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Thermophysical Properties of Gmelina Arborea Biodiesel

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Abstract- The depletion of petroleum reserves, rising cost of conventional fuels and the ill effect of emission from the use of fossil fuel on human health and environment have driven scientific research towards the development of alternative source of fuels such as biofuel and biodiesel. Biodiesel is a fuel from a renewable sources and it has the potential of being used as an alternative to fossil diesel in compression ignition engine. Some of the challenges encountered in the use of biodiesel in compression ignition engine are its availability, use of edible oil for its production, cost of biodiesel feedstock and unfavorable properties of biodiesel such as its high viscosity. Presently, there is a search for more inedible oil seeds since the available inedible feedstock are still not enough to replace more than 20 - 25% of the total transportation fuels. The thermophysical properties of the biodiesel which vary from feedstock have a significant impact on the combustion process thereby affecting the overall engine performance and emissions. The aim of this study is to test the compatibility of biodiesel from Gmelina arborea seed oil in the compression ignition engine through its thermophysical properties. The biodiesel was produced using transesterification method and the thermophysical properties tests were carried out. The results showed that the density and viscosity of Gmelina arborea seed oil was 868.8 kg/m^2 (at 27.5°C) and 1.882(mm)^2/s (at 40.0°C) respectively. It also showed that the biodiesel obtained had a density and viscosity value of 821.2 kg/m^3 (at 27.5°C) and 0.794 9 (mm)^2/s (at 40.0°C) respectively. Comparing these results with other biodiesel, it was observed that Gmelina arborea oil has a lower viscosity and density than other biodiesel from different feedstocks; therefore it has potential to perform better in the diesel engine in comparison to other biodiesel.

Key Words: Viscosity, Biodiesel, Density, Thermo-physical properties, Transesterification, Gmelina Arborea

I. Introduction

Energy is important in the development and growth of any nation. Over the past years, most of the energy consumed in the power and transportation sectors is gotten from fossil fuel. With the depletion of petroleum reserves, rising cost of conventional fuels and the ill effect of emission from the use of fossil fuel on human health and environment, the total dependence of energy from this source is no longer sustainable. Due to these energy crises faced by the world and the desire to reduce greenhouse gases in the transportation and other sectors, several researches are ongoing on renewable energy technologies such as biodiesel, biomass, ethanol, solar and wind in order to produce and promote the use of alternative energy that are renewable, competitive, sustainable and its emission has little or no effect on the human and the environment when compared with fossil fuel (Raj et al., 2011).

Amongst the various biofuel that are being investigated for use in compression ignition engine, biodiesel has recently been considered as one of the best alternative to diesel fuel because it is simple to produce and use, biodegradable, non-toxic, reduces air pollutants and greenhouse gases such as particulates, sulphur, carbon monoxide, hydrocarbons and can be used in a compression ignition engine with little or no modification to the core engine configuration (Dennis et al, 2009; Ma and Hanna, 1999).

