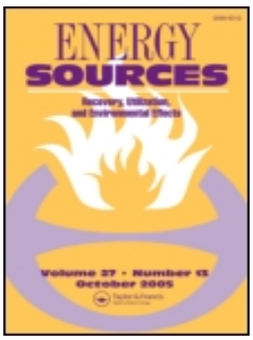

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Optimization of biodiesel production from waste cooking oil

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ABSTRACT

The sequences of development that cut across industrialization, population growth, environmental and economic reasons led individuals and organizations to have direct responsibilities in the development and implementation of sound technologies that will curtail the emissions of hazardous gases and particulate matter. As a result, this study focuses on the optimization and characterization of biodiesel from waste cooking oil. It involves the characterization of the feed stock, the transesterification, the purification of the transesterified waste cooking oil, the optimization of the biodiesel produced using 2^4 factorial experimental designs, and the characterization of the biodiesel produced from waste cooking oil. Result obtained reveals that operating temperature of 30°C, transesterification time of 60 min, catalyst weight of 0.5%, and alcohol to oil ratio of 6:1 are the optimum conditions with optimum yield of 90% of biodiesel from waste cooking oil. Experimental determinations of some useful properties of the biodiesel produced were carried out for the purpose of confirming the quality as well as the identification of the biofuel. These were moisture content, specific gravity, viscosity, acid value, sulfated ash, cetane number, cloud point, flash point, distillation characteristic, and refractive index. The results obtained were 0.097%, 0.854, 4.90 mm^2/s, 0.80 mgKOH/g, 0.01%, 48.00, 53°F, 143°C, 320°C, and 1.412, respectively. The results obtained showed that all the parameters compare favorably with literatures and the standard biodiesel specifications; hence production of biodiesel from waste cooking oil is possible.

KEYWORDS

Alternative energy; biodiesel; optimization and characterization; waste cooking oil

1. Introduction

Energy is globally regarded as an index for economic development and a fundamental requirement for human existence, a live-wire of transportation and industrial sustainability as well as electricity generation in conventional thermal power plants (Bugaje and Muhammad, 2008, 60). A high percentage of the world's total energy output is generated from fossil fuels, and experts suggested that the current oil and gas reserves are fast depleting, hence the need for an alternative source of energy for the transport, industrial, and domestic consumptions (Tapanes et al., 2008, 2289). The threat of supply instabilities and the increased public awareness on the impacts of fossil fuels emission on the environment and their potential health hazards have triggered governments around the world to impose restrictions on the emissions and the need for alternative energy sources (Tapanes et al., 2008, 2290). The quest for alternative energy sources by the researchers and government agencies led to the discovery that biofuel is a perfect alternative energy source that can compete with the fossil fuel in terms of efficiency and availability. The adoption of biodiesel as an alternative source of energy is favored by the fact that emissions from ignition that utilizes bio-diesel as energy source is very minimal compared with that of the fossils (Demirbas, 2008, 20). Biofuels such as biogas, bioethanol, and biodiesel are

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the most promising alternatives in energy generation and in curbing the menace of greenhouse gases (GHG) emissions – sulfur and its compounds, nitrogen and its compounds (Tapanes et al., 2008, 2290). Biodiesel is a mono-alkyl ester of fatty acids produced by the transesterification of vegetable oils or animal fats with methanol or ethanol as catalyst (Knothe and Steidly, 2005, 81). In a similar development, the production of biodiesel from waste vegetable cooking oil has been reported to be economical (Choloda, 2010, 1075). However, the inherent difficulties in gathering and processing hinder the use of waste cooking oil as a feedstock for biodiesel production. Despite the problems associated with gathering and processing, it is still considered the most economic feedstock because it constitutes what is termed as "environmental nuisance" (Choloda, 2010, 1075). Literatures revealed that production cost of biodiesel is generally influenced by the production method, feedstock, and production volume; however, production cost is sensitive to the cost of feedstock (Abdulkareem et al., 2010, 108). It is therefore imperative to consider availability and cost of feed stock in the production of biofuel. Each of the feed stock for the production of biofuel has its own merits and demerits (Abdulkareem et al., 2010, 108). For instance production of biofuel from vegetable oils gives good yield and qualities, but there is problem of food crisis associated with the production of biofuels from vegetable oils. Abdulkareem et al. (2010, 109) reported in their work that utilization of non-edible oil as a feed stock in the production of biofuel will help in resolving the sour relationship between the energy sectors and critics of production of biofuel from edible oil. This present study therefore focuses on production of biofuel from waste vegetable oil that constitutes nuisance to the environment during disposal. It also includes statistical analysis of the results obtained for the purpose of developing a statistical model for the process.

