biodiesel had a peroxide value much lower than that of the commercial biodiesel, primarily due to its larger content of saturated fatty acids and thus higher oxidation stability, A peroxide value of 21.70 for the biodiesel is high compared to common vegetable oils.

3.11 Oxidation stability

Biodiesel ages because of their nature origin and aging properties vary with method of production, raw materials used, exposure to sunlight high temperature and oxygen. This can lead to the formation of insoluble sediments and gums, which are associated with fuel filter blocking and deposits within the injection system and the combustion chamber. It leads to increased viscosity and acid value. The oxidative stability of CNO at 110°C was 19 hr, 9 hours for CNOME, 27 and 18 for B10 and B20 respectively. It reduces after transesterification but increases with blending and in all case higher than diesel.

3.12 Acid number and free fatty acid

This is the quantity of base required to titrate a sample to a specified end point. It is a measure of free fatty acid in biodiesel. Excessive free fatty acid in the fuel can be corrosive and may be a symptom of water in the fuel or poor production or subjected to oxidative degradation. Excessive free fatty acid in the fuel can inhibit the transesterification process and lead to soap formation. The free fatty acid and acid values of the oil are 2.29 mgKOH/g and 4.56 mgKOH/g respectively. The acid value reduced after transesterification but increased with increasing amount of diesel on the blends.

3.14 Saponification values

Saponification is the chemical reaction between the CNO and NaOH and resulted in the production of soap and glycerin. Water is also present, but it does not enter into the chemical reaction. High value can inhibit the transesterification process. The Saponification value of the oil is 117.11 for the oil and is within the range for most vegetable oils (Alatise and Akinhanmi, 2009, Mittelbach and Remschmidt, 2004). It would be suitable for the production of soap and shampoo.

3.15 Soap content

Soap in biodiesel is as a result of poor transesterification process and tends to reduce biodiesel yield. It makes the fuel more viscous, reduces flammability and hence must be regulated. The soap content for CNO was zero but increased to 4 for CNOME as a result of transesterification. It reduced further with blending.

3.16 Refractive index

The refractive index was 1.466 and reduced to 1.334 after transesterification but increases to 1.481 after blending. Reflective index value is a measure of purity of the fuel.

3.17 Carbon residue

The carbon residue test gives the remaining part when a sample of biodiesel has been subjected to thermal decomposition and hence an indication of coking tendency of the fuel. The most common cause of excessive carbon residue in biodiesel is the excessive level of

total glycerin soaps and other organic impurities. The carbon residue is 0.07 (mol/mol) CNOME and below the maximum ASTM D4530 limits for biodiesel of 0.05%.

3.18 sulfated ash

This is a measure of the mineral ash residue when a fuel is burned. It is an important test for biodiesel because it is an indicator of the quantity of residue metals in the fuel that came from the catalyst used in the transesterification process. It is limited by ASTM D874 and EN ISO 3987. The sulfated ashes for B100 are 0.03 % (mol/mol) and lower than the 0.05 ASTM maximum limits.

3.19 Total glycerol

Total glycerol is the sum of the concentrations of free glycerol and glycerol bound in the form of mono-, di- and triglycerides. The concentration depends on the production process and high value may originate from complete transesterification or inadequate washing. Free glycerol can separate from the biodiesel when stored and accumulate at the bottom of the tank, where it can mix with other polar components from sediments in the fuel tank. High level of glycerol can result into injector coking and affect a wide range of fuel properties, which can affect operational efficiency and engine durability hence the need for its regulation. It is limited by ASTM D6584 and EN 14105/14106 (McCormick and Westbrook, 2007) Table 3. Shows all the glyceride contents.

3.20 Distillation temperature, 90% recovered, maximum

This parameter is related with the boiling point of a liquid fuel and affects the combustion characteristics of diesel engines and commonly used to determine the cetane number. The vacuum distillation end point is below the 360°C maximum at 90% distillation of EN D1160.The distillation temperature increases with the amount of methyl ester in the blend this result was also noted by (Alptekin and Canakci, 2009). The result is shown in Figure 1.