Biodiesel is defines as a mixture of mono-alkyl ester of long chain (C16-C18) fatty acid derived from vegetable oil or animal fats and meets the specification of ASTM D 6751 (Knothe, 2005). Biodiesel can either be used in its pure form called (B100) or can be blended with petroleum diesel at any level to create a biodiesel blend (B5, B10, B20 etc.). Several methods such as direct blending with diesel, pyrolysis, micro emulsification and transesterification have been used to reduce the high viscosity of vegetable oil and fat in order to enable their use in existing diesel engine without operational problems such as formation of large droplets in injection which could cause poor fuel atomization during the spray, increase depositions on the engine, more energy to pump the fuel and wears in fuel pump elements and injectors (Xue et al., 2011). High viscosity of biodiesel can also cause poor combustion, increase exhaust smoke and emission (Knothe and Steidley, 2005). Biodiesel can be produced from animal fat, plants' oil, waste frying oil and recently microorganism such as microalgae, yeast, fungi and bacterium (Meng et al., 2008). Plant oils are promising feedstocks for the production of biodiesel since they are renewable in nature, readily available and can be produced on a large scale. The plant oils may be categorized into edible oil from sunflower, groundnut, soybean, palm and coconut oil while the inedible oils can be gotten from jatropha, karanja, rubber seed, neem, mahua (Kumar and Sharma 2011; Ogbonnaya 2010; Sharma et al. 2008). More than 95% of biodiesel produced comes from edible oils since the properties of biodiesel produced from these oils are suitable alternative to diesel fuel (Gui et al., 2008). However, several debates are ongoing on the effect of using edible oil for biodiesel production on food production and its price. It is believed that the use of edible oils will give rise to food scarcity. Some economic analysts believe that the increase in staple food prices is connected with the use of edible oil for biodiesel production (FAO, 2008). Animal fat which is also a potential alternative to edible oil contains higher saturated fatty acids and normally exist as solid in atmospheric temperature and pressure; thus requiring multiple chemical steps or other methods which may increase the cost of biodiesel production. Therefore, there is a need to source for more inedible plant oil seeds which has the potential to replace the edible oil seeds and thereby increase the available inedible feedstock which are still not enough to replace more than 20-25 % of the total transportation fuels.

Researches have shown that the thermophysical properties of biodiesel strongly depend on the feedstock used in the production of biodiesel. The composition of a particular plant feedstock depends on the soil type, climatic conditions, plant health and maturity upon harvest (Abdullah et al., 2007). The properties of the various individual esters that compose biodiesel determine its overall properties (Knothe, 2005). Alamu et al. (2008) studied the properties of palm-kernel biodiesel. Result of the study was compared to that of the European biodiesel standard, rapeseed biodiesel and canola biodiesel. The result showed that biodiesel from palm kernel had a cloud point of 6°C which was higher than biodiesel from rapeseed and canola oil with values of -2°C and -1°C respectively. Ogbonnaya (2010) studied the effect of varying biodiesel production parameters such as the amount of catalyst used on biodiesel yield and thermophysical properties of biodiesel using jatropha oil. Result of the study showed that at optimal yield of 95%, the kinematic viscosity was 4.7 mm^2/s while the density was 865 kg/m^3. The results also showed that the thermophysical properties of jatropha biodiesel were within the ASTM standard for diesel and biodiesel which makes it suitable for use in compression ignition engines.

Yuan et al. (2003) developed a method to predict the physical properties of biodiesel for combustion modelling. The prediction of the critical properties of the biodiesel is very important because they are used to estimate the biodiesel's properties such as liquid density, heat of vaporization, thermal conductivity and diffusion coefficient. These parameters have direct effect on the performance of the compression ignition engine using biodiesel (Tesfa et al, 2010). Lin (2011) investigated the effect carbon composition of different vegetable oil which in includes carbon contents, carbon chain lengths and saturated or unsaturated carbon bond on engine performance, fuel consumption, the exhaust emissions and exhaust gas temperature. The result showed that biodiesel with shorter carbon length and more saturated carbon bond can effectively reduce exhaust emission, smoke, HC, NOx, and exhaust gas temperature. The engine performance was satisfactory.

The prime aim of this paper is to produce biodiesel from an alternative inedible feedstock known as Gmelina arborea seed oil usin 59 transesterification method and to experimentally determine the thermophysical properties of the biodiesel produced. The obtained values are to be compared with ASTM D 6751 of biodiesel and ASTM D 975 of petroleum diesel to ascertain the possibility of using biodiesel produced from Gmelina arborea directly or blended with diesel fuel in a compression ignition engine without modification to the engine core.

II. Methodology

Preparation and extraction of oil from Gmelina arborea seed

Gmelina arborea trees make up about 60% of Nigeria's planted forest. The Gmelina arborea seeds are not consumed by humans or animals. Oil can be extracted from this seed, thereby making it a viable good source of biodiesel. The Gmelina arborea seeds used was obtained from Ututu in Arochukwu Local Government, Abia state, Nigeria. The seed obtained was de-hulled and dried under the sun for about 2 - 4 days. The kernel was then separated from the shell to remove the oil seed. The ideal conditions to store the oil seed are; 26 - 27°C and 60 - 70% humidity in a well-ventilated place to prevent the seeds from decaying.

