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Full Length Research Paper

Characterization of palm-kernel oil biodiesel produced through NaOH-catalysed transesterification process

O. J. Alamu[1]*, T. A. Akintola[2], C. C. Enweremadu[3] and A. E. Adeleke[1]

[1]Department of Mechanical Engineering, University of Agriculture, PMB 2240, Abeokuta, Nigeria.
[2]Olabisi Onabanjo University, Ibogun Campus, Ogun State, Nigeria.
[3]Ladoke Akintola University of Technology, Ogbomoso, Nigeria.

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Palm kernel oil (PKO) biodiesel was produced through transesterification of PKO with ethanol using sodium hydroxide (NaOH) catalyst. The biodiesel was characterized as alternative fuel for diesel engine through ASTM standard fuel tests. The transesterification process using 100 g PKO, 20.0% ethanol (wt% PKO), 1.0% NaOH, 60°C reaction temperature and 90 min reaction time yielded average 95.8% PKO biodiesel for three replications. Fuel tests conducted on the biodiesel showed 85.06% reduction of viscosity over its raw PKO at 40°C. Higher specific gravity, cloud and pour points were obtained compared to that of petroleum diesel. Results obtained are in good agreement with published data for other vegetable oil biodiesel as well as various international standards for biodiesel fuel.

Key words: Fuel, ethanol, palm kernel oil, biodiesel, renewable energy.

INTRODUCTION

Modern biofuels have been reported as a promising long-term renewable energy source which has potential to address both environmental impacts and security concerns posed by current dependence on fossil fuels (Batidzirai et al., 2006; Alamu et al., 2007a; Gupta et al., 2007). Fossil fuels such as petroleum, coal and natural gas, which have been used to meet the energy needs of man are associated with negative environmental impacts such as global warming (Munack et al., 2001; Saravanan et al., 2007). Besides, supply of these non-renewable energy sources is threatening to run out in a foreseeable future (Sambo, 1981; Munack et al., 2001). It has been widely reported that not less than ten major oil fields from the 20 largest world oil producers are already experiencing decline in oil reserves. Recently published data also revealed a total of 29 major world oil producing countries already experiencing declining oil reserves from year 2005 to 2007 (EIA, 2007; Alamu et al., 2007a).

In comparison to petroleum-based fuels, biodiesel offered reduced exhaust emissions, improved biodegradability, reduced toxicity and higher cetane rating which can improve performance and clean up emissions. Typical biodiesel produces about 65% less net carbon monoxide, 78% less carbon dioxide, 90% less sulphur dioxide and 50% less unburnt hydrocarbon emission (Margaroni, 1998; Ryan et al., 1982; Knothe and Steidley, 2005; Krahl et al., 2006).

The search for renewable energy resources continues to attract attention in recent times. It has been reported that in diesel engines, vegetable oils can be used directly as fuel, or as blend with petroleum diesel (Gupta et al., 2007; Math, 2007). However, due to high viscosity of these oils, poor fuel atomization occurs in CI engines resulting in improper fuel-air mixture and inefficient combustion (Bari et al., 2002; Saravanan et al., 2007). The problem also manifests in injector coking, engine deposits and thickening of lubricants during extended operation of the engine (Ryan et al., 1982; Alamu et al., 2007a). The high viscosities of vegetable oils are however reduced through the process of transesterification.

Satisfactory results have appeared in the literature on production of biodiesel through transesterification of different kinds of vegetable oil from different parts of the world. Such feedstock include soybean (US), rapeseed (Europe), oil palm (South-East Asia), jatropha curcus and rice bran oil (India). Biodiesel from canola, waste restau-

*Corresponding author. E-mail: tolasum@yahoo.com.

Table 1. Fatty acid profile of PKO.

Type of fatty acid	Percentage
Lauric (C12:0)	48.2
Myristic (C14:0)	16.2
Palmitic (C16:0)	8.4
Capric (C10:0)	3.4
Caprylic (C8:0)	3.3
Stearic (C18:0)	2.5
Oleic (C18:1)	15.3
Linoleic (C18:2)	2.3
Others (unknown)	0.4

rant oil as well as animal fats have also been used in the existing CI engines without any modification (Al Widyan and Al Shyoukh, 2002; Chitra et al., 2005; Krahl et al., 2006; Gupta et al., 2007; Saravanan et al., 2007).

