Some fuel properties of biodiesel produced from *Vitellaria paradoxa* and Elaeis guineensis oil

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Abstract: Tranesterification reaction was carried out on raw shea butter oil (SBO) and palm kernel oil (PKO) to separate the ester from glycerol using ethanol in the presence of potassium hydroxide as catalyst. The properties of biodiesel (ethyl ester) obtained from varying proportions of diesel were experimentally determined and compared with that of conventional diesel. The fatty acid profile of the oil samples was determined using standard methods. Four blends (10%, 20%, 25% and 30%) of SBO and PKO by volume with diesel oil were produced and fuel properties determined include viscosity, relative density, specific gravity, flash, cloud and pour points. Mean values of the six fatty acids (palmitic, stearic, oleic, linoleic) obtained for shea butter and palm kernel oil samples were 5.3%, 1.5%, 13.5%, 15.6% and 8.4%, 2.5%, 15.3%, 2.3%, respectively. The viscosity ranged between 1.52 - 16.6 at 40℃ and 100℃; relative density ranged between 826 - 856 kg m^{-3}, specific gravity ranged between 0.861 – 0.901; flash point ranged between 55℃ - 260℃, cloud and pour point values ranged from 4.85℃ to 6℃ and from –25℃ to –12℃, respectively. The transesterification of the oil samples decreased cloud and pour point of the shea butter and palm kernel oil samples. Based on the findings of this study, blends with 10%, 20% and 25% of PKO and SBO content were found to have acceptable fuel properties for use in internal combustion engine. The adoption of the biodiesel will help to meet the increasing demand for energy in West African countries due to the quality of the oil.

Keywords: diesel, shea-butter oil (SBO), palm kernel oil (PKO), transesterification, biodiesel

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1 Introduction

1.1 Diesel and biodiesel

Diesel is an important working fluid of most power machines such as tractors, trucks and earth moving equipment due to the advantage of longer life of engines, maximum power output, fuel economy and its working efficiency. These factors have made the demand of diesel fuel very high throughout the world. Diesel oil used as fuel is one of the fractions of crude oil which are regarded as fossil fuel. In 1911 Rudolf Diesel practicalized and confirmed the possibility of using vegetable oil as fuel for diesel engine (Abdullah et al., 2013). This has given challenges on trying different types of vegetable oils for biodiesel production. Biodiesel is an environmentally friendly alternative diesel fuel consisting of the alkyl monoesters of fatty acids. It is obtained from triglycerides through the transesterification process. It is completely soluble in commercial petroleum-based diesel fuel.

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Therefore biodiesel can be used as a blend and one fuel tank can be used for storage of both fuels, which makes the vehicle flexible. This is a unique advantage compared with most alternative fuels, as no extra cost for engine modifications is avoidable. Biodiesel has been standardized by American Society for Testing Material (ASTM, 2002) standard D 6751-02 and in Europe DIN V 51506 in 1994. Depending on the trade-off between cost and its environmental benefits, biodiesel is most commonly used in the United States as a blend with No. 1 or No. 2 diesel fuels. The advantageous features of biodiesel result from the fact that biodiesel has different physical and chemical properties from petroleum-based diesel fuel. Eleven percent of biodiesel is oxygen by weight and this appears to result in more complete combustion. Also, it has a higher cetane number that makes the combustion smoother and the engine is less noisy. However, biodiesel has higher values of viscosity, density, speed of sound, and bulk modulus that may cause changes in the injection system and combustion system behavior. Fuel quantity, injection and injection spray pattern in the combustion chamber are directly affected by these parameters. Biodiesel's lower heating value is about 12% less than petroleum-based diesel fuel and this causes a power loss that must be compensated by increasing the injected fuel amount (Kleopatra et al. 2018). When injecting this greater quantity of fuel, some fuel injection systems start the injection earlier and hold the injection needle open longer, changing the fuel injection timing and the start of combustion timing. These differences in physical properties may shift the engine timing settings from their optimized factory settings, leading to earlier combustion. Biodiesel is renewable, biodegradable, non-toxic, and typically produces about 65% less net. Several researchers have reported the transesterification and use of vegetable oil for biodiesel (Tosacano and Maldini, 2007; Alamu et al., 2008; Okullo et al., 2010; Bello et al., 2011; Bello and Anjorin, 2012; Blin et al., 2013; Olaniyan and Oje, 2013; Abdullah et al., 2013; Verma et al., 2016; Gorey et al., 2017; Chika et al., 2018; Ajala et al., 2018; Khairul and Manabu, 2018; Kleopatra et al., 2018; Konan et al., 2018).

1.2 Shea nut

Shea nut (*Vitellaria paradox*) is of a botanical family *sapoteceae* and has a botanical name *Butryospermum parkli*. Other names are *Karite* (French), *Nku* (Ghana), *Igba* (Nigeria), Shea butter tree and bambuk butter tree. The tree can be found growing naturally in the southern region of the sahel and the northern regions of the Guinea Zone. It thrives in savanna areas where oil palm cannot grow due to low rainfall (GTZ, 1986). The major producing countries are West African countries (Mali, Burkina faso, Benin, Senegal, Ivory Coast, Ghana and Nigeria). Shea butter is basically composed of fatty acids, stearic acids and oleic, which together account for 85% – 90% of the total fatty acids. Shea butter with a higher oleic content is known to be softer than one with a lower oleic content. The oleic content and stearic content of West African Shea Nut Butter ranges from 37% to 55% and from 25% to 50%, respectively (Okullo et al., 2010). Once the shells are removed, the shea kernels are dried and if properly done, the dried kernels have a shelf life of 5 years or more (Tulashie et al., 2018). The pulps of the harvested berry are being crushed under foot after fermentation. This berry (almond) sticks to the shell wall. To separate them, the nuts are immersed in boiling water and sun dried for a few days. Shelling of the nuts is traditionally carried out using stone, hammers and pestles. This process can also be carried out mechanically. Winnowing is achieved by holding basket filled with nut at arm length and gradually emptying them. The number of times of the winnowing is done, which depends on the prevailing wind speed. The shelled almonds are dried again from a moisture content of 40% – 50% to 6% – 7% prior to extraction (Olaniyan and Oje, 2013).

