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Synthesis and Characterization of Biodiesel and Its Blends from Palm Kernel Oil (*Elaeis guineensis*) as a Renewable Energy Alternative

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Abstract

This study aims to examine a sustainable source of energy from environmentally friendly and renewable resource. Crude palm kernel oil (CPKO) obtained from kernel of African oil palm (*Elaeis Gunieensis*) was transesterified into biodiesel using alcohol (methanol) and base catalyst (sodium hydroxide) to produce 80.6% PKO methyl ester (biodiesel). Biodiesel produced was blended with diesel fuel in various proportions. Physiochemical properties of biodiesel produced, and its blends evaluated according to American Society for Testing and Materials (ASTM D6751). The results showed that; most of Physiochemical properties of PKO biodiesel and its blends were met the requirements of ASTM standard methods.

Keywords: Environmentally Friendly, Crude Palm Kernel Oil, Transesterified, Biodiesel, Physiochemical Properties, ASTM.

INTRODUCTION

Environmental pollution challenges and high energy demand for fossil diesel are the important key factors leading to search for the alternative renewable energy sources and environmentally friendly (Maulidiyah M *et al*., 2022). In recent years, scientific researchers' interest in one of the most important alternative energies to fossil diesel is biodiesel. Due to its renewable, non-toxic and bio-degradable (Meme L *et al*., 2024). Biodiesel defined as a mono alkyl ester of long chain fatty acids derived from renewable feedstock such as vegetable oils, non-vegetable oils and animal fats. Vegetable oils include edible and non-edible oils are renewable feedstock for biodiesel production. Soybean oil, palm oil, sunflower oil, rapeseed seed oil, jatropha seed oil, rubber seed oil and watermelon oil were some sources of the oils which been used in biodiesel production. Several technologies have been utilized to produce biodiesel from renewable feedstocks, including pyrolysis, supercritical alcohol, micro-emulsification, and transesterification. All these technologies have demonstrated the ability to produce high-quality biodiesel (Samuel K *et al*., 2024). However, transesterification remains the most widely used process for biodiesel production from oils and animal fats (Jane A *et al*., 2024). This process involves the reaction of triglycerides with an alcohol (methanol or ethanol) in the presence of an acid or alkaline catalyst, resulting in the formation of fatty acid alkyl esters (biodiesel) and glycerol, as illustrated in Fig. 1. The choice of catalyst depends on the fatty acid composition of the feedstock used (Marwan A *et al*., 2021).

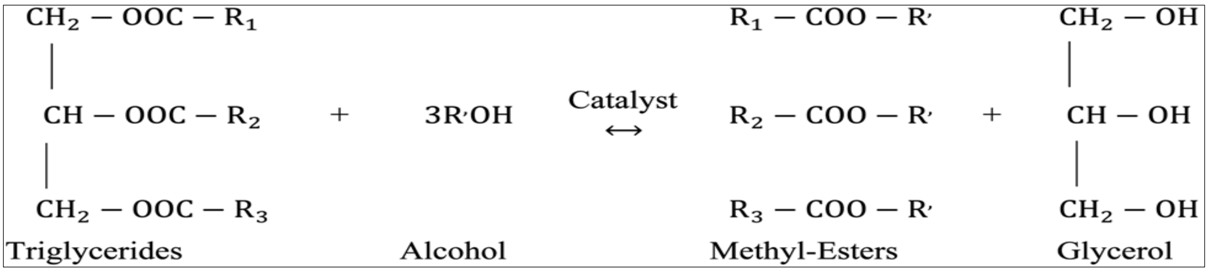

Figure 1: Transesterification reaction of vegetable oils or fats

Alkaline transesterification is not recommended for feedstock oils having over 2% FFAs; the alkaline catalyst reacting with FFAs and creates soap, hence consumes catalyst required for transesterification, resulting in an incomplete reaction and reduces the biodiesel yield. In such case a two-step transesterification process is recommended: acid esterification to decreasing FFAs (1% –2%) followed by alkali transesterification to obtain a higher yield of biodiesel (Abdul Haq *et al*., 2023).

