

Fuel and Physiochemical properties of Cashew (*Anacardium 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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Keywords: cashew nut oil, biodiesel, blend, physiochemical properties.

LIST OF ABBREVIATIONS

AOCS	American Oil and Chemist's Society
ASAE	American Society of Agricultural Engineers
ASTM	American Society for Test and Materials
B100	Neat biodiesel
B20	Blend with 20% biodiesel and 80% diesel
B10	Blend with 10% biodiesel and 90% diesel
CNO	Cashew Nut Oil
CNSL	Cashew Nut Shell Liquid
CNOME	Cashew Nut Oil Methyl Esters

INTRODUCTION

Cashew nut is one of the possible feed stocks that can be commercially exploited in Nigeria for biodiesel production and other uses, 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. Cashew is extensively cultivated 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 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 (Alexander, 2008). The second Oil 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. 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 evolved from fossil fuel standards and ensure 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 Akure, in southwest of Nigeria 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 and diesel fuel was purchased from Mobil petrol station both 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.

$$\% \text{ Oil yield} = \frac{\text{Weight of oil extracted}}{\text{Total weight of cashew nuts used}} \times 100 \quad 1.$$

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 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 °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 further remove impurities, 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 (Na₂SO₄) (Schinas et al., 2009). The biodiesel produced and the glycerol was weighed and percentage yield calculated using equation 2. (Giwa et al., 2010)

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

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 and HP INNOWAX column (30 m x 0.25 mm x 0.20 µm film thickness). Nitrogen was the carrier gas and the oven initial temperature was 60 °C. The first ramping was at 10 °C/min. for 20 minutes and maintained for 4 minutes. The second ramping was at 15 °C/min for 4 minutes and maintained for 10 minutes. The detector temperature was 320 °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 were 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 ratio 10% 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 soaked filter is a mandatory quality control test introduced by ASTM in 2008 to prevent particulate matters in biodiesel from precipitating at low temperature to clog filters and block fuel pipes thus cutting off fuel flow to the engine. A cold filter plug apparatus model MC840 with 0.8 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 processes formed mushy crystal like material that can clog the fuel filter. The biodiesel is passed through the two filters and the time in seconds it takes for cold soaked biodiesel to pass through two 0.8 micron filters and the amount of matters collected are measured.

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 (mm²/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 number The cetane number of the biodiesel was calculated using equation 3 (Willard, 1976).

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

Where G is the API (American Petroleum Institute) specific gravity and T₅₀ is the distillation temperature as 50 vol.% fuel sample distilled and condensed in a unit of °F.

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 (4) and (5).

$$\text{Iodine value} = \frac{(B-T) \times C \times 0.001269}{Y} \quad 4.$$

$$\text{Peroxide value} = \frac{(T-B) \times C \times 1000}{Y} \quad 5.$$

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 °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 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.

2.16 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 and the volume of water and sediment was read to the nearest 0.005 ml.

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2.17 Carbon residue Carbon residue was determined following standard procedure which involved heating a sample of the fuel to 500 °C in nitrogen filled chamber at controlled rate to ensure that the sample cokes and does not combust. The volatile compounds formed were then flushed from the chamber with nitrogen after which the mass remaining was determined. The aim of the test was to simulate the formation of carbon deposits in the engine by the fuel.

2.18 Sulfated ash Isotemp muffle furnace was used for the test. The residue was allowed to cool down and thereafter treated with sulfuric acid and heated to 750 °C until oxidation of carbon was complete. The resulting ash was then cooled, retreated with sulfuric acid and heated to 750 °C to constant weight. After which the percentage weight was calculated.

2.19 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.

2.20 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.

2.21 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.

2.22 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, and 30.00, 40.00 ppm of Na, K, Ca, Mg, P and S.

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

3.0 RESULTS AND DISCUSSION

The Oil yield was 32% and biodiesel conversion 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

258	Myristic	C14:0	0.59	0.96
259	Palmitic	C16:0	28.87	23.13
260	Palmitoleic	C16:1	3.16	5.16
261	Stearic	C18:0	4.06	5.57
262	Oleic	C18:1	34.48	31.65
263	Linoleic	C18:2	4.67	7.62
264	Linolenic	C18:3	20.97	20.71
265	Total Saturation %		36.71	34.87
266	Total unsaturation %		63.28	65.13

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268 **3.1 Density and relative density**

269 The density of biodiesel is generally higher than that of diesel fuel and depends on their fatty acid
270 composition as well as on its purity. It is an important parameter as far as weight of fuel delivered to
271 the cylinder is concern. CNO density of 902 kg/m³ reduced to 874, 856 and 854 for the B100, B20
272 and B10 respectively. The relative density of CNAME is within the limits for biodiesel and higher
273 than diesel except for B20.