Two types of method were used to extract the oil from the seed which are the hydraulic manual pressing machine and the solvent method. The oil extracted using hydraulic manual pressing machine was about 20 - 30% while the solvent method gave a higher oil yield of about 40 - 50%. Comparing result with the oil yield of 35%, 30.40% and 40% for coconut, jatropha, and neem, respectively (Ogbonnaya, 2010), the Gmelina oil seeds has greater oil yield thereby making it more economical in biodiesel production.

Optimization of biodiesel production process

The oil obtained was heated to about 100^{o}C and held at that temperature to allow any trace of water present to evaporate. The presence of water will slow the rate of reaction and also cause the formation of soap during the biodiesel production. The cartilage filter was used to remove solid particles from the oil.

Titration process was performed before the production of biodiesel to determine the appropriate amount of potassium hydroxide (KOH) catalyst that would produce optimal yield of biodiesel. The materials used for titration are Iso-propyl alcohol, deionized water and phenolphthalein. 0.1 KOH solution was created by dissolving 1 gram of KOH in 1 liter of distilled water. The Isopropyl-oil mixture was obtained by measuring 10 ml of Isopropyl alcohol with a syringe and mixed it with 1 ml of warm oil (40°C) in a beaker labelled "alcohol and oil". The solution was warmed and stirred gently until the mixture turned clear. The KOH solution was poured out in a beaker and 3 ml was measured out with a syringe. Two (2) drops of phenolphthalein were added to the isopropyl-oil mixture. 0.5ml of KOH solution was then added sequentially into the isopropyl-oil mixture, stirring all the time, until the mixture stayed pink for 10 seconds.

The process of transesterification was used in the production of biodiesel because it is simple and cost effective when compared with other processes. Transesterification involves stripping the glycerin from the fatty acid with a catalyst and replacing it with an anhydrous alcohol as shown in Figure 1. The alcohol and catalyst used was methanol (CH3OH), 99% pure and

Potassium hydroxide (KOH) respectively. This process yielded alcohol esters and glycerol as the by product.

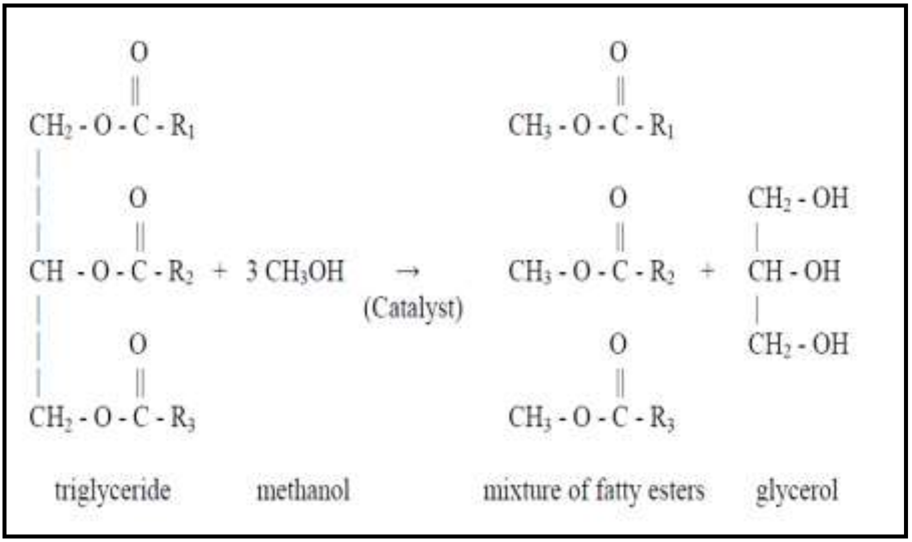

Fig. 1: Transesterification reaction process (Schuchardt *et al*., 1997)

R_1, R_2 and R_3 are long chains of carbon and hydrogen atoms, sometimes called fatty acids. The chains are usually of different length and degree of saturation within the triglyceride molecule of the lipid.