Biodiesel can be used without blending (as B100) or blended with conventional diesel fuel in various proportions to improve the efficiency of compression engines. Biodiesel is produced from different feedstocks of varying origin and quality; it was necessary to install a standardization of fuel quality to ensure engine performance. American Standard for Testing Materials (ASTM) has established standard requirements ASTM D6751 for biodiesel fuel blend Stock (B100) as shown in “Table 1”, and ASTM D7467 for biodiesel blends (B6 to B20). Blends of B5 and lower are acceptable under the standard specifications for diesel fuel, ASTM D975. The European Committee for Standardization (CEN) also has established standard specifications for B100, called EN 14214(Samuel K *et al*., 2024).

Table 1: ASTM 6751 Standard Specification for Biodiesel Fuel Blend Stock (B100)

No.	Property	Unit	Test Method	Limit
1	Flash point	ºC	ASTM D93	Min. 130
2	Water and sediment	%	ASTM D2709	0.050
3	Kinematic viscosity at 40°C	mm^2/s	ASTM D445	1.9 - 6.0
4	Copper Strip Corrosion	-	ASTM D130	Max. No.3
5	Cetane number	-	ASTM D613	Min. 45
6	Pour point	°C	ASTM D97	Report
7	Cloud point	°C	ASTM D2500	Report
8	Acid number	mg KOH/g	ASTM D664	Max. 0.5
9	Carbon residue	%	ASTM D4530	Max.0.050
10	Sulfated ash	%	ASTM D874	Max.0.020
11	Free glycerin	%	ASTM D6584	Max.0.02
12	Phosphorus	%	ASTM D4951	Max.0.001
13	Distillation temperature	°C	ASTM D1160	Max. 360

The African oil palm (*Elaeis Gunieensis*) initially originated in Africa in the tropical rainforest region of West Africa (Farhatun M *et al*., 2020), now expanded worldwide due to its multipurpose such as food, medicine and biotechnological applications (Panugalla R *et al*., 2022). Palm fruits bunches contain two types of oil; crude palm oil (CPO) extracted from mesocarp, and crude palm kernel oil (CPKO) extracted from the kernel (Denis J *et al*., 2021). Due to their high yields, good properties and availability; palm oil and palm kernel oil were promising sources for biodiesel production (Anetokhe, M *et al*., 2023).

This study focuses on producing biodiesel from crude palm kernel oil, examining its physicochemical properties and suitability for biodiesel ASTM standards, and analyzing the impact of blending it with conventional diesel to improve performance and efficiency as a sustainable, environmentally friendly alternative.

MATERIALS AND METHODS

Materials

Crude palm kernel oil was previously extracted from kernel of African oil palm by soxhelet extraction method. All chemicals used were analytical grade.

Methods

Transesterification Reaction

Transesterification reaction was carried out in 500 ml flask. The CPKO was heated to 50-55℃ and stirred at 250 rpm with mechanical stirrer in a hot plate. Sodium hydroxide 0.5% based on oil weight was dissolved in the required amount of methanol (6:1 methanol to oil) and added to the oil. The reaction was conducted for 120 min. The resulting product was taken into a separating funnel and stand for 12 hours. Two phases were distinct: biodiesel on the top and the glycerol at the bottom. The two phases were separated. The biodiesel was then washed twice by using de-ionized water to remove impurities like soap. Finally, the biodiesel was heated to 110°C, for 1 hour to remove the moisture (T. Ahilana *et al*., 2024).

Biodiesel Blending

The biodiesel obtained after transesterification was blended with diesel obtained from fuel station at different proportions. Two blends of biodiesel-diesel were prepared and namely as B5 (5% biodiesel and 95% diesel) and B20 (20% biodiesel and 80% diesel). Additionally, one blend of biodiesel-ethanol-diesel was prepared, and named B20E20D60 (20% biodiesel, 20% ethanol and 60% diesel).