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275 **3.2 Cloud and pour points**

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

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280 **3.3 Flash point**

281 CNO has a flash point of 167 °C, the value for CNAME is 136°C while the values for B10 and B20
282 are 82 °C and 89 °C respectively and which although are below the minimum for biodiesel, are higher
283 than that for diesel fuel. High flash point can prevent auto ignition and reduced fire hazards at high
284 temperatures during transportation and storage periods. It is hence a measure of flammability of fuels
285 and an important safety criterion.

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287 **3.4 Viscosity**

288 Kinematic viscosity is the (dynamic viscosity)/(relative density). The dynamic and
289 kinematic viscosities of the CNO are 49.62 cts and 54.92 mm²/s respectively. Those of CNAME and
290 the blends are within the limits for biodiesel. Viscosity is an important property of biodiesel since it
291 affects the operation of fuel injection equipment, particularly at low temperatures when the increase in
292 viscosity affects the fluidity of the fuel or leakage at high temperature when too thin. Dynamic
293 viscosity is of interest in relation to the settling rates of contaminants, and kinematic velocity in
294 respect of pumping and atomization.

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296 **3.5 Higher and lower heating values**

297 Heating value is the enthalpy released after the complete combustion reaction of fuel at a constant
298 pressure or volume. Fuels having higher heating values, would require lower fuel flow rate than the
299 fuel with lower heating value for the same engine power output. Monyem and Van Gerpen (2001)
300 found that a biodiesel had a heating value lower than that of ASTM No. 2D diesel by about 12.7–
301 14.7%. The higher and lower heating values for CNO and CNAME are 40 MJ/kg and 37.30 MJ/kg,
302 44.00 MJ/kg and 37.20 MJ/kg respectively and are slightly less than that of diesel fuel which is
303 consistent with the trend for biodiesel. The heating values increases slightly after transesterification
304 because the glycerol removed from the oil has lower heating values and it also increases with the
305 amount of diesel in the blend because diesel has higher heating values.

3.6 Calculated cetane index/number

The cetane number, or cetane index, is frequently used to indicate the quality of the compression ignition of diesel fuel (Cherng-Yuan and Rong-Ji, 2009). It is generally accepted that a larger cetane number for a diesel fuel results in a shorter ignition delay and duration of the combustion period, less occurrence of knocking, and lower formation of nitrogen oxides (NO_x) (Lin and Lin 2007). Graboski and McCormick (1998) found that the cetane index of biodiesel produced from soybean oil ranges between 45.7 and 56.4.

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

3.7 Water and sediment, and moisture content

CNO contains 10% water by volume. This falls drastically after transesterification, washing and drying. The moisture content was 3420 ppm and reduced to 221ppm after transesterification. Excess water in the fuel can promote microbial growth which can degrade the oil and lead to the formation of whitish solid substances that can clog filters and restrict fuel flow to the engine. Moreover, high water contents can react with the free fatty acids to form acidic solution that can lead to corrosion of fuel equipment metallic components.

3.8 Cold soak filtration

This test was introduced by ASTM and measures the time in seconds, for cold soaked biodiesel to pass through two 0.8 micron filters. It is an indicator of the amount of particulate matter collected on the filter. The test is done to ensure that solids do not precipitate in biodiesel during cold weather which can clog filters and restrict fuel flow to the engine. The cold soak filtration is 310 seconds for CNO and falls to 230, 77 and 95 seconds for the CNO ME and the B10 and B20 blends respectively.

3.9 Iodine values

Iodine number is a measure of the total unsaturation of the fuel, and is expressed in grams of iodine which react with 100 grams of biodiesel. Unsaturated biodiesel because of the double bonds present can react with other elements present to form solid matters and create storage stability problems. The iodine values for the CNO, CNO ME, B10 and B20 are below the TM maximum values for biodiesel. The value for CNO is 85.28 and 82.75 for CNO ME. The iodine values are all below the maximum for biodiesel and reduce further with blending. Iodine value is an indication of the drying quality of the oil.

3.10 Peroxide value

Peroxide value is used to determine the level of fuel oxidation. The value is related to the degree of auto ignition, oxidation stability and rancidity. Cherng-Yuan and Rong-Ji, (2009) reported that marine fish-oil biodiesel had a peroxide value that is much lower than that of commercial biodiesels primarily because of its larger content of saturated fatty acids. A peroxide value of 21.70 for the biodiesel is high compared to common vegetable oils.

3.11 Oxidation stability

Biodiesels age faster than diesel because of their nature origin and the rate of aging varies with method of production, raw materials used, exposure to sunlight, high temperature and oxygen. The oxidative stability of CNO at 110°C was 19 hr, 9 hours for CNO ME, 27 hr and 18 hr for B10 and B20 respectively. It reduces after transesterification but increases with blending and in all cases 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 react with any water present to form acidic solution making the biodiesel corrosive. Excessive free fatty acids in the fuel can inhibit the transesterification process due 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 higher amount of diesel in the blends.

3.13 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.

