

BIODIESEL PRODUCTION USING WASTE COOKING OIL

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ABSTRACT

In this study, a domestic blender was used as the reactor to synthesize biodiesel from Used Cooking Oil (UCO). The transesterification process involved 1 litre of UCO, 250g of methanol, 6.5g of NaOH at a reaction temperature of 65°C and reaction time of 20 minutes and the process was catalysed by alkali base. The process was triplicated and average results evaluated. A high yield of 93.71% of UCO methyl ester (UCOME) was obtained after it was washed and dried. The UCOME produced was blended with petroleum in the following percentage by volume of the UCOME; 5%, 10%, 20%, and 30% corresponding to B5, B10, B20, and B30 respectively. The fuel properties of UCOME and its blends were measured and found to satisfy both ASTM D6751 and EN14214 Standards for biodiesel fuel, and other reported works from different authors. From the biodiesel blends obtained, B30 and B20 proved to be more efficient compared to other blends due to their satisfactory properties such as their densities (0.847 and 0.846) g/cm³ respectively and flash point of 145°C and 136°C respectively.

1.0 INTRODUCTION

Biodiesel fuel has become attractive throughout the world due to increasing knowledge of fossil fuel depletion and concerns of environmental protection. It is a renewable fuel, non-toxic and does not spoil water quality. It is also biodegradable. Used cooking oil is readily available and could be employed in the production of biodiesel rather than discarding it. It can also be used directly in most diesel engines without requiring extensive engine modifications (Nada Elsolh, 2011). Used cooking oil is one of the economical sources for biodiesel production. However, the products formed during frying, can affect the transesterification reaction and the biodiesel properties. Nevertheless the production of biodiesel from waste vegetable oil offers economic, environmental and waste management benefits. Producing biodiesel from used frying oil is environmentally beneficial, since it provides a cleaner way for disposing these products; including valuable cuts in CO₂. Its other advantages include reduction of sulphate, hydrocarbon emissions and particulate matter. It runs a diesel engine just as petroleum-based diesel would. The increase in population and improved economic activities the world over have led to huge increase in energy demand. The major part of all energy consumed worldwide comes

from fossil source. However, these sources are limited. The increasing depletion of world petroleum reserves, uncertainties concerning availability of petroleum source and its increasing environmental effects have inspired the need for a cleaner renewable energy source which should be environmentally friendly. Nigeria's transport sector mainly depends on fossil fuels. This is particularly worrying because fossil fuels are the chief culprit implicated in the environmental issue of climate change phenomenon commonly referred to as global warming. This problem has resulted in intense search for alternative renewable energy considered to supplant the dwindling conventional Transportation fuels in Nigeria. Fatty acid methyl ester (FAME) commonly referred to as Biodiesel shows great potential as substitutes for petroleum diesel. (Anitha, 2012).

Biodiesel, an alternative diesel fuel is made from renewable biological sources such as vegetable oils, animal fat, or used cooking oils. This fuel is biodegradable and non-toxic, and has low emission profiles as compared to petroleum diesel. It is synthesized from direct transesterification of vegetable oils. It is a renewable fuel comprising of mono-alkyl esters of long chain fatty acids, derived from a renewable lipid feedstock (Sharma and Singh, 2008). It can also reduce greenhouse gas effect and does not contribute to global

warming. Biodiesel has become a substitute for petroleum diesel because of its similar properties to the traditional fossil diesel with little or no engine modification (Ma and Hamna, 1999, Oliveira et al, 2006). It is essentially free of sulphur, making it a cleaner burning fuel than petroleum diesel with less emission of carbon monoxide (CO) and unburnt hydrocarbons. It can be used in its pure form B100 or can be blended with petroleum diesel. Technically, biodiesel is better used as a blend fuel in order to improve its performance.

