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Full Length Research Paper

Pig-fat (Lard) derivatives as alternative diesel fuel in compression ignition engines

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Prime steam lard obtained from pig fat by rendering was characterized and refined. The lard was transesterified with methanol and sodium hydroxide (as catalyst) at 40, 50, 60, and 70°C. Fuel properties of the fatty acid methyl esters (FAME) or biodiesel were determined alongside that of petroleum derived diesel obtained commercially. Results obtained showed that the saponification and iodine values of the lard were 198 and 64.08, respectively, while the flash point and viscosity were 203°C and 47.87 mm^2s^{-1}, respectively. While the refractive index of the methyl esters decreased with increase in temperature from 1.4480 to 1.4430 (1.4459 ± 0.0022), the specific gravity increased from 0.860 to 0.875. The flash point and the pH of the biodiesel samples were 134.25°C ± 1.71°C and 7.05 ± 0.03, respectively, and the viscosity was 4.23 ± 0.1 mm^2s^{-1}. The flash point, iodine value, viscosity, cetane index, and the specific gravity of the petrodiesel were 79°C, 84, 3.12, 46, and 0.84, respectively. The values obtained for the FAME are within the standard limits and compares well with that reported in the open literature. It can be used alone or in blends with petrodiesel to run compression ignition engines.

Key words: Pig fat, rendering, transesterification, fatty acid methyl esters, cetane index.

INTRODUCTION

Fatty acid methyl esters also known as biodiesel are mono-alkyl esters of long-chain fatty acids derived from lipids such as vegetable oils and animal fats, restaurant greases or used frying oils (Van Gerpen, 2005; Tapasvi et al., 2005; Dunn and Knothe, 2001). Large harvests of traditional crops, low farm prices, dependence on foreign energy sources and environmental problems due to combustion of fossil fuels have increased interests in renewable energy sources such as biodiesel (Tapasvi et al., 2005; Dunn and Knothe, 2001; Knothe and Steidly, 2005).

Vegetable oils were technically found to be suitable as diesel fuel because of their chemical structure (presence of long, saturated, unbranched hydrocarbon chains of fatty acids). The direct use of vegetable oils in compression ignition engines led to several problems such as fuel injector deposits, incomplete combustion and toxic substances formation as a result of their high viscosity amongst other factors (Ejikeme, 2008). Four methods, viz; dilution, thermal cracking, microemulsification and transesterification have been adopted to overcome the above problems and approximate the properties and performances of biodiesel to petro-diesel. Transesterification is the most popular method and it is used in both large and small scale productions.

Several environmental advantages of biodiesel as opposed to petro-diesel include its zero sulphur content and the consequent reduction in the SO_2 emissions, aromatic hydrocarbons and particulate emissions as well as reducing life-cycle of CO_2 emissions by over 78% as

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opposed to petrodiesel, (Sinha and Agarwal, 2005; Pinto et al., 2005; Van Gerpen et al., 2007; Graboski and McCormick, 1998). Chhetri et al. (2008) reported that total change in the environmental (Cn_t), economic (Ce_t), and social (Cs_t) capitals; $d(Cn_t)/dt \geq 0$, $d(Ce_t)/dt \geq 0$, and $d(Cs_t)/dt \geq 0$, respectively, were higher after the introduction of biodiesel use in set studies.

The use of animal fats in biodiesel production has been reported by several authors. Chung et al. (2009) reported 81.3% FAME content in a transesterification reaction involving duck tallow with methanol using NaOH catalyst. In a paper, Raine et al. (2008) reviewed the resource, production and engine performance of New Zealand tallow (beef/mutton fat) sourced biodiesel and concluded amongst other things, that unmodified engine performance was equal to that of the petro-diesel-fuelled engine when using blends up to 100% biodiesel. Biodiesel made from tallow using the very similar processes to plant oils have been shown to have higher cetane number, implying cleaner and more efficient burning in diesel engines than plant oils (Miller-Klein Associates, 2006) though exhibiting higher cloud points because of their higher level of saturates. Chicken fat amongst other fats/oils were used to produce biodiesel that met standard specifications (Mattingly et al., 2004; Mattingly, 2005). Standard biodiesel have been produced from varying grades of beef tallow and chicken fat (Babcock et al., 2007), and the kinetics of biodiesel production from Chinese tallow tree oil was studied by Crymble et al. (2006).