2. Methodology

The feedstock (waste cooking oil) was sourced locally from restaurant located in Minna, Niger state, Nigeria. The waste oil collected was filtered to remove particles of food in the oil during frying before further pre-treatment. After which the waste vegetable oil was analyzed to determine its basic properties. Prior to the production of biodiesel from waste vegetable oil, the oil sample was pre-treated by heating the sample at 100°C for 1.5 h in a hot plate. The transesterification process was based on two catalyst values of variation taken the lower level to be 0.5 wt% and the higher level to be 1 wt% of NaOH, and two reaction temperatures at 30 and 60°C, respectively; alcohol to oil molar ratio was taken to be 4:1 and 6:1. The pre-treated samples of used vegetable oil were measured in conical flasks of 50 ml each and were preheated to a uniform temperature. While a certain amount of sodium hydroxide and methanol was measured in another conical flask and allowed to dissolve. The dissolved solution of sodium hydroxide and methanol was then added to the preheated samples of oil and was kept in a water bath that has a shaker, at a required temperature and time, at a fixed stirring speed of 200 rpm for the reaction to take place. After the predetermined time of reaction, the mixture was transferred to a separating funnel and allowed to settle, by separating the biodiesel from the glycerol, overnight. The washing process was repeated until the ester layer became clear. For each washing process the pH of wash water and biodiesel layer were constantly measured until when a pH of 7 was reached. The biodiesel was heated to evaporate any water present. Optimization of the variable affecting the synthesis of methyl esters from waste vegetable oil was carried out using factorial design (2^4 factorial designs). The factors chosen are reaction time, reaction temperature, catalyst concentration, and alcohol to oil ratio, taking two levels to study the optimization process in the oil conversion as shown in Table 2. The produced biodiesel was then purified to remove alcohol, catalyst, entrained glycerol, soap, and other impurities that are present in the product; the process of purification includes washing and drying of the methyl ester. After which the biodiesel produced was characterized to determine its basic properties.

Table 1. Summary of waste vegetable oil properties in comparison with standard and literatures.

Properties	Unit	Experimental results	AOCS standard
Specific gravity	–	0.911	0.915_{max}
Density	g/cm^3	0.946	0.98_{max}
Moisture content	%	23.50	–
Iodine value	$gI_2/100$ g	86.00	100_{max}
Acid value	mgKOH/g	3.142	3.0_{max}
Saponification value	mgKOH/g	194.14	195_{max}
Unsaponification value	%	1.72	1.0_{max}
Free fatty acid	%	1.571	$<1.0_{max}$
Viscosity at 25°C	mm^2/s	–	–
Refractive index	–	1.461	–

3. Results and discussion

Prior to the production of biodiesel from waste cooking oil, the oil sample was characterized to determine its properties and the results obtained are presented in Table 1. Results obtained as presented indicate that iodine value and saponification values obtained for the waste cooking oil falls with the set standard by AOCS. While the unsaponifiable value, acid value, and free fatty acid of the waste cooking oil are higher than the set limit. High values of FFA of the waste cooking oil are an indication for the need of pre-treating the oil before production. Other qualities tested for and reported are the viscosity and moisture content of the waste vegetable oil, and results obtained indicate that the viscosity and moisture content of the waste vegetable oil are higher than the set limits. The variation in the values of refractive index can be attributed to the fact that the feedstock used in this study was waste vegetable oil.