Physiochemical Properties of Palm Kernel Oil Biodiesel

The physiochemical properties of PKO biodiesel and its blends; including free fatty acid, total acid number, iodine value, water content and saponification value were determined according to AOAC methods (2005). Color, kinematic viscosity at 40 ºC, cloud point, pour point, flash point, density at 15ºC, copper strip corrosion and cetane number were determined according to ASTM methods, and results shown in Table 2 and Table 3.

RESULTS AND DISCUSSIONS

Biodiesel Production

PKO biodiesel produced successfully through base catalyst transesterification process; the yield obtained was 80.6%. Fig. 2 shows Produced biodiesel.

Figure 2: PKO biodiesel produced

Physiochemical Properties of Palm Kernel Oil Biodiesel

The physiochemical properties of PKO biodiesel were determined and the results shown in Table2.

Viscosity is most important factor for biodiesel to ensure that it meets diesel engines requirements of operation. The lower the viscosity of a fuel, the easier the flow of the fluid in an engine, thus good injection (Maulidiyah M *et al*., 2022). The kinematic viscosity@ 40ºC of PKO biodiesel was found 3.92 cSt which is higher than that of palm kernel oil biodiesel determined by (Meme L *et al*., 2024), and watermelon waste oil biodiesel studied by (Ejiro T, Samuel O, 2020) which was found 2.84 cSt and 3.32 cSt respectively, and lower than that of Almond oil biodiesel obtained by (Ketema B *et al*., 2022) which was found 26.59 cSt. This value obtained in this study close to 3.95 cSt of palm kernel biodiesel determined by (Anetokhe *et al*., 2023), and within specified range of ASTM D6751.

Table 2: physiochemical properties of PKO biodiesel in comparison with biodiesel from other feedstocks according to ASTM D6751

TESTS	ASTM D6751	PKO biodiesel (this study)	Almond oil biodiesel [a]	Palm kernel oil biodiesel	Watermelon waste oil biodiesel
Color, ASTM	-	0.0	-	-	-
Kinematic Viscosity at 40ºC, cSt	1.9-6.0	3.92	26.59	2.84	3.32
Cloud Point, °C	Report	9.6	16	1	9.5
Pour point, °C	Report	-3	11	-6	8.3
Flash Point, °C	Min. 93	138	212	134.0	-
Free Fatty Acids, %FFA	-	0.18	-	-	-
Density at15ºC, g/ml	-	0.8595	0.9	0.865	0.884
Total Acid Number, mg KOH g^{-1}	0.50	0.36	-	0.421	0.35
Water Content, wt%	0.050	0.01	-	-	-
Iodine value (mg/g^{-1})	-	60.36	76.65	20.21	64.5
Saponification value, mg/KOH g^{-1}	-	202	-	-	185.6
Copper Strip Corrosion (3Hours at 100°C)	Max. 3	1B	-	2B	-
Cetane number	Min.45	59.7	-	59.04	-

The two most critical properties of the biodiesel are the cloud point and pour point. The cloud point represents the temperature at which the wax first observed when fuels are cooled. The pour point is the lowest temperature at which the fuel can flow (Abdul Haq *et al*., 2023). The cloud point of PKO biodiesel found 9.6°C which was close to 9.5 ºC of watermelon waste oil biodiesel reported by (Ketema B *et al*., 2022), and which is higher than that of palm kernel oil biodiesel evaluated by (Meme L *et al*., 2024) which was found 1 °C. The pour point of PKO biodiesel was found -3ºC which is lower than that of Almond oil biodiesel and watermelon waste oil biodiesel which were found 11°C and 8.3 °C respectively (Ejiro T, Samuel O, 2020), (Ketema B *et al*., 2022).