Meat, fat and bone meals which were fed to cattle and other domestic animals have been banned in developed countries as they have been implicated as the main route for the spread of bovine spongiform encephalopathy, BSE (mad cow diseases), which also did not spare human beings. More recently, bird and swine flu have also been reported to be ravaging birds and pigs in many countries (WhipNet Technologies (2009). Rendered fats from beef (tallow) and pigs (lard) as well as birds could be channeled to the production of fatty acid methyl esters which is used as either a substitute or is blend with the conventional petro-diesel. For instance, the amount of rendered fats produced in Austria in 2004 alone was 25,000 tons and life cycle analysis for biodiesel from rendered fats is better than for rapeseed oil methyl ester (Apel, 2006).

A major aim of this work was therefore to use pig fat (lard) obtained from Nsukka, Enugu State-Nigeria to produce FAME's and characterize same to ascertain its suitability or otherwise as diesel fuel substitutes.

MATERIALS AND METHODS

Methanol 99.7% purity was a product of Merck Darmstadt, Germany, while NaOH was a product of Loba Chemie GmbH, Switzerland. All other reagents are of analytical grade unless otherwise stated. Mixed pig fat was collected from the Slaughter house at Ogige Market, Nsukka, Enugu State, Nigeria as fat trimmings from meat cuts. It was rendered according to the modified method of Schneider (2006). The fat was chopped into small pieces of approximately 10 mm^2, put in a 5 L beaker with water of about a quarter the volume of the fat. The set up was heated gradually to boil with continuous stirring until the water evaporated completely. Further cooking led to the melting of the solid fat which was sieved through a sieve cloth, allowed to cool to about 50°C and water equivalent to twice the volume added and allowed to stand overnight to clarify some of the little protein bits. The thick slab of lard floating on the water was collected, dried, weighed and stored in a refrigerator for biodiesel production.

Biodiesel (FAME) production

The thick slab of lard obtained as described above was cut into small bits and melted over low and sustained heating procedure at 40°C. 180 cm^3 of the melted lard was put in the reaction vessel maintained at 40°C. 1.4 g NaOH dissolved in 138 cm^3 of methanol and heated to 40°C was added to the reaction vessel and stirred mechanically. The system was maintained at that temperature for 90 min and the reaction quenched by removing the vessel from the heating system and immersed in cold water. The methods of Ikwuagwu et al. (2000) as described elsewhere (Ejikeme, 2008) was used to separate the upper (biodiesel) layer from the lower (glycerol) layer. The methods of Journey to Forever as described by Alamu et al. (2007) was applied in the washing of the lower (biodiesel) layer for four times to completely remove the unreacted catalyst, etc.

Fatty acid methyl esters were also produced at temperatures of 50, 60, and 70°C. Some properties of the FAME's produced that were determined using standard methods include; flash point (ASTM D 93), heating value, iodine (ASTM D-1959-67) and pH values, refractive index (ASTM D 6751), viscosity (ASTM D 445) and specific gravity. The colour was determined by visual observation while the cetane index was calculated from the four variable equation of the ASTM (ASTM D 6751).