3.1. *Optimization of process variables*

The effect of reaction parameters, namely temperature (°C), time (min) catalyst concentration (mole), and mole ratio (ratio) were investigated using 2^4 full factorial experimental designs. Each of the aforementioned parameters was considered at two specified intervals (upper and lower) and the results obtained are tabulated in Table 2. As shown in Table 2, the best biodiesel yield of 90% was obtained under the optimal conditions of temperature (30°C), time (60 min), catalyst concentration (0.5), and mole ratio (6:1). This value was better compared with 88 and 79% reported by Galadima et al. (2008, 142) and Ibeto et al. (2011, 801), respectively. The variation can be attributed the variation of process parameters employed, the variation in the properties of waste cooking oil, and the rigorous treatment undergone by the feedstock (frying) before it was subjected to transesterification.

Mole ratio of alkali to oil is one of the most important parameters that affect biodiesel production. To evaluate the effect of mole ratio on biodiesel yield, the transesterification process was conducted using two molar ratios (upper and lower) of 4:1 and 6:1. The stoichiometric ratio for all transesterification reactions require one mole of triglyceride and three moles of alcohol to yield three moles of fatty acid alkyl esters and one mole of glycerol (Gerpen, 2004, 1105). The optimum yields ranging from 88 to 90% were obtained at molar ratio of 6:1. As an equilibrium reaction, lower oil to alcohol ratio may result in an incomplete reaction and thus increasing the molar ratio will shift the reaction to the ester direction. However, when the molar ratio is set too high, the excessive alcohol favors the conversion of triglycerides to diglycerides and then monoglycerides and a slight recombination of esters and glycerol to monoglycerides because their concentrations keep increasing during the course of the reaction (Fillières et al., 1995, 430). This observation necessitates the need to investigate the influence of molar ratio on the yield of biodiesel. It can be observed from the results presented that the yield of biodiesel increased as the molar ratio of alcohol to oil increases from ratio 4:1 to 6:1 while keeping other parameters constant. The pattern of results obtained in this study conforms to the results reported by Abdulkareem et al. (2010, 112). Also investigated was the effect of temperature on the yield of biodiesel from waste cooking oil. Transesterification reactions occur at various

Table 2. Experimental and predicted responses of dependent variable (biodiesel yield) (Y).

				Methyl ester yield
Temperature, °C	Time, min	Catalyst concentration, mole	Mole ratio	Experimental results
30	30	0.5	4:1	86
60	30	0.5	4:1	80
30	60	0.5	4:1	78
60	60	0.5	4:1	68
30	30	1	4:1	66
60	30	1	4:1	72
30	60	1	4:1	76
60	60	1	4:1	80
30	30	0.5	6:1	88
60	30	0.5	6:1	82
30	60	0.5	6:1	90
60	60	0.5	6:1	88
30	30	1	6:1	84
60	30	1	6:1	78
30	60	1	6:1	80
60	60	1	6:1	87