1.3 Palm kernel

Palm kernel oil production as a whole consists of seven readily defined unit operations, namely palm-nut drying, palm-nut cracking, palm-kernel roasting, palm-kernel crushing, PKO sifting and PKO bottling/pumping. PKO is a kind of white to yellowish oil of vegetable origin which is solid at normal temperatures and is obtained from the kernels of the oil palm (*Elaeis guineensis*). The heating value of PKO is about 39.7 MJ kg^{-1}. From a previous work (Jekayinfa and Bamgboye, 2007), it was reported that the fossil energy requirement in the production of PKO is between 0.1 and 0.16 MJ L^{-1} depending on the category of the PKO mill. The percentage of oil extracted per kilogram of kernels is between 19.5% and 21.5%. Three distinct categories of PKO mills exist in Nigeria (Jekayinfa and Bamgboye, 2007; Alamu et al. 2008). These are small, medium and large scales based on their production capacity and mechanization level of their operations.

Oil extraction can be done in three ways; a traditional village process, mechanical and chemical method. The traditional method, which is predominant in Nigeria, is time consuming and human energy-sapping. Some of the problems inherent in the traditional methods are those involving mesocarp removal, drying, shelling, winnowing, crushing, mixing and temperature control (Aremu and Ogunlade, 2016a). In the mechanical method, which is less time consuming, the kernels are pounded to a fine powder and a screw or hydraulic press is used to express oil out of the seeds or kernels while the chemical method involves the use of chemicals to dissolve the already grinded kernels and extract the vegetable oil (Aremu and Ogunlade, 2016b; Ogunlade and Aremu, 2018).

Transesterification is the process whereby fats and oils obtained from plants and animals are reacted with alcohol (ethanol or methanol) and catalyst (alkali or acid) and the mixture of the methyl/Ethyl esters (biodiesel) and glycerol (byproduct) is allowed to undergo separation and purification steps before further stage. The main aim of this study was to produce biodiesel from varying proportions of shea butter and palm kernel oil with diesel fuel, and the specific objective of this study was to study some selected fuel properties of shea butter and palm kernel oil blended with diesel fuel and compare these properties with those of the conventional diesel fuel.

2 Materials and methods

2.1 Sample preparation

Samples of shea butter oil and palm kernel oil used for the experiment were purchased at a local market in Ogbomoso, Oyo State, Nigeria. The oil samples were subjected to frying to allow them to loose absorbed moistures. The samples were then filtered to remove dirty particles.

2.2 Biodiesel preparation / transesterification

Each 100 g of shea butter oil (SBO) and palm kernel oil (PKO) was used for transesterification process. Ethanol made from sugar cane was used for this experiment, and it is 99% pure and has a boiling point of 78℃. Potassium hydroxide (KOH) used was also an analytical grade. 500 mL reactor was stirred and equipped with a heater, and the reactor was surmounted by a coolant to avoid evaporation of the alcohol most especially in cases when reaction goes beyond boiling temperature of alcohol. The mixture was allowed to settle and the upper layer was scooped and washed with hot distilled water as reported by Sankalp and Savita (2016) and Konan et al. (2018). Materials used in the course of the study include a dry and wet mill blender, scales, measuring beakers, translucent white plastic container with bung and screw on cap, funnels, Polyethylene terephthalate(PET) bottles, duct tape and thermometers.

Four blends of diesel fuel with SBO and PKO were used. They were obtained by mixing the oil and diesel by volume in the following proportions:

a) 0 percent vegetable oil and 100 percent diesel

b) 100 percent vegetable oil and 0 percent diesel

c) 10 percent oil and 90 percent diesel

d) 20 percent oil and 80 percent diesel

e) 25 percent oil and 75 percent diesel

f) 30 percent oil and 70 percent diesel

In lieu of this, 12 samples of biodiesel mix were produced together with SBO, PKO and diesel in their natural forms. Laboratory KOH catalyzed transesterification tests were then carried out using ASTM standard. The biodiesel mix sample tested for fuel properties and mixing ratio is presented in Table 1.

Table 1 Biodiesel mix from SBO and PKO code

Serial Number	Code	Description
1	SBO	Natural shea butter oil
2	PKO	Natural palm kernel oil
3	D	Natural diesel
4	SD 1	SBO: D = 0: 100 (0% SBO and 100% diesel)
5	SD 2	SBO: D = 100: 0 (100% SBO and 0% diesel)
6	SD 3	SBO: D = 10: 90 (10% SBO and 90% diesel)
7	SD 4	SBO: D = 20: 80 (20% SBO and 80% diesel)
8	SD 5	SBO: D = 25: 75 (25% SBO and 75% diesel)
9	SD 6	SBO: D = 30: 70 (30% SBO and 70% diesel)
10	PD 1	PKO: D = 0: 100 (0% PKO and 100% diesel)
11	PD 2	PKO: D = 100: 0 (100% PKO and 0% diesel)
12	PD 3	PKO: D = 10: 90 (10% PKO and 90% diesel)
13	PD 4	PKO: D = 20: 80 (20% PKO and 80% diesel)
14	PD 5	PKO: D = 25: 75 (25% PKO and 75% diesel)
15	PD 6	PKO: D = 30: 70 (30% PKO and 70% diesel)

2.3 Fatty acid profile

The fatty acid profile of natural SBO and PKO was determined using a chromatography analyzer in accordance with Association of Official Agricultural Chemists (AOAC) methods of analysis as reported by Okullo et al. (2010).