Palm kernel oil (PKO) is one lauric vegetable oil (Table I) in Nigeria, which had hitherto been underutilized as edible oil. Available records however ranked Nigeria as one of the world producers of palm kernel. Between 1995 and 1998, Nigeria's share in the world production of palm kernel were 0.27, 0.26 and 0.25 million metric ton for 1995/96, 1996/97 and 1997/98 production seasons respectively. This record placed Nigeria next to Malaysia and Indonesia, and ahead of PKO producing countries like Cote d'ivore, Colombia, Thailand, Zaire and Equador (Alamu et al., 2007a, b).

Limited studies were however found in the literature on production and testing of biodiesel from Nigerian lauric oils. Abigor et al. (2000) produced biodiesel from palm kernel oil and coconut oil by transesterification of the oils with different alcohols using PS30 lipase catalyst. From a few recent works published on this subject, potassium hydroxide catalyst was used for the transesterification process (Alamu et al., 2007a, b; Alamu et al., 2008). In this work, biodiesel was produced through transesterification of PKO with ethanol using NaOH (alkali) catalyst. The PKO biodiesel produced was further characterized as alternative diesel fuel through ASTM standard tests for basic fuel properties such as specific gravity, viscosity, pour point and cloud point.

MATERIALS AND METHODS

By stoichiometry, 1 mole of PKO is required to react with 3 moles of ethanol to produce 3 moles of the biodiesel and 1 mole of glycerol. Values for different parameters used are results of preliminary experiments and previous works (Ma et al., 1998; Alacantara et al., 2000; Chitra et al., 2005; Alamu et al., 2007a, b; Gupta et al., 2007; Alamu et al., 2008).

Palm kernel oil was purchased at the local market in Onitsha, Nigeria. 100 g PKO was used for the transesterification process. The ethanol used (99% pure) is an analytical grade with boiling point of 78°C; while the NaOH used was also an analytical grade product of Aldrich Chemicals, England. The blender used was a Dry and Wet mill Blender with a clear glass (1,250 cc capacity) containers and stainless steel cutting blades. Other major materials used include scales, translucent white plastic container with bung and screw-on cap, funnels, PET bottles and thermometer.

Experimental procedures

20.0 g of ethanol was measured and poured into a plastic container after which 1.0 g of NaOH was carefully added. The container was swirled round thoroughly for about 2 min repeatedly about six times for complete dissolution of NaOH in the ethanol to form sodium ethoxide.100.0 g of PKO was measured out, pre-heated to 60°C in a beaker and poured into the blender. Sodium ethoxide from the plastic container was carefully poured into the PKO, the blender lid was secured tightly and the blender switched on while agitation in the blender was maintained for 90 min.

The mixture was poured from the blender into a PET bottle for settling and the lid was screwed on tightly. The reaction mixture was allowed to stand overnight while phase separation occurred by gravity settling. The PKO biodiesel was carefully decanted into a PET bottle leaving the glycerol at the base. The biodiesel was washed with water adopting the method earlier reported (Alamu et al., 2007b; Alamu et al., 2008).

The procedure was replicated three times and average biodiesel yield as well as glycerol yield was measured on weight basis.

Biodiesel fuel characterizations

ASTM standard fuel tests were conducted on the PKO biodiesel and low sulphur diesel fuel purchased at a fuel station in Iwo, Nigeria. Specific gravity and viscosity measurements were made using the Thermal-Hydrometer apparatus and Viscometer (Canon-Fenske Calibrated, 15cSt max. range), following ASTM standards D1298 and D445 respectively. The biodiesel was analyzed for cloud point and pour point using Baskeyl Setapoint cloud and pour point apparatus following ASTM standards D25100-8 and D97 respectively. Procedures for these tests have been reported (Alamu et al., 2008).