Three batches of methoxide solution were prepared to confirm the result of the titration for the optimal yield of biodiesel before the commencement of the biodiesel production. 20ml of oil and 20% by volume of methanol (4ml) was measured. KOH of 0.14g, 0.6g, 1.0g were used to prepare 3 batches of methoxide solution by dissolving it in 4ml of methanol. The methoxide solutions were added to the heated oil and agitated vigorously using the magnetic stirrer. The resultant mixture was then poured into 3 different separating funnels labelled 0.14g, 0.6g, 1.0g respectively based on the amount of KOH used for each batch as shown in Figure 2. The mixture was left for 72 hours until it separated into two layers. The biodiesel on the upper and glycerol in the lower layer of the separating funnel. The glycerol was carefully separated from the biodiesel.

Warm water was used to wash the biodiesel to remove any trace of methanol and catalyst which may likely to cause corrosion in the engine core if present. The process was repeated continuously until the PH value for the water was neutral. Residue water was removed from the biodiesel through heating.

Fig. 2: Biodiesel separation

III. Results And Discussion

Determination of thermophysical properties of Gmelina arborea oil and biodiesel

The quality of biodiesel is expressed in terms of its properties such as viscosity, density, flash point, FFA, acid value, cloud point, pour point, iodine value and saponification value. In Table 1, the thermophysical properties of gmelina oil and gmelina biodiesel are presented. The measurement was carried out at atmospheric pressure and temperature of 27.5°C. From Table 1, it can be seen that the viscosity and density of the gmelina arborea oil reduce after the process of transesterification which makes it suitable for use in compression ignition engine.

Table 1: Thermophysical properties of gmelina oil and gmelina biodiesel

	Gmelina oil	Gmelina Biodiesel	Method
Density (kg/m^3)	868.8	821.2	ASTM D1298
Kinematic Viscosity (mm^2/s) at 40°C	1.882	0.794	ASTM, D445
Cloud Point (°C)	2.0	4.0	ASTM D 2500
Pour Point (°C)		-1	ASTM D 97
Flash point (°C)	130	110	ASTM D 93
Color	1.5 – 2.0	0.5 – 1.0	ASTM D

The thermophysical properties of Gmelina biodiesel was compared to other biodiesel produced from inedible oil as shown in Table 2. Comparing the kinematic viscosity of gmelina biodiesel and other biodiesels from inedible vegetable oils, it can be seen that the kinematic viscosity of the gmelina biodiesel is lower which makes it more suitable for use in existing compression ignition engine without operational problems. High viscosity can plug the fuel filter and injection system in the engines (Tat and Van Garpen, 1999). The lower cloud point of gmelina biodiesel makes it more suitable for use as fuel at low temperatures. The lower density of gmelina biodiesel will reduce the specific fuel consumption of biodiesel when compared with other biodiesel. A denser biodiesel has higher energy content and will give better mileage and increased power.

Table 2: Comparison of thermophysical properties of gmelina arborea and other inedible vegetable oil biodiesel (Lal et al. 2010; Ogbonnaya, 2010; Atabania *et al*. 2011; Kumar *et al*. 2014)

	Gmelina biodiesel	Jatropha biodiesel	Karanja biodiesel	Polanga biodiesel
Density (kg/m^3)	821.2	865	890	872
Kinematic Viscosity (mm^2/s) at 40.0°C	0.794	4.73	5.12	4.1
Cloud Point (°C)	4.0	-	16.3	12.9
Pour Point (°C)	-1	-	14.6	3.9
Flash point (°C)	110	184	166	129
Color	0.5 – 1.0	2.5	clear	-

Comparison analysis of gmelina biodiesel and ASTM standard for biodiesel and diesel is shown in Table 3. The viscosity of gmelina biodiesel is shown to be lower than the ASTM standard for biodiesel and diesel. Hence problems related to high viscosity will not exist but the low viscosity may result to inadequate lubrication the engine parts. The result showed that the flash point of gmelina biodiesel to be lower than the ASTM standard of biodiesel but higher than the diesel which makes it safe to handle.