3.21 Alkaline and metal components

The origin of alkaline metallic elements in the fuel is from the catalysts used during transesterification while earth metal ions that emanates from the hard water used for washing in the fuel. They are deposited on engine components after combustion as incombustible ash and can react with metallic components of fuel systems and should hence be limited to recommended values to reduce deposits on engine components, injectors and catalytic system. All the metals levels are high for the oil but below the limit for biodiesel for B100. Sulfur however increases with blending since the diesel used contains sulfur. The result is shown in Table 3.

3.22 Phosphorous content

Phosphorus in biodiesel originates from phospholipids (animal and vegetable material) and inorganic salts contained in the feedstock. Phosphorus has adverse effect on long term activity of exhaust emission catalytic systems and therefore limited by specification. The value for the oil is less than the maximum of 10 mg/kg specified by EN standard.

3.23 Colour Table 5 shows the colours of the tested fuels. The colours changed with transesterification but become darker with blending with diesel.

Table 2. Properties of cashew nut oil, its biodiesl and blends to ASTM D6751-02 and EN 14214

Property	CNO	B100	B10	B20	Diesel	ASTM Limits	EN 14214
Density kg/m^3 at 15°C	902	874	854	856	850		860-900
Relative density kg/m^3	0.914	0.875	0.855	0.857	0.852		

at 15°C							
Cloud point ^{o}C	20	6	7	9	-12		
Pour point ^{o}C	13	1	5	5	-20		
Cold filter plug point ^{o}C	15	4	6	7	-15		
Flash point ^{o}C	167	136	82	89	68	93	120 min
Dynamic viscosity cts at 40°C	49.62	4.21	2.46	2.67	2.23		
Kinematic viscosity mm^{2}/s 40°C	54.92	4.81	2.88	3.12	2.62	1.9-6.0	3.5-5.0
Lower heating Value KJ/kg	37.30	37.20	42.80	42.20	43.40		
Higher heating value KJ/kg	40	40.40	45.30	44.85	45.90		
Calculated cetane number (ASTM D4737)	49.28	60.83	46.22	47.75		47 min	51 min
Free fatty acid %	2.29	0.188	0.188	0.225			
Acid value mgKOH/g	4.56	0.374	0.45	0.37		0.80 max	0.05 max
Iodine value gI2/100g	85.28	82.74	16.24	23.65	8.63		120 max
Peroxide value gI2/100g	21.70	27.00	17.30	16.30	15.00		
Oxidation stability (hours) 110°C	19	9	27	18		3 min	6 min
Saponification value mgKOH/g	117.11	187.94	162.69	165.50	159.89	120 max	159.89 max
Soap content %	0	4	0.5	1.0			
Cold soak filtration ^{o}C	310	230	77	95			
Water and sediments % (vol/vol)	10.00	0.02	0.002	0.004			500 max
Moisture content ppm	3420.	221.0	24	48			
Refractive index at 15°C	1.47	1.34	1.48	1.48	1.48		
Sulfated ash % (mol/mol)	0.60	0.03	0.01	0.01		0.020 max	0.02 max
Carbon residue % (mol/mol)	0.17	0.07	0.03	0.02		0.050 max	0.30 max
Copper strip corrosion test (3h, 50°C)	4	2	1	1		No.3 max	1
Distillation temperature 90% ^{o}C	355	350	320	322		360 max	

Table 3. Glycerine contents

Property	**CNO**	**B100**	**B10**	**B20**	**ASTM Limits**	**EN 14214**
Methanol Content % (mol/mol)	0.003	0.096	0.011	0.021		0.20 max
Free Glycerol % (mol/mol)	0.960	0.011	0.002	0.003	0.020 max	0.02
Monoglycerine % (mol/mol)	0.002	0.150	0.018	0.032		0.80
Diglycerine % (mol/mol)	0.001	0.009	0.002	0.003		0.20
Triglyceride % (mol/mol)	98.752	0.005	0.003	0.005		0.20
Total Bounded glycerol	98.755	0.164	0.023	0.040		
Total Glycerol	99.715	0.175	0.025	0.043	0.240 max	0.025

Table 4. Metal content (mg/kg).