RESULTS AND DISCUSSION

Transesterification process

The transesterification process yielded 95.8 g PKO biodiesel and 22.4 g glycerol, while 2.8 g of the total reacting masses could not be accounted for. These losses have been attributed to some un-reacted alcohol, residual catalyst and emulsion removed during the washing stage of the production process (Alamu et al., 2007a, b). The results stated are averages of three different experimental runs. Detailed results for each of the experimental runs are as presented in Table 2. Economic considerations showed positive results as cost per kilogramme of the biodiesel was found to be less than that of fossil diesel. Besides, the major feedstocks are renewable agricultural products (Alamu et al., 2007a; Alamu et al., 2008).

Fuel characterization

The laboratory scale PKO biodiesel produced and the commercial grade petroleum diesel were analyzed for

Table 2. Results for the transesterification experiment.

Experimental Conditions	1st Run	2nd Run	3rd Run	Average
Reaction temperature (approximated) (°C)	60	60	60	60
Reaction time (min.)	90	90	90	90
Palm kernel oil (PKO) quantity (g)	100	100	100	100
Ethanol quantity (g)	20.00	20.00	20.00	20.00
NaOH (catalyst) concentration* (%)	1.00	1.00	1.00	1.00
PKO biodiesel obtained (g)	96.20	95.30	95.90	95.80
Glycerol obtained (g)	22.40	22.60	22.20	22.40
Losses (g)	2.40	3.10	2.90	2.80
PKO biodiesel yield (%)	96.20	95.30	95.90	95.80

*Weight % of 100 g PKO.

Table 3. Fuel characterization results for PKO biodiesel and petroleum diesel fuel.

Fuel Characteristics (Properties / Parameters)	(PKO biodiesel)	(Petroleum diesel)	EN14214 European biodiesel standard	Rapeseed * (Ethyl ester) biodiesel	Canola * (Ethyl ester) biodiesel
Viscosity (@ 40°C), (mm²/s)	4.839	2.847	3.50-5.00	6.170	4.892
Specific gravity (@ 60°F/60°F)	0.883	0.853	0.86-0.90	0.876	0.878
Pour point (°C)	2	-16	-	-2	-1
Cloud point (°C)	6	-12	-	-10	-6
Flash point (°C)	167	74	>120	124	177

*Peterson et al. (1990).

basic fuel properties. Results obtained are presented in Table 3. With raw PKO having viscosity 32.40 mm²/s as earlier reported (Abigor et al., 2000; Alamu et al., 2007a; Alamu et al., 2008), the PKO biodiesel viscosity obtained showed 85.06% reduction. This will enhance the biodiesel's fluidity in diesel engines. Higher specific gravity, pour point, and cloud point were obtained compared to that of petroleum diesel. At 15.56°C, specific gravity of PKO biodiesel was 1.033958 times that of fossil diesel. A comparison of specific gravity of PKO biodiesel with selected biodiesel from other oil crops is presented in Figure 1. Values obtained for other properties compared favourably with previous results in the literature (Peterson et al. 1990; Graboski, and McCormick, 1998; Abigor et al., 2000) for biodiesel from rapeseed, canola, beef tallow, soybean, frying oil and coconut oil as well as KOH catalysed PKO biodiesel (Alamu et al., 2007a; b; Alamu et al., 2008).

These values were also checked against various international standards for biodiesel including ASTM D6751 (US), EN 14214 (Europe) and BIS (India) as well as other plant-oil based biodiesel. Comparison made revealed good agreement as evident from Table 3 for EN 14214 standard as well as rapeseed ethyl ester and canola ethyl ester biodiesel.

The specific gravity obtained for the PKO biodiesel at 15°C falls within the limit specified by various international standards for biodiesel. EN14214 (Europe), ONC1191 (Austria), CSN656507 (Czech Republic), Journal Official (France), DINV51606 (Germany), UNI10635 (Italy) and SS155436 (Sweden) standards specify specific gravity ranges (0.86 - 0.9), (0.85 - 0.89), (0.87 - 0.89), (0.87 – 0.90), (0.875 - 0.9), (0.86 - 0.90) and (0.87 - 0.90) respectively for biodiesel fuel. From the results of this study, the specific gravity of 0.884 at 15°C obtained for the PKO biodiesel is in very good agreement with the above biodiesel standards.