temperatures depending on the type of feedstock used. Several research groups are of the opinion that the temperature increase influences the reaction in a positive way (Ma and Hanna, 1999, 12). For the purpose of optimization of this parameter, upper and lower level temperatures of 30 and 60°C were investigated. Results obtained indicate that the best yield (90%) was obtained at the lower temperature level (30°C). It is observed that at 30°C, the yields obtained at various experimental conditions were greater compared with those produced at 60°C. This is attributed to the fact that higher temperatures tend to evaporate reasonable quantities of the alcohol used during the transesterification reaction, thereby leading to a lower biodiesel yield (Anitha and Dawn, 2010, 15). To optimize the process of biodiesel production from waste vegetable oil, the influence of transesterification time was studied, and the results obtained are presented in Table 2 show that increase in time does not favor the yield of biodiesel. For instance, at operating parameters of 30°C, 6:1, 0.5 wt%, and 60 min the yield obtained was 90%. By keeping the operating parameters constant and varying the production time to 30.00 min, the yield was found to decrease by 8%. This observation was due to increased mixing and the dispersion of alcohol in the oil phase with time. It has been reported that increase in catalyst concentration favors the conversion of triglyceride and biodiesel. However, this phenomenon can only be attributed to the increase in the available number of catalytically co-active sites (Anitha and Dawn, 2010, 15). For the purpose of this study, upper and lower level catalyst concentrations (NaOH) were used. From the experimental results obtained, it is deduced that the best or optimum yield was obtained using 0.5 wt% (NaOH) at 30°C, 6:1, and 60 min of temperature, mole ratio, and time, respectively. Although the smaller the catalyst concentration, the lower the yield due to insufficient amount of catalyst to catalyze the transesterification reaction to completion, hence, this yield was attained due to excess alcohol used. Results presented in Table 2 indicate that the biodiesel yield was higher at a catalyst concentration of 0.5 wt% than 1.0 wt%. It was also observed that with catalyst concentration of 1.0 wt%, using the optimum operating conditions of temperature (30°C), mole ratio (6:1), and time (60 min), a low yield was obtained. Hence, low concentration of catalyst favors production of biodiesel from waste cooking oil. One advantage of using alkaline catalyst is that they give rise to a relatively fast reaction and thus low catalyst concentrations are required, that is, 0.5–2% (Lotero et al., 2009, 5560).

3.2. *Characterization of biodiesel produced*

The biodiesel produced from waste cooking oil was characterized to determine the basic properties and compared with standard and literature values and the results obtained are presented in Table 3.

Table 3. Properties of the biodiesel produced from waste cooking oil.

Properties	Unit(s)	Experimental results	ASTM (D 6751)	Petrol diesel
Specific gravity	–	0.854	–	0.86_{max}
Viscosity at 100°C	mm^2/s	4.90	6.0_{max}	16.5_{max}
Acid value	mgKOH/g	0.80	0.50	–
Moisture content	%	0.097	0.050	–
Sulfated ash	%	0.01	0.05_{max}	0.3_{max}
Cetane number	–	48.00	47_{min}	–
Cloud point	°F	53.00	–	–
Flash point	°C	143.00	130_{min}	66_{max}
Refractive index	–	1.412	–	–
Distillation characteristics	°C	320.00	<400	–
IBP	°C	130		
10		300		
50		308		
90		320		
FBP		330		

Specific gravity is an important parameter for fuel injection systems. High specific gravity causes excessive exhaust smoke thereby causing environmental pollution and global warming. The specific gravity of the biodiesel produced was 0.854 as shown in Table 3, this value falls within the range of 0.9_{max} recommended by the ASTM (D 975) (2012) and a little lower than 0.880 reported by Jimoh et al. (2012). However, the specific gravity obtained is a clear indication that the transesterification reaction has satisfactorily reduced the specific gravity of the feedstock used, from 0.911 to 0.854. Also tested for is the viscosity of the biodiesel which is described as the resistance of a fluid flow under gravity and it is an important parameter for the determination of optimum handling and storage. High value of viscosity can cause fuel flow problems and fuel pump failure (Jimoh et al., 2012). The viscosity of the used vegetable oil biodiesel produced was found to be 4.90 mm^2/s as shown in Table 3. This value falls within the range of 1.9–6.0 mm^2/s recommended by ASTM (DS 6751) standard (2012). However, the value reported in this study is lower compared with 5.86 mm^2/s reported by Jimoh et al. (2012). The viscosity value of 4.90 mm^2/s obtained in this study is a clear indication that the conversion process has significantly reduced the viscosity of the raw material from 6.0 to 4.90 mm^2/s. This increases the tendency with which the biodiesel flows in engines. Another property tested for is the acid value of the produced biodiesel. Acid value indicates the level of free fatty acids (FFAs) present in the biodiesel produced from waste cooking oil, as well as the presence of process acids and degradation by the products (Refaat et al., 2008, 79). The acid number correlates to the fuel's long-term stability and corrosion, hence, the smaller the value, the higher the quality of the biodiesel produced and vice versa. In this study, an acid value of 0.800 mgKOH/g was recorded, which is higher than the recommended ASTM (D 6751) standard (2012) of 0.5 mgKOH. However, this value is lower than 4.96 mgKOH/g reported by Ibeto et al. (2011, 800). The high acid value obtained for the biodiesel produced can be attributed to the possibility of high level of unsaturated matter in the waste cooking oil utilized as the feedstock in this study. The presence of water (moisture) in biodiesel beyond the standard limit always results in poor ignition, filter clogging, and fuel starvation, hence the need to evaluate the quantity of moisture in the produced biodiesel (Refaat et al., 2008, 79). As shown in Table 3, the standard maximum water content of biodiesel is 0.05% volume (Lotero et al., 2009, 5360). However, the moisture content of the biodiesel produced was 0.097% volume (Table 3). This value exceeds the standard by 0.047% volume and compares favorably with the value (0.081%) put forward by Galadima et al. (2008, 140). Sulfur content contributes significantly to engine wear, deposit, and emission. However, the effect of sulfur varies according to operating conditions. The sulfated ash content of the biodiesel produced from WVO was found to be 0.01% by weight (Table 3). This value (0.01 wt%) is very low compared with 0.05 wt% recommended by ASTM (2012). Hence, the biodiesel produced can be termed as "sulfur free" biodiesel. The cetane number is an important parameter that relates to the readiness of the