The flash point of the fuel is the least temperature at which its vapor got ignited upon contact with an ignition source (Joseph V *et al*., 2024). Biodiesel with high value of flash point, is an indicator its highly safe during storage and transportation (Meme L *et al*., 2024). PKO biodiesel showed flash point of 138.0°C which is higher than that of palm kernel oil biodiesel reported by (Meme L *et al*., 2024) which was found 134 °C, and which is lower than that of Almond oil biodiesel evaluated by (Ejiro T, Samuel O, 2020) which was found 212 °C. This value within acceptable limit of ASTM D6751 standard for biodiesel.

Density is one of the principal fuel properties used to determine the quantity of fuel injected to provide proper combustion (Samuel K *et al*., 2024). Same factors effect on density of the biodiesel fuels; like feedstock used and fatty acids profile of feedstock. Biodiesel produced from saturated fatty acids has a lower density comparison to biodiesel made from unsaturated fatty acids (Joseph V *et al*., 2024). The density value at 15ºC of PKO biodiesel was found 0.8595 g/ml which is close to 0.865 g/ml of palm kernel biodiesel reported by (Meme L *et al*., 2024), and lower than that of Almond oil biodiesel and watermelon waste oil biodiesel which were found 0.9 g/ml and 0.884g/ml respectively (Ejiro T, Samuel O, 2020), (Ketema B *et al*., 2022).

Acid number shows the quantity of free fatty acids (FFAs) in the fuel sample (Abdul Haq *et al*., 2023). PKO biodiesel showed total acid number of 0.36 mg KOH g^{-1} which is close to 0.35 mg KOH g^{-1} of watermelon waste oil biodiesel determined by (Ketema B et al., 2022). This value within the range of ASTM D 6751which is maximum 0.5 mg KOH g^{-1}.

In a diesel engine, a high water content can cause corrosion and enhance the hydrolysis reaction of biodiesel, leading to the formation of fatty acids. These acids can further contribute to the corrosion of engine parts (Alexandre C *et al*., 2021). The water content of PKO biodiesel evaluated 0.01% showed conformance to the ASTM D6751 standard (0.05% max).

The iodine value represents the number of double bonds in the fatty acids of biodiesel. A higher number of double bonds leads to a higher iodine value, making the biodiesel more susceptible to oxidation (Maulidiyah M *et al*., 2022). The PKO biodiesel showed an iodine value of 60.36 mg/g, indicating a low number of double bonds due to the high degree of saturation in the oil used. As a result, the produced biodiesel exhibits high oxidative resistance, making it a suitable alternative fuel for diesel engines.

The saponification value (SV) is the amount of KOH (in mg) required to completely saponify a given amount of biodiesel. It indicates the presence and amount of fatty acids (Ketema B *et al*., 2022). The PKO biodiesel has a saponification value of 202 mg KOH/g, which is lower than the 226 mg KOH/g reported for palm kernel biodiesel by (Johnson O *et al*., 2015). This lower value suggests a lower free fatty acid content in the PKO biodiesel, which was found to be 0.18% in this study.

The Copper Strip Corrosion test is one of the key parameters used to evaluate biodiesel corrosion. Several factors influence the extent of corrosion, including water content, acid number, level of unsaturation, storage temperature, and the presence of metallic ions. These factors can reduce biodiesel shelf life and increase corrosion (Alexandre C *et al*., 2021). The Copper Strip Corrosion test result for PKO biodiesel at 100ºC was 1B, which is below the maximum limit of 3 set by ASTM D6751. This indicates that PKO biodiesel is safe for use in engines.

The cetane number (CN) is an important parameter for diesel fuel, used to measure its ignition quality. It represents the interval between the beginning of injection and the start of combustion (Samuel K *et al*., 2024). The cetane number of PKO biodiesel was found to be 59.7, which is close to the 59.4 reported for palm kernel biodiesel by (Meme L *et al*. 2024). This value falls within the acceptable range of ASTM D6751.