RESULTS AND DISCUSSION

Results of the various parameters measured at the various temperatures used in the transesterification process are given in Table 1. From the table, the yield of both the glycerol and the methyl esters did not vary significantly when students T test is applied to the values at 95% confidence interval or 0.05 level of significance. They are 24.00 ± 0.82 and 70.78 ± 1.71, respectively. The maximum yield of the methyl esters after 90 min. at 70°C was 73%. This value is 91% of the value (79%) reported by Xiu and Ting (2009) for fat melts of pig using 0.3 g SO_4^{2-}/TiO_2 heterogeneous catalyst and 1.5 g ethanol to 1 g of oil after 8 h. The yield obtained is though higher than 64.3 and 71% obtained with 210 ml/g and 250 ml/g, respectively of expanded graphite catalyst in the esterification of acetic acid with isoamyl alcohol (Xiu et al., 2008) by 13.2 and 2.8%, respectively. Chung et al. (2009) reported a percent conversion of 79.7, 62.3 and 79.3, respectively using KOH, NaOH and CH_3NaO catalysts in the transesterification of duck tallow with methanol. FAME content of their biodiesel at different temperatures did not vary significantly with temperature as observed in our work. At all the temperatures, the pH

Table 1. Yield of glycerol and biodiesel at different temperatures*.

T (°C)	Glycerol (%)	Ester (%)	Flash point (°C)	pH	Refractive index
40	25	69	132	7.03	1.4480
50	24	70	136	7.06	1.4470
60	24	71	135	7.03	1.4455
70	23	73	134	7.08	1.4430
Mean±SD	24.00±0.82	70.78±1.71	134.25±1.71	7.05±0.03	1.4459±0.0022

*SD = Standard deviation.

was almost constant with an average value of 7.05 ± 0.03. The reason for the near-neutral pH obtained at all temperatures is the number of washes that the methyl esters were subjected to. The refractive index varied by a value of 0.005 units only between the two extremes of temperatures studied.

The flash points recorded did not follow a specific trend with respect to the temperature. On the average, the flash point for methyl esters from lard as determined in this work was 134.25°C ± 1.71. Wörgetter et al. (2006) reported values as high as 169 and 182°C for animal fat and lard, respectively. The standard flash points in degrees Celsius for various countries are: >101 (Europe); >100 (Sweden, Italy, France and Austria); > 110 (Czech Republic and Germany); >120 (Australia) and >130 (USA-ASTM) (National Standards for Biodiesel 2009). The highest minimum standard value of >130 is comparable to the 134.25°C ± 1.71 obtained in our work and as such, it could be said that the flash point obtained from our work conformed to standard specifications. The value implies that less methanol was carried over from the production process.

Results of some of the fuel-related properties of the lard FAME, petrodiesel and ASTM standard values are given in Table 2. The specific gravity of 0.8668 obtained is greater than 0.859 reported for cotton seed oil methyl ester (Alhassan et al., 2005) and within the 0.86 to 0.90 ASTM standard specifications.

The viscosity of the product was 4.23 mm^2s^{-1}. Values of 4.14 and 4.54 mm^2s^{-1}, respectively at 40°C have been reported for animal fat and lard (Wörgetter et al., 2006), while Chung et al. (2009) reported kinematic viscosities of 5.5, 6.0 and 5.8 mm^2s^{-1} for duck tallow biodiesel using KOH, NaOH and CH_3NaO, respectively. The implication of the relatively low viscosity obtained in our work is that atomization of the biodiesel in the engine will be enhanced and the coking of the cylinders caused by highly viscous FAME may be averted by its use. The ASTM recommended viscosity range is 1.9 to 6.0 mm^2s^{-1} (National Standards for Biodiesel, 2009). The viscosity of the parent refined lard was reduced by about 91.2% in the lard methyl esters, thus obviating the problems associated with the use of underivatised and melted lard in powering diesel engines. Li and Li (2009) produced biodiesel from crude fish oil from the soapstock of marine fish and reported among other things greater kinematic viscosity than obtained for biodiesel from waste cooking oil. Mixtures of animal fats (beef tallow, choice white pork fat, poultry fat and yellow grease) with fuel oil exhibited rheological properties very near to those of pure petro-diesel than vegetable oil (Goodrum et al., 2003).

The calculated cetane index of the pig fat methyl ester was 54.8. This value is higher than 51.96 reported for soybean oil methyl esters (Ejikeme, 2008). Cetane number increases with increase in the number of carbon atoms for saturated carboxylic acids. This is exemplified by methyl caprylate (33.6); methyl caprate (47.7); methyl laurate (61.4); methyl palmitate (74.5) and methyl stearate (86.9) (Klopfenstein, 1985). The ASTM standard for cetane index is ≥ 40.