biodiesel to self-ignite when exposed to high temperatures and pressures in the diesel engine combustion chamber. It affects a number of engine performance parameters such as combustion, stability, drivability, white smoke, noise, and the emission of carbon monoxide (CO). It also indicates the relative fuel stability (Korbitz 1999, 81). The cetane number of the biodiesel produced was determined as 48.00 as shown in Table 3. This value is slightly above the ASTM (D6751) minimum standard which is 47. Hence, a slight ignition delay is expected when using the produced biodiesel in an automobile engine. Another important property of the biodiesel tested for is the cloud point, which is described as the temperature at which crystal agglomeration is extensive enough to prevent free pouring of fluid (Korbitz 1999, 81; Owen and Coley 1990, 400). The cloud point of the biodiesel produced was found to be 53°F. This conforms to ASTM (D975) standard of 58°F for petroleum-based diesel fuel. Hence, the biodiesel can be operational even in polar region where the temperature (atmospheric) is not less than 53°F. The flash point is described as the lowest temperature at which the biodiesel can be made to ignite momentarily in air. The flash point of the biodiesel produced was found to be 143°C, which is higher than the 130°C_{min} put forward by ASTM (D 6751) standard as shown in Table 3. Refractive index which is optical medium to measure the propagation of light through the biodiesel which helps in physical examination of sediments was also evaluated. Results indicate that the refractive index obtained was 1.412 at a wavelength of 550–600 rpm. This compares favorably with the refractive index put forward by Ibeto et al. (2011, 800), who reported a refractive index of 1.463. The difference being 0.051 is attributed to the fact that different feedstock have different physical and chemical properties, so also binding energies. Distillation characteristics is a tool to measure the ester content of biodiesel which can be used to determine the presence of other substances and in some cases meeting the legal definition of biodiesel. The value obtained at 90% recovery was 320°C as shown in Table 3, which compared favorably to literature values. Hence the biodiesel produced can be considered as an alternative energy source.

4. Conclusion

This study is focused on the optimization and characterization of biodiesel from waste cooking oil. Results obtained indicate that the production of biodiesel from waste vegetable oil is dependent on the transesterification time, temperature, catalyst weight, and mole ratio of oil to methanol. It can be inferred from the results obtained that production time of 60 min, temperature of 30°C, weight of catalyst of 0.5%, and alcohol to oil ratio of 6:1 are the optimal conditions for the production process with optimum yield of 90% of biodiesel. Results obtained on the characterization of the biodiesel produced indicate that the properties of biodiesel conform to the set standard and literature values. It can be inferred from the results obtained that biodiesel can be produced from waste cooking oil.