Characterizations of PKO Biodiesel Blends

The physiochemical properties of PKO biodiesel blends ware determined and the results shown in Table 3.

The results showed that the effect of blends on the color of PKO biodiesel decreased as the percentage of PKO biodiesel in the blend increased. The density @15ºC of B20E20D60 blend and B20 blend are very close which were 0.8251g/ml and 0.8264g/ml respectively. The density of B5 blend is very close to of diesel fuel which were 0.8191g/ml and 0.8170g/ml respectively; and within the range of ASTM D975 for diesel fuel.

Table 3: physiochemical properties of PKO biodiesel blends

TESTS	ASTMD7467	ASTM D975	B20E20D60	B20	B5	Fossil Diesel
Color, ASTM	-	-	1	1	2	0.5
Density @15ºC, g/ml	-	0.820 - 0.860	0.8264	0.8251	0.8191	0.8170
Kinematic Viscosity @ 40ºC, cSt	1.9-4.1	2 - 4.5	2.73	2.7	2.47	2.55
Cloud Point, °C	-	-15 to -5	18	14	18	-12
Pour point, °C	-	-35 to -15	-6	-12	-6	-3
Flash Point, °C	Min 52	60 - 80	63	83	73	79
Total Acid Number, mgKOH/g	Max 0.03	-	0.06	0.023	0.045	-
Water Content, wt%	Max 0.05	Max 0.05	0.29	0.0038	0.0017	-
Copper Strip Corrosion (3 Hours @100ºC), Rating	Max 3	Max1	-	1B	1B	-

Kinematic viscosity @ 40ºC of B20E20D60 blend and B20 blend are very close which were 2.73 cSt and 2.7 cSt respectively. Kinematic viscosity of B5 blend and diesel fuel which were founded 2.7 cSt and 2.55 cSt respectively; and within the range of ASTM D7467 and ASTM D975 Standards. From these results, Kinematic viscosity increases as the percentage of biodiesel in the blends increases, PKO biodiesel showed highest value of kinematic viscosity which is 3.92 cSt.

Cold properties (cloud point and Pour point) have no specification limits in the ASTM standard specification. These results showed that; cloud point and Pour point of B20E20D60 blend and B5 blend are similar which were 18 °C and -6 °C respectively; and higher than of B20 blend which were 14°C and -12°C respectively.

B20 blend showed highest flash point compere with B20E20D60 blend and B5 blend which were 83°C, 63°C and 73°C respectively. These values of flash point of B20E20D60 blend and B20 blend within the range of ASTM D7467, the flash point of B5 blend within the range of ASTM D7467 and ASTM D975 for diesel fuel.

Copper strip corrosion result of B20 blend was found 1B which is below the maximum limit of ASTM D7467 which is number 3. This good result of copper strip corrosion indicating also low content of acid number and water content of B20 blend obtained in this study which were founded 0.023 mg KOH/g and 0.0038 % respectively; that is mean the use of B20 safe for the engines. Acid number and water content of B20E20D60 blend had not met the standard requirements; which were found 0.06 mg KOH/g and 0.29% respectively; Water content and acid number are two of several factors that influence the extent of corrosion (Alexandre C *et al*., 2021). B5 blend showed a Copper Strip Corrosion result of 1B, which is within the limits of ASTM D7467 and ASTM D975.

CONCLUSIONS

PKO biodiesel was successfully synthesized using base-catalyst transesterification process. Physiochemical properties of biodiesel produced were determined, and results showed that, the produced biodiesel met the requirements of STM D6751 for biodiesel.

- B20 blend had met all the requirements of ASTM D7467 for biodiesel blend.
- B20E20D60 blend had met the requirements of ASTM D7467 except acid number and water content.
- B5 blend had met all the requirements of ASTM D975 of fossil fuel.

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