Determination of fuel properties

The fuel properties determined include viscosity, relative density, specific gravity, cloud point, pour point, and flash point and they were determined for all samples reported in Table 1.

a) Viscosity: This is the measurement of fluid internal resistance to flow at a specified temperature. Viscosity of fats and oils decreases slightly with an increase in unsaturation. Therefore, viscosity is increased slightly by hydrogenation. Oils and fats containing a greater proportion of fatty acids of relatively low molecular weight are slightly less viscous than the ones of an equivalent degree of unsaturation, but containing a higher proportion of high molecular weight acids. It was determined in accordance with ASTM D445 04 standard test using Ostwald viscometer (450 Orifice), and the time taken for the oil samples to drop was measured and viscosity was calculated (Suleiman et al., 2013; Ogunlade and Aremu, 2018).

$$V = \mathrm{k} \times t \quad (1)$$

Where V is the kinematic viscosity (centistokes or mm^2 s^{-1}), k is the Ostwald constant, and t is the time taken for oil to fall in the meniscus (s).

b) Relative density and specific gravity: This was determined using density and specific gravity bottles of 50 ml respectively at a temperature of 22℃. The mass of the bottle was determined using a top pan balance (GAZOOD, Ohaus Corporation, Germany, resolution - 0.0001 g). The bottle was then weighed with the oil sample after wiping off the outside to remove any oil sticking to the outer dace. The filled bottle was weighed and the difference in these two values of masses gave the mass of the oil (Ogunlade and Aremu, 2018). The mass (g) of the sample recorded was divided by 50 (mL) to obtain the density of crude oil in g ml^{-1} as presented in Equation 2.

$$p = \frac{M}{V}\ (\mathrm{kg\ m^{-3}}) \quad (2)$$

Where: p is the density in kgm^{-3}, M is the mass of the product (kg), V is the volume (m^3).

c) Cloud and pour point: Cloud and pour point are used for low temperature performance of fuel. The pour point is the minimum temperature at which a liquid will cease to flow (Chika et al., 2018). They were determined using the Baskeyl Setapoint cloud and pour point apparatus in accordance with ASTM D97 standard method of evaluation by pouring the samples into a test jar (placed on the disk inside the bath jacket maintained at 6℃) to the mark and using a thermometer (immersed 3 mm below sample surface). At every 3℃ decrease in temperature, the jar was removed from bath jacket and tilted at an angle to ensure flow of samples and this was repeated until samples stop to flow when tilted for almost 3 seconds, and the pour point was obtained by adding 3 ℃ to this temperature (Thirumarimurugan et al., 2012; Chika et al., 2018).

d) Flash point: The lower the flash point is, the greater the fire hazard will be (Sankalp and Savita, 2016). Flash point indicates the possible presence of highly volatile and flammable material in relatively non-volatile material (Rehman et al., 2009). It is also essential in the durability, storage, safety and handling of fuels (Vilas and Raheman, 2005). The flash point of the oil samples determines the minimum temperature at which volatile liquid will vapourize to form ignitable mixture in air. The flash points of the diesel and the biodiesel produced from the mixture of diesel and SBO and PKO were determined in accordance with ASTM D6751 standard methods by using a flashpoint tester (Type 00-ESR, Newcastle). A thermometer was placed in the metal cup of the tester and 100 mL sample was poured and the flashpoint tester was switched on. The flash point was determined every 2℃ and accurate values were recorded.

3 Results and discussion

3.1 Fatty acid profile

The fatty acid composition of shea butter and palm kernel oil is presented in Table 2. The mean values of the six fatty acids obtained in shea oil samples, palmitic, stearic, oleic, linoleic, alpha linoleic and arachidic, were 5.3%, 1.5%, 13.5%, 15.6%, 62.2% and 0.1% respectively. Linoleic fatty acid is the dominant fatty acid in the shea oil. However, no significant difference ($p \leq 0.05$) was observed in the value of the fatty acids. Similar result was reported by Okullo et al. (2010) in their work on physico-chemical characteristics of shea butter (*Vitellaria paradoxa*) oil from the shea districts of Uganda. Also, the mean values of the eight fatty acids (palmitic, stearic, oleic, linoleic, lauric, myristic, capric and caprylic) obtained for palm kernel oil were 8.4%, 2.5%, 15.3%, 2.3%, 48.2%, 16.2%, 3.4% and 3.3% respectively. Lauric and myristic fatty acids were the predominant fatty acids in the palm kernel oil but no significant difference was observed in the fatty acid values ($p \leq 0.05$).

Table 2 Fatty acid profile of SBO and PKO

Fatty acid type	Percentage, %	
	SBO	PKO
Palmitic	5.3	8.4
Stearic	1.5	2.5
Oleic	13.5	15.3
Linoleic	15.6	2.3
Alpha linolenic	62.2	—
Arachidic	0.1	—
Lauric	—	48.2
Myristic	—	16.2
Capric	—	3.4
Caprylic	—	3.3

3.2 Viscosity

The viscosity values of diesel, SBO, PKO and biodiesel mix samples at 40℃ and 100℃ are presented in Figure 1. It was observed that the viscosities of SBO and PKO biodiesels decreased as the percentage of diesel increased. At 40℃, the viscosities of 70%, 75%, 80% and 90% blends of SBO and PKO were 10.4, 6.02, 5.66, 5.31 and 10.5, 6.0, 5.34, 5.28 respectively. Similar values at 100℃ are 2.85, 2.03, 1.69, 1.6 and 2.93, 2.0, 1.7, 1.6. The fluctuation in viscosity values may be attributable to the effect of the changes in the temperature, and similar trend was reported by Nourrechni et al. (1992) and Ogunlade and Aremu (2018).