The presence of about 34% saturated fatty acids (20% palmitic and 16% stearic) in pig fat may have led to the relatively high value of cetane index obtained since the unsaturated components are mainly monounsaturated, oleic (~54%) and linoleic (~11%). Ikwuagwu et al. (2000) reported a cetane index value of 44.81 for rubber seed oil biodiesel. Rubber seed oil has a preponderance of unsaturated fatty acids relative to lard.

Generally, biodiesel from more saturated feedstocks have higher cetane numbers and better oxidation stability but poor cold flow properties (Van Gerpen et al., 2007). Either too high or too low a cetane number can cause operational problems (Knothe et al., 1997). In the former case, combustion can occur before the fuel and air are properly mixed resulting in incomplete combustion and smoke whereas in the latter case, engine roughness, misfiring, higher air temperatures, slower engine warm-up and incomplete combustion occurs.

The colours of vegetable and animal oils are usually transferred to the biodiesel made from them. This makes the use of synthetic dyes less important as opposed to petrodiesel which are colourless on fractionation from petroleum. The values of the fuel-related properties of the petrodiesel from Table 2 compares well with the pig fat methyl esters with respect to the benefits derivable from the use of biodiesel. The lower flash point of the commercial petrodiesel relative to the biodiesel produced is one of the advantages of the latter over the former in cases of accidents as stated earlier. The higher cetane index of the biodiesel means that its ignition temperature

Table 2. Fuel-related properties of pig fat biodiesel produced.

Properties	Refined lard	Biodiesel	Petro-diesel	ASTM values
Colour	Milkish yellow	Amber yellow liquid	Clear liquid	-
Sp. gravity	-	0.8668	0.8400	-
Viscosity (mm^2s^{-1}) (at 40°C)	47.87	4.23	3.12	1.9-6.0
Refractive index		1.4435	-	-
Flash point (°C) (D6751-07a)	206	134	79	≥93
Iodine value (mgI/g)	61.22	64.08	84	<125 (SS155436-96)
Cetane index		54.8	46	≥ 40
pH	6.75	7.05	-	-
Calorific value (kJ/g^{-1})	-	42.50	44.96	-
Saponification value (mgKOH/g)	198	-	-	-

is better than that of the commercial petrodiesel used for comparison. The higher calorific value of the petrodiesel implies that it has a little higher energy supply potential.

Also, the viscosities of both the petro- and biodiesel are not very different from each other. The viscosity of the latter is 1.356 times that of the former. This value is lower than the 1.684 to 1.712 times that of the petrodiesel reported for palm kernel oil biodiesel by Alamu in a PhD thesis submitted to the Mechanical Engineering Department of Ladoke Akintola University of Technology, Ogbomosho, Nigeria. The higher viscosity of biodiesel relative to petrodiesel has been reported to lead to decreased leakages of fuel in plunger pair as well as changing the parameters of fuel supply process (Lebedevas and Vaicekauskas, 2006). The reduction of overall cost of biodiesel was reported in a study using a mixture of 50% of both low grade animal fat and soybean oil (Canoira et al., 2008) and the biodiesel obtained were shown to have acceptable standards with a lower final cost.

Conclusions

i. The production of biodiesel from pig fat by transesterification with methanol and NaOH catalyst was assessed,

ii. The flash point, specific viscosity, cetane index and other fuel related properties of methyl esters of pig fat methyl esters are within the various limits provided for in the standards for biodiesel,

iii. The result of the present work therefore suggests that methyl esters which were produced using pig fat obtained from an abattoir in Nsukka could be used as biodiesel in running compression ignition engines,

iv. If the harvesting of this and other animal fats is properly organized in this part of the world, it could add to the energy mix and reduce the anticipated pressure in the use of edible vegetable oil in biodiesel production.

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