Metal	Detection Limit (ppm)	Spike recovery	CNSO	B100	B20	B10	ASTM	EN
Sodium Na 589.592r	0.0193 80	100.9	4.50	2.50	0.03	0.02		5.0 max
Potassium K766.491r	0.0704 40	101.1	2.80	1.00	0.08	0.04		5.0 max
Calcium Ca317.933r	0.0029 2	101.6	3.40	0.50	0.01	0.06		5.0 max
Magnesium Mg285.213r	0.0009 0.20	99.1	28.50	0.70	0.15	0.08		5.0 max
Phosphorous P213.618r	0.0227 5	99.1	40.60	5.20	7.50	3.60	10 max	10.0 max
Sulphur S180.731r	0.114 15	98.7	21.00	9.20	27.50	26.9	15/500	10.0 max

Table 5. State of cashew nut oil, methyl ester and blends.

Fuel	State at room temperature (25°C)	Colour
Cashew nut oil	Liquid	Dark brown
B100	Liquid	Golden yellow
B20	Liquid	Dark brown
B10	Liquid	Dark brown
Diesel	Liquid	Dark brown

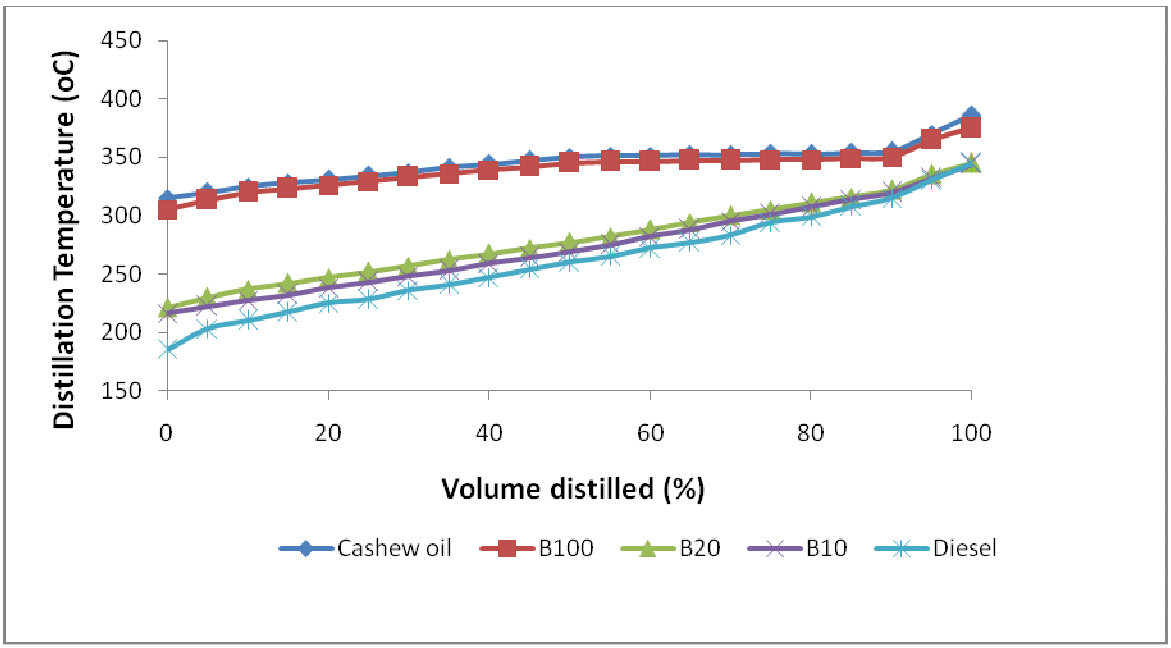

Fig.1. Distillation curves for cashew nut oil, methyl ester and blends.

4.0. CONCLUSIONS AND RECOMMENDATIONS

Cashew nut has oil content of 32% and the biodiesel yield was 87%. Cashew nut oil biodiesel contains 23.74% oleic, 37.9% linoleic, 15.160% linolenic, 19.32 palmitic and 3.876 stearic acids. It is 76.80% unsaturation. The fatty acid value was very high and it required pretreatment with sulphuric acid before alkaline transesterification. Most of the properties of the biodiesel are within the limits for biodiesel and can hence be used as alternative fuel for diesel engines

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