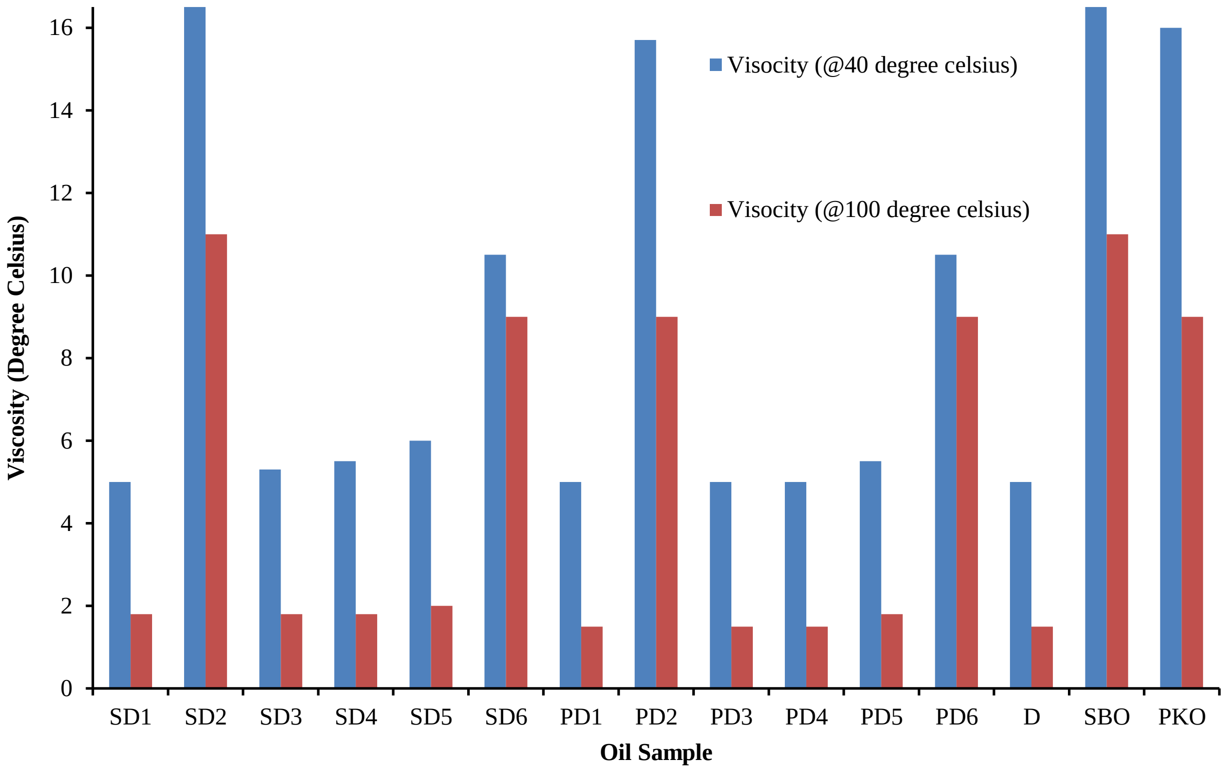


Figure 1 Viscosity of SBO, PKO and biodiesel

Note: SBO stands for shea butter oil, PKO stands for palm kernel oil, D stands for diesel, SD stands for SBO + D, PD stands for PKO + D, SD 1 means SBO : D = 0 : 100, SD 2 means SBO : D = 100 : 0, SD 3 means SBO : D = 10 : 90, SD 4 means SBO : D = 20 : 80, SD5 means SBO : D = 25 : 75, SD 6 means SBO : D = 30 : 70, PD 1 means PKO : D = 0 : 100, PD 2 means PKO : D = 100 : 0, PD 3 means PKO : D = 10 : 90, PD4 means PKO : D = 20 : 80, PD5 means PKO : D = 25 : 75, PD 6 means PKO : D = 30 : 70

3.3 Relative density

The relative densities of the biodiesel mix samples, diesel fuel, SBO and PKO are presented in Figure 2. It was observed that the relative densities of diesel, SBO and PKO are 0.8442, 0.855 and 0.856 respectively and these values were not significantly different. With the addition of diesel, the relative densities of the oil-diesel blends changed depending on the proportion of diesel in the mixture. As shown in Figure 2, as the percentage of diesel in the blends increased, the relative density increased. This finding compares well with those earlier reported by Ajav and Akingbehin (2002). When these results are compared with that of diesel, the difference is not significantly different based on statistical analysis at 5% level of significance. The density values are suitable for excluding material other than vegetable oil, and the values obtained are lower than the limit value proposed in pre-standard DIN V 51605 (900—960 kg m^{-3}). However, low density implies that the energy content per unit of volume decreases which results in a lower fuel-air equivalence ratio inside the combustion chamber and a decrease in the energy delivered per cycle (Joel et al., 2018).

3.4 Specific gravity

The specific gravity of the samples ranged from 0.861 to 0.901, where the highest specific gravity value was obtained for SD 6 which is a biodiesel mix of 30% of SBO and 70% of diesel fuel, and all values obtained showed that the biodiesel produced is pure, which is less dense than water and therefore would flow and spread easily on surfaces (Oyeleke et al., 2012; Yahaya et al., 2012; Ogunlade and Aremu, 2018). The specific gravity value of the shea butter and palm kernel vegetable oil and their respective biodiesel mix is presented in Figure 3.