3.14 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 inadequate purification process that allow for excessive level of total glycerin soaps and other organic impurities. The carbon residue is 0.07 (mol/mol) for the CNAME which is below the maximum ASTM D4530 limits for biodiesel of 0.05%.

3.15 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 related to 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 CNAME is 0.03 % (mol/mol) and lower than the 0.05 ASTM maximum limits.

3.16 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 incomplete 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 (Mittelbach et al., 1983, McCormick and Westbrook, 2007). It is limited by ASTM D6584 and EN 14105/14106. Table 3. Shows all the glyceride contents.

3.17 Distillation temperature, 90% recovered, maximum

This parameter is depended on the boiling point of a fuel and affects the combustion characteristics of diesel engines. It is also commonly used to determining the cetane number of diesel and related fuels. 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.

3.18 Alkaline and metal components

The origin of alkaline metallic elements in the fuel originates from the catalysts used during transesterification while earth metal ions emanates from the hard water used for washing. They are deposited on engine internal components after combustion and can react with metallic components of fuel systems, they 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 limits for biodiesel. Sulfur however increases with blending since the diesel used contains sulfur. The result is shown in Table 3.

3.19 Phosphorous content

The origin of phosphorus in biodiesel is the phospholipids (animal and vegetable material) and inorganic salts contained in the feedstock. Phosphorus can have adverse effects the performance of the catalytic elements in the exhaust systems and therefore limited by specification. The value for the oil is less than the maximum of 10 mg/kg specified by EN standard.

3.20 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 biodiesel and blends to ASTM D6751-02 and EN 14214

Property	CNO	B100	B10	B20	Diesel	ASTM Limits	EN 14214
Density kg/m ³ 902	874	854	856	850		860-900	
at 15°C							
Relative density kg/m ³ at 15°C	0.914	0.875	0.855	0.857	0.852		
Cloud point °C	20	6	7	9	-12		
Pour point °C	13	1	5	5	-20		
Cold filter plug point °C	15	4	6	7	-15		
Flash point °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)	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 gI ₂ /100g	85.28	82.74	16.24	23.65	8.63		120 max
Peroxide value gI ₂ /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 °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% °C	355	350	320	322		360 max	

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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 and colour of CNO, CNAME 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	Light Brown

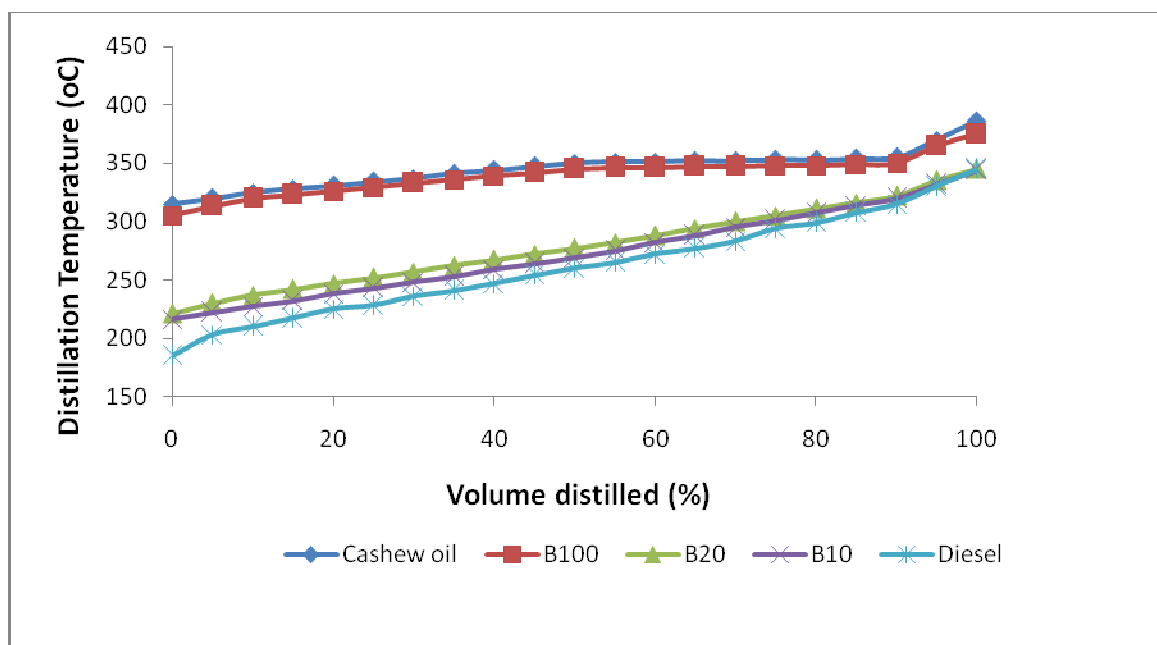


Fig.1. Distillation curves for cashew nut oil, methyl ester and blends.

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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