Conclusions

From the production and fuel characterization of PKO biodiesel carried out, the following conclusions can be drawn: The transesterification process carried out using 100 g PKO, 20.0 g ethanol, 1.0% NaOH (by weight of PKO) at 60°C reaction temperature and 90 min reaction time yielded 95.8 g PKO biodiesel. At 15.56°C, specific gravity of PKO biodiesel is 1.033958 times that of fossil diesel. At 40°C, the PKO biodiesel had 85.06% reduction of viscosity over its raw vegetable oil. Higher pour (2°C), cloud (6°C) and flash (167°C) points were obtained for the PKO biodiesel compared to -12, -16 and 74°C respectively obtained for commercial grade fossil diesel fuel. The limited fuel characterization carried out demonstrated that the PKO biodiesel produced can fuel a diesel engine.

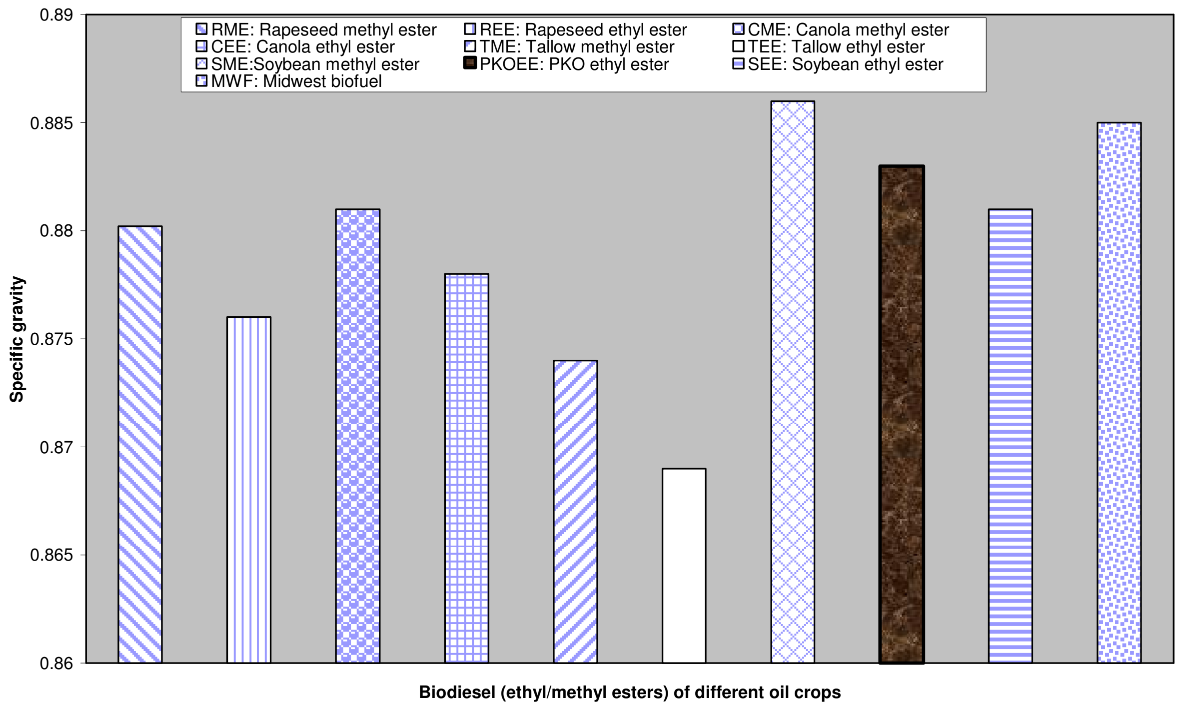

Figure 1. Comparison of specific gravity of PKO biodiesel with other biodiesel fuel at 15.56°C.

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