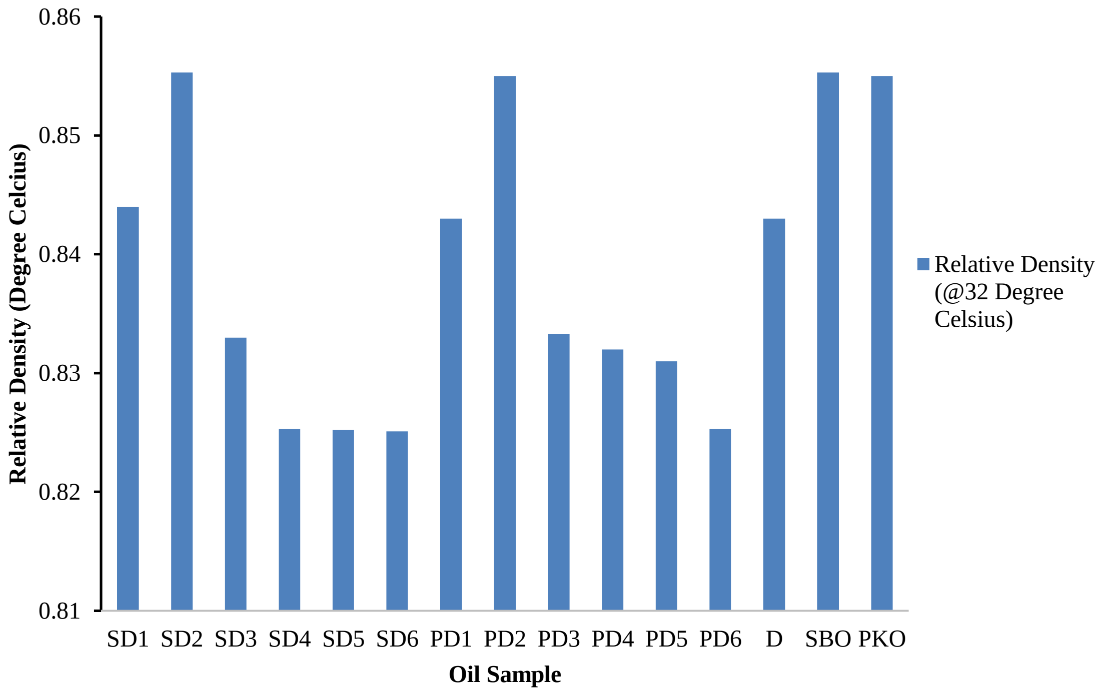


Figure 2 Relative densities of diesel fuel and vegetable oil samples

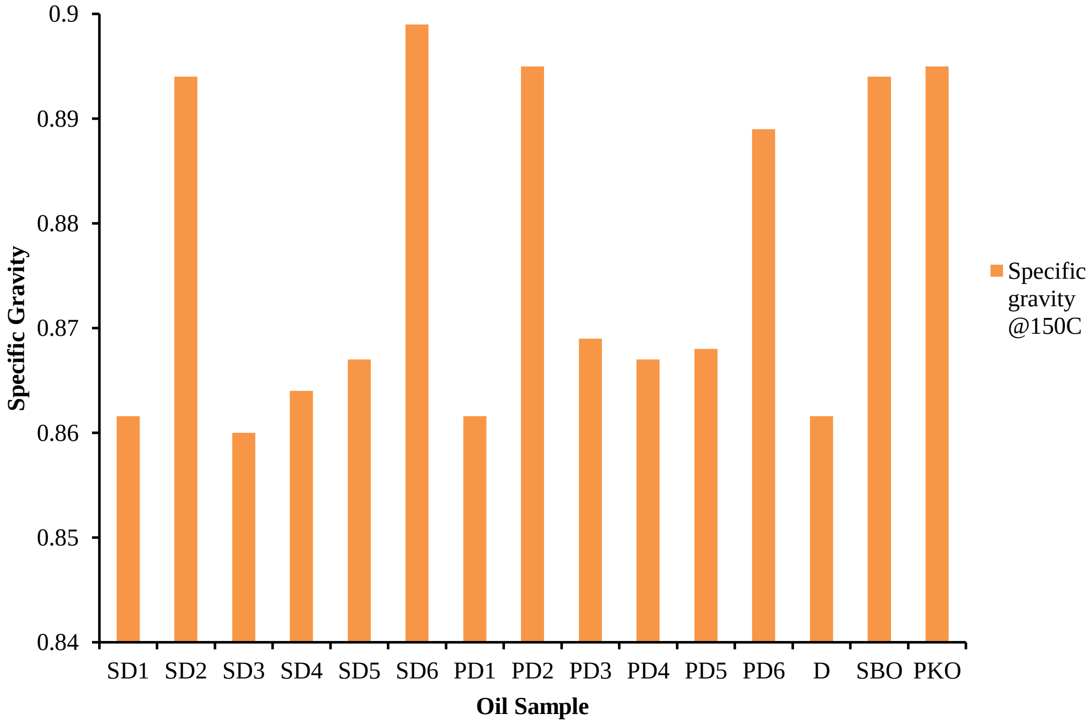


Figure 3 Specific gravity of SBO, PKO and Biodiesel mix

3.5 Flash point

The flash point is important for safety storage and handling parameter, and it does not really influence the engine performance (Joel et al., 2018). The values obtained ranged from 55℃ to 260℃, which falls within minimum temperature at which liquids can vaporize to form ignitable mixture in air. The highest flash point of 260℃ and 250℃ was obtained for SD 2, PD 2, SBO and PKO, compared to diesel flash point of 55℃ as shown in Figure 4, and the values fall within acceptable range reported by Sidibe et al. (2010) and Pandey et al. (2013), which also supports the claim of Abdullah et al.

(2013) that biodiesel burns at higher temperature compared to standard diesel. This also implies that the biodiesel obtained from shea butter and palm kernel is much safer to use compared to standard diesel due to the significantly high flash point. The flash point levels are higher than acceptable limit 130℃ set by ASTM and fall within values reported by Bello et al. (2011) for Castor, Pumpkin and groundnut oil biodiesel, which indicates that the biodiesel produced from SBO and PKO is safe for use.