Table 3: Comparison of G*melina* biodiesel with ASTM standard of Biodiesel and diesel

	Gmelina oil Biodiesel	ASTM D6751 Biodiesel	ASTM D975 Diesel
Density (kg/m^3)	868.8	Report	820-870
Kinematic Viscosity (mm^2/s) at 40.0°C	0.794	1.9-6.0	1.6-5.5
Cloud Point(°C)	4.0	Report	3^0C for winter 15^0C for summer
Pour Point(°C)	-1	Report	Report
Flash point(°C)	110	130 min	35^0C min
Color	0.5 – 1.0	3.5	3.5

Qualitative and Quantitative Analysis of Biodiesel

Quantitative and qualitative analysis of the reaction mixture was conducted using gas chromatography (GC). This procedure is used in determining the composition of a mixture of methyl esters. The result of the gas chromatography is presented in Figure 3. The Bruker Table Top FTIR was used to perform infrared Spectroscopy to determine the functional group present and to compare it with the standard infrared Spectroscopy of FAME and diesel.

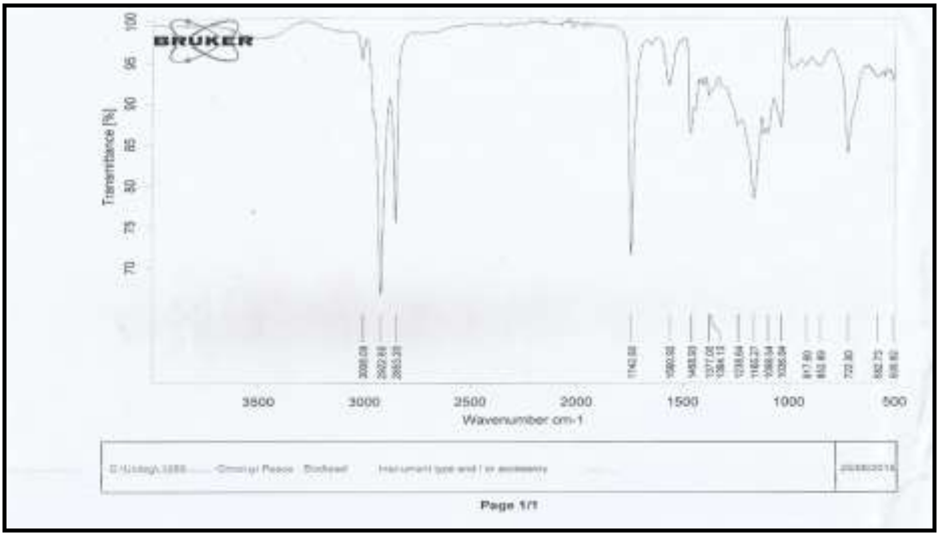

Fig. 3: Infrared Spectroscopy of Gmelina biodiesel

The infrared spectroscopy result obtained shows that the obtained product has the functional groups of FAME and matches exactly with the standard Infrared spectra of FAME as prescribed by the ASTM D7371 method.

IV. Conclusion

From the result above it can be concluded that oil from Gmelina arborea seed, which is non-edible and rarely consumed by man or animals has the potential to be used in the production of biodiesel for direct use in the internal combustion engine. This study also showed that Gmelina arborea seed has greater oil content when compared with other inedible oil seeds. Hence, it is more economical to utilize it for biodiesel production.

In order to further validate the acceptability and sustainability of gmelina arborea for use in internal combustion engine, experimental studies need to be carried out to evaluate the engine performance and emission when using different blends of biodiesel. The econometric study of biodiesels' production needs to be carried out to evaluate the cost of producing a litre of biodiesel.

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