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References

Abdulkareem, A. S., Odigure, J. O., and Kuranga. M. B. 2010. Production and characterization of bio-fuel from coconut oil. *Energy Sour. Part A J.* 32:106–114.

America Society for Testing and Materials (ASTM International). 2012. Testing methods. 190 Howard St, Ste 404; Franklin, PA – USA 16323 – 2362, Info@wetestII.com (Accessed January, 2012) pp. 1–18.

Anitha, A., and Dawn, S. S. 2010. Performance characteristics of biodiesel produced from waste groundnut oil using supported heteropolyacids. *Int. J. Chem. Eng. and Appl.* 1:2010–0221, 261–265,

Bugaje, I. M., and Muhammad, I. A. 2008. *BioFuels Production Technology*. Zaria, Nigeria: Science and Technology Forum (STF). pp. 56–78.

Choloda, K., and Sathsporn, C. 2010. Methanol-based transesterification optimization of waste cooking oil over potassium hydroxide catalyst. *Am. J. Appl. Sci.* 7:1073–1078.

Demirbas, A. 2008. Progress and recent trends in biodiesel fuels. *Energy Convers. Manage.* 50:14–34.

Fillières, R., Benjelloun-Mlayah, B., and Delmas, M. 1995. Ethanolysis of rapeseed oil: Quantitation of ethyl esters, mono-, di-, and triglycerides and glycerol by high performance size-exclusion chromatography. *JAOCS* 72:427–432.

Galadima, A., Garba, Z. N., and Ibrahim, B. M. 2008. Homogeneous and heterogeneous transesterification of groundnut oil for synthesizing methyl biodiesel. *Int. J. Pure Appl. Sci.* 2:138–144.

Gerpen, V. J. 2004. Biodiesel processing and production. *Fuel Process. Technol.* 86:1097–1107.

Ibeto, C. N., Ofoefule, A. U., and Ezeugwu, H. C. 2011. Fuel quality assessment of biodiesel produced from groundnut oil and its blend with petroleum diesel. *Am. J. Food Technol.* 6:798–803.

Jimoh, A., Abdulkareem, A. S., Afolabi, A. S., Odigure, J. O. and Emmanuel, F. 2012. Effects of transesterification parameters on the biodiesel produced from crude groundnut oil. *4th International Conference on Chemical Engineering and Advanced Materials* (CEAM).

Korbitz W. 1999. Biodiesel production in Europe and North America, an encouraging prospect. *Renewable Energy* 16:80–83.

Knothe, G., and Steidly, K. S. 2005. Kinematic viscosity of biodiesel fuel components and related compounds: Influence of compound structure and comparison to petro diesel fuel components. *Fuel Elsevier* 84:1059–1065.

Lotero, E., Liu, Y. J., Lopez, D. E., Swannakarn, K., Bruce, D. A. and Godwin, J. G. 2009. Synthesis of biodiesel via acid catalysis. *Ind. Eng. Chem. Res.* 44:5353–5363.

Ma, F., and Hanna, M. A. 1999. Biodiesel production: A review. *Bioresour. Technol.* 70:1–15.

Owen, K., and Coley, T. 1990. *Automotive Fuels Handbook*. Warrendale: Society Automotive Engineers, PA, pp. 353–403.

Refaat, A. A., Attia, N. K., Sibak, H. A., Elsheltawy, S. T., and ElDiwani, G. I. 2008. Production optimization and quality assessment of biodiesel from waste vegetable oil. *Int. J. Environ. Sci. Tech.* 5:75–82.

Tapanes, N. C. O., Aranda, D. A. G., Caneiro, J. W. D. M., and Antunes, O. A. C. 2008. Transesterification of *Jatropha curcas* oil glycerides. Theoretical and experimental studies of biodiesel reaction. *Fuels* 87:2286–2295.