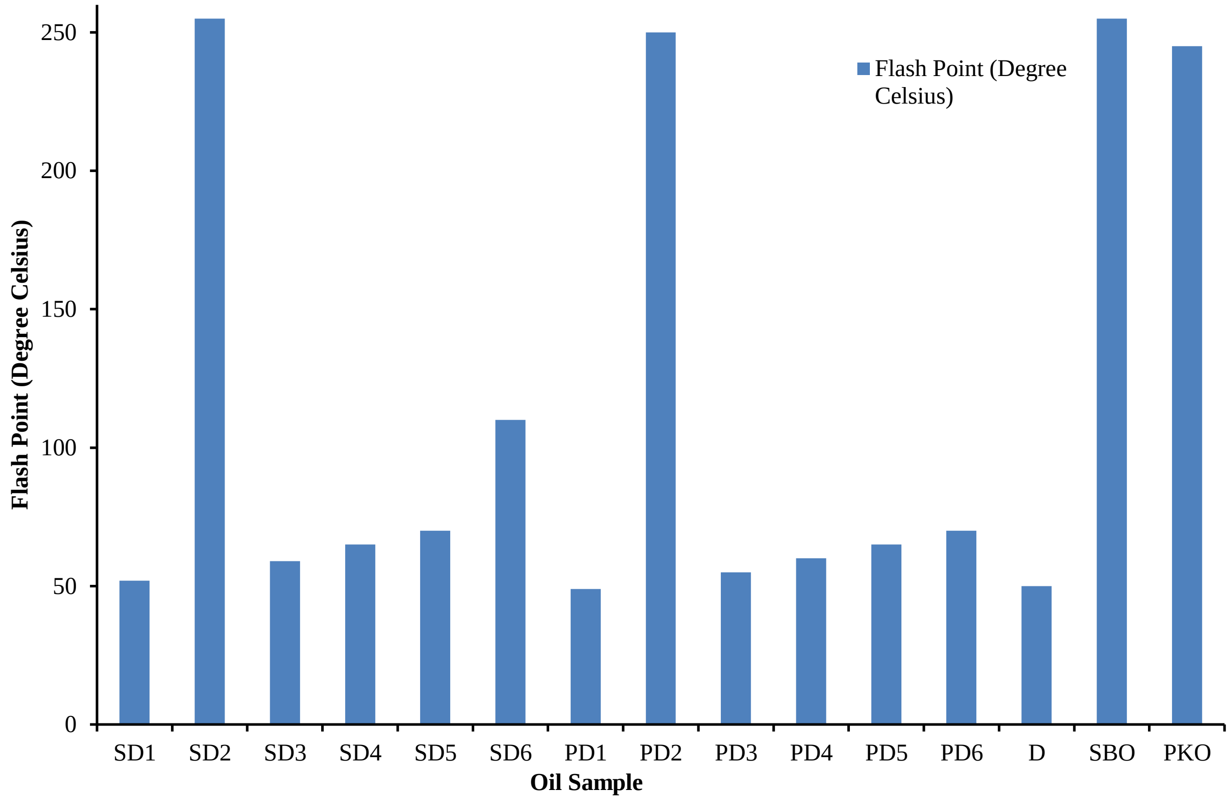
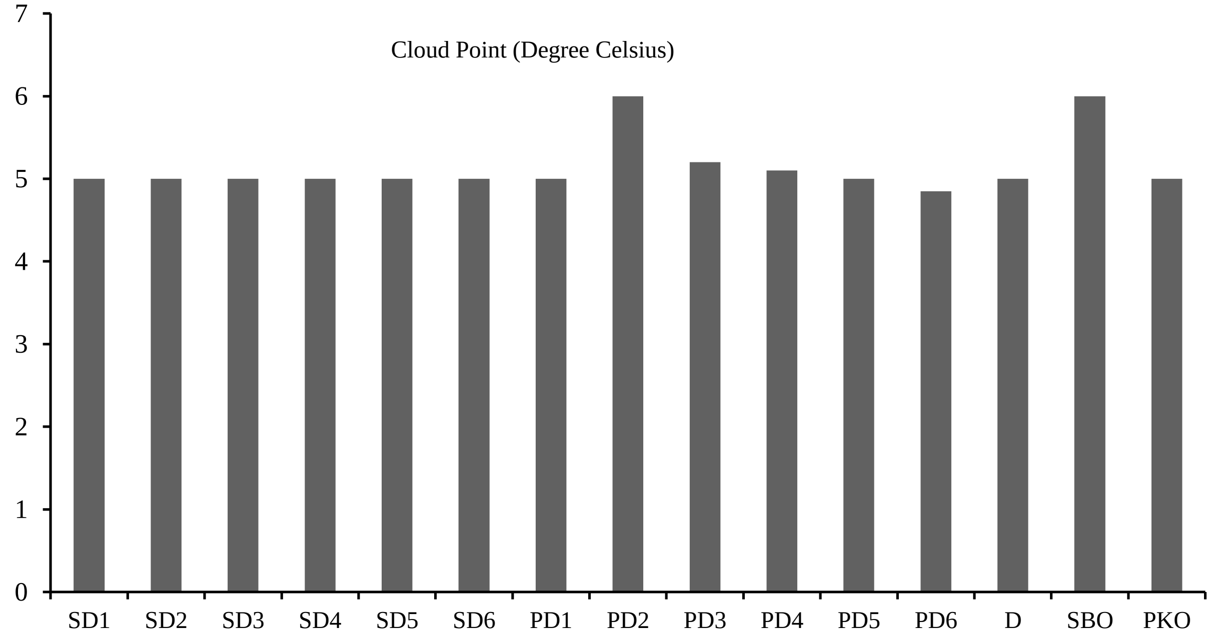
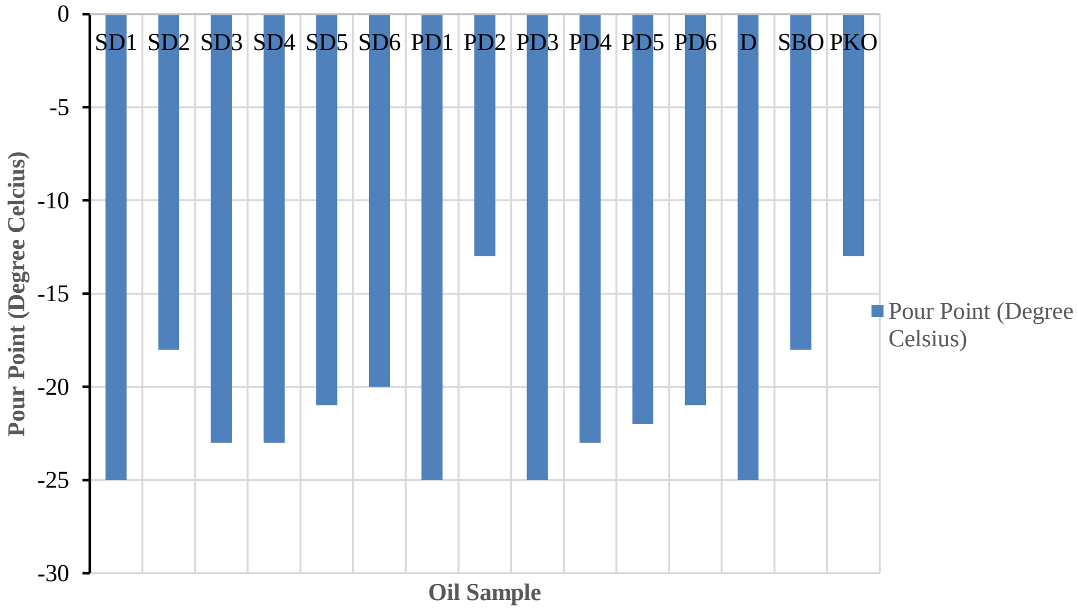


Figure 4 Flash point of standard diesel, SBO, PKO and biodiesel mix



(a) Cloud point



(b)Pour point

Figure 5 Cloud point and pour point of standard diesel, SBO, PKO and biodiesel mix

3.6 Cloud and pour point

The cloud and pour point obtained ranged from 4.85℃ to 6℃ and from －25℃ to －12℃, where the values obtained follow the proof that biodiesel fuels exhibit poor. The transesterification of the oil samples decreased cloud and pour point of the shea butter and palm kernel oil samples, which implies that the oil samples can be used in extremely cold regions, and values obtained are in similar trend with Bello et al. (2011) who reported a 75% and 66% whopping decrease in cloud points of castor and pumpkin oil together with a 73%, 50% and 100% decrease in pour points of castor, pumpkin and groundnut oil due to tranesterification. The values of cloud and pour point of the samples are presented in Figure 5a and Figure 5b respectively.

4 Conclusion

Transesterification of vegetable oil aids in making its properties close to that of diesel in this study where the transesterification of shea butter and palm kernel oil was carried out in varying mix ratios with conventional diesel, and it was obtained that the biodiesel produced from the vegetable oils falls within acceptable values for diesel fuels considering some selected fuel properties like viscosity, relative density, specific gravity, flash, cloud and pour points. Based on the findings of this study, blends with 10%, 20% and 25% of PKO and SBO content were found to have acceptable fuel properties for use in internal combustion engine. The adoption of the biodiesel will help to meet the increasing demand for energy in West African countries due to the quality of the oil .

References

Abdullah, A. M., S. Shaila, and M. E. B. Sheikh. 2013. Selection of an efficient method of biodiesel production from vegetable oil based on fuel properties. *International Journal of Engineering Trends and Technology*, 4(8): 3289-3293.

Ajala, E. O., F. Aberuagba, A. M. Olaniyan, M. A. Ajala, M. O. Sunmonu, and M. M. Odewole. 2018. Design, construction and performance evaluation of a mini-scale batch reactor for biodiesel production: A case study of shea butter. *Songklanakarin Journal of Science and Technology*, 40(5): 1066-1075.

Ajav, E. A., and O. A. Akingbehin. 2002. A Study of some fuel properties of local ethanol blended with diesel fuel. *Agricultural Engineering International: the CIGR Journal of Scientific Research and Development*, 01 003 (4): ?1-9.

Alamu, O. J., T. A. Akintola, C. C. Enweremadu, and A. E. Adeleke. 2008. Characterization of palm-kernel oil biodiesel produced through NaOH-catalysed transesterification process. *Scientific Research and Essay*, 3(7): 308-311.

Aremu, A. K., and C. A. Ogunlade. 2016a. Effect of operating parameters on mechanical oil expression from African oil bean seeds. *Global Journal of Science Frontier Research:Agriculture and Veterinary,* 16(1): 19-26.

Aremu, A. K., and C. A. Ogunlade. 2016b. Influence of moisture content and seed dimension on mechanical oil expression from African oil bean (*Pentaclethra macrophylla*) seeds. *Journal of Bio-Systems Engineering,* 41(3): 193-200?.

ASTM.2002. *Annual book of American Society for Testing and Material Standards*. Philadelphia, PA.

Bello, E. I., and S. A. Anjorin. 2012. Fatty acid compositions of six Nigeria's vegetable oils and their methyl esters. *Research Journal in Engineering and Applied Sciences*, 1(3): 166-170.

Bello, E. I., T. S. Mogaji, and A. Makanju. 2011. The effects of transesterification on selected fuel properties of three vegetable oils. *Journal of Mechanical Engineering Research*, 3(7): 218-225.

Blin, J., C. Brunschwig, A. Chapuis, O. Changotade, S. Sidibe, E. Naomi, and P. Girard. 2013. Characteristics of vegetable oils for use as fuel in stationary diesel engines — towards specifications for a standard in West Africa. *Renewable and Sustainable Energy Reviews*, 22(?): 580-597.

Chika, M., U. Zaliha, and A. Francis. 2018. Biodiesel production from *Ceiba pentadra* seed oil using CaO derived from Snail shell as catalyst. *Petroleum Science and Engineering,* 2(1): 7-16.

Gorey, N., S. Ghosh, P. Srivastava, and V. Kumar. 2017. Characterization of palm oil as biodiesel. *IOP Conference Series: Materials Science and Engineering*, 225(2): 1-8.

GTZ 1986. New shea butter technology. The Hydraulic Shea Butter Press, 2-4.

Jekayinfa, S. O., and A. I. Bamgboye. 2007. Development of equations for estimating energy requirements of palm-kernel oil processing operations. *Journal of Food Engineering,* 79(1): 322-329.

Joel, B., B. Christel, C. Arnaud, C. Odilon, and S. Sayon. 2018. Characteristics of vegetable oils for use as fuels in stationary diesel engines — towards specifications for a standard in West Africa. *Renewable and Sustainble Energy Reviews,* 22(1): 580-597.

Khairul, A. Z., and K. Manabu. 2018. Biodiesel production from palm oil, its by-products and mill effluent: A review. *Energies*, 2132(11): 1-25.

Kleopatra, P., S. Marinos, A. Agapios, K. Christos, and K. Nikolaos. 2018. Determination of quality properties of low-grade biodiesel and its heating oil blends. *Environments*, 96(5): 1-16.

Konan, E. K., A. Abollé, B. Kouassi, D. B. Yao, A. Kopoin, D. Patrick, and D. T. Rajeshwar. 2018. Optimization of rubber seed oil transesterification to biodiesel using experimental designs and artificial neural networks. *Green and Sustainable Chemistry*, 8(2): 39-61.

Nourrechni, H., Teoh, B. C., and Clement, L. D. 1992. Viscosity of vegetable oils and fatty acids. *Journal of American Chemical Society,* 69, 1184 – 1188.

Ogunlade, C. A., and A. K. Aremu. 2018. Influence of processing conditions on yield and quality of mechanically expressed African oil bean (*Pentaclethra macrophylla* Benth) kernels: A response surface approach. *Journal of Food Process Engineering*, 42(2): 1-9.

Okullo, J. B. L., F. Omujal, J. G. Agea, P. C. Vuzi, A. Namutebi, J. B. A. Okello, and S. A. Nyanzi. 2010. Physico-chemical characteristics of shea butter (*Vitellaria paradoxa* C.F. Gaertn.) oil from the shea districts of Uganda. *African Journal of Food, Agriculture, Nutrition and Development,* 10(1): 2070-2084.

Olaniyan, A. M., and K. Oje. 2013. Process conditions governing mechanical expression of shea butter from crushed shea kernel under uni-axial compression. *International Journal of Engineering Research in Africa,* 10(?): 37-48

Oyeleke, G. O., E. O. Olagunju, and A. Ojo. 2012. Functional physicochemical properties of watermelon (*Citrullus lanatus*) seed-oil. *Journal of Applied Chemistry*, 2(2): 29–31.

Pandey, R. K., A. Rehman, and R. M. Sarviya. 2013. Impact of alternative fuel properties on fuel spray behaviour and atomization. *Renewable and Sustainble Energy Reviews,* 16(2): 1762-1778.

Rehman, A., R. K. Pandey, S. Dixit, and R. M. Sarviya. 2009. Performance and emission evaluation of diesel engine fueled with vegetable oil. *International Journal of Environmental Research,* 3(?): 463-470.

Sankalp, D., and D. Savita. 2016. Optimization and fuel properties of water degummed linseed biodiesel from transesterification process. *Chemical Sciences Journal*, 7(2): 1-6.

Sidibe, S. S., J. Biln, G. Vaitilingom, and Y. Azoumah. 2010. Use of crude filtered vegetable oil as a fuel in diesel engines state of the art: Literature review. *Renewable* *and Sustainble Energy Reviews*, 14(?): 2748-2759.

Suleiman, A. M. E., B. Mashear, A. Mohammed, and O. Ali. 2013. Physicochemical and sensory properties of traditionally and laboratory made ghee (*Samin*) of the Sudan. *International Journal of Food Science and Nutrition Engineering*, 3(1): 7-11.

Thirumarimurugan, M., V. M. Sivakumar, A. M. Xavier, D. Prabhakaran, and T. Kannadasan. 2012. Prepartion of biodiesel from sunflower oil by transeterification. *International Journal of Bioscience and Bioinformations*, 2(6): 441-444.

Toscano, G., and Maldini, E. 2007. Analysis of the physical and chemical characteristics of vegetable oils as fuel. *Journal of Agricultural Engineering* 38(3):39-47. https://doi.org/10.4081/jae.2007.3.39.

Tulashie, S. F., P. Kalita, F. Kotoka, O. K. Segbefia, and Quarshie, L. 2018. Biodiesel production from shea butter: A suitable alternative fuel to premix fuel. *Materialia*, 000(2018): 1-7.

Verma, D., J. Raj, A. Pal, and M. Jain. 2016. A critical review on production of biodiesel from various feedstocks. *Journal of Scientific and Innovative Research*, 5(2): 51-58.

Vilas, G. S., and H. Raheman. 2005. Biodiesel production from Mahua (*Madhuca indica*) oil having high free fatty acids. *Biomass and Bioenergy*, 28(4): 601-605.

Yahaya, A. T., O. Taiwo, T. R. Shittu, L. E. Yahaya, and C. O. Jayeola. 2012. Investment in cashew kernel oil production; Cost and return analysis of three processing methods. *American Journal of Economics*, 2(3): 45-49.