Biodiesel can be produced from several vegetable oils and animal fats with a varied composition in fatty acids. However, biodiesel produced from vegetable oils have more economical setback due to high cost of pure vegetable oils. This has led to high cost of production of biodiesel making it more expensive than petroleum diesel. Because vegetable oils are a source of staple food, their usage for biodiesel production may also result in high cost of food supply, as more land will be needed for the cultivation of oil crops, in order to tackle the challenges between food supply and fuel. One of the means to address the higher price hurdle of biodiesel production is to produce biodiesel from waste fats and oils (Anitha, 2012). Used Cooking Oils (restaurant greases) can be recycled and used to produce biodiesel. This will significantly reduced the dependence on edible vegetable oils for biodiesel production and will as well reduce the cost of production. Used Cooking Oil is readily available from homes, restaurants, bakeries, etc, and is affordable at low or no cost. In addition, it is on record that millions of tons of used cooking oils are disposed annually in manners that contaminate the environment (Samuel et al, 2013). Therefore, the proper utilization and management of Used Cooking Oils (UCO) will pave way for a conducive environment.

2.0 MATERIALS AND METHODS

Biodiesel fuel can be produced through the chemical reaction of transesterification and esterification in which vegetable oil or animal fats are reacted with alcohol (methanol or

ethanol) under the influence of a catalyst (acid, alkali base or enzyme). The ratio of oil is an important variable affecting the yield of methyl ester. The stoichiometry of the transesterification reaction requires 3moles of alcohol per mole triglyceride to yield three moles of fatty esters and one mole glycerol. Alkali metal alkoxides are the most effective transesterification catalyst compared to the acidic catalyst. Sodium hydroxide is among the most efficient catalysts used for this purpose, although KOH can also be used. Trans-methylations occur faster in the presence of an alkaline catalyst than those catalysed by the same amount of acidic catalyst as has been reported (Refaat et al., 2008, Mohammed et al, 2012, Samuel et al., 2013, Kumar et al., 2014).

Due to high free fatty acid of Used Cooking Oil, it is necessary to carry out titration test of the oil in order to determine the additional catalyst (NaOH) needed for the conversion of triglyceride into methyl esters. The oils that do not contain FFA require 3.5g of NaOH per litre of oil as catalyst. The excess FFA demands additional NaOH for neutralization which is determined by titration test. High FFA content leads to soap formation during the transesterification process.

The materials used in this work include:

- (a) Used Cooking Oil
- (b) Sodium Hydroxide
- (c) Isopropyl Alcohol
- (d) Distilled Water
- (e) Laboratory Glass Wares
- (f) Laboratory Apparatus
- (g) Domestic Blender
- (h) Electric Hot Plate

The major feedstock used in this experiment is Used Cooking Oil (UCO), which was donated by Mr Biggs's (UAC Restaurants Limited), Aba Road, Umuahia, Abia State, Nigeria. The fatty acid composition of the Used Cooking Oil is shown in Table 1. Methanol and Isopropyl alcohol used are analytical grade products of BDH Chemicals LTD, Poole, England, and Sodium hydroxide (pellet) were supplied by the Chemistry Department. The Distilled water was obtained from the *Manesty Distillation Plant* at the

Agricultural and Bio-resources Engineering laboratory, MOUAU.

Table 1: Fatty Acid composition of Used Cooking Oil (From: Obi, 2000)

FATTY ACID COMPOSITION	PERCENTAGE (%)
Lauric, C12:0	3.0
Myristic-oleic, C14:1	2.3
Palmitic, C16:0	7.3
Stearic, C18:0	1.9
Oleic, C18:1	12.4
Linoleic, C18:2	9.6
Linolenic, C18:3	15.4
Others (unidentified)	48.2

The Laboratory glassware include 250ml and 500ml beakers, 250ml conical flask, 1000ml conical volumetric flask (Pyrex), graduated cylinder and pipette, 1000cm² volumetric flask, burettes, separating funnel, stirrer, syringe, thermometer and test jar.

The blender used was a multi Dry and Wet Master Chef Blender, with a clear gas jar of 1.25 Litres capacity. 6.8KW Ceran Electric Hot Plate, Analytical Weigh Balance, spatula, retort stand, and clamp, litmus paper, filter cloth and funnel.

2.3 Experimental Procedure

The experimental procedure for the production of biodiesel includes:

- UCO Pre-treatment.
- Titration Test.
- Sodium Methoxide production.
- Alkali base Transesterification Reaction.
- Settling and Separation.
- Purification.

2.3.1 Pre-Treatment of the Used Cooking Oil

The Used Cooking Oil (UCO) was filtered with a filter cloth to remove debris and other solid materials and then heated up to 30°C.

2.3.2 Titration Test

One gram of NaOH was dissolved and made up to the mark in 1000cm³ volumetric flask with distilled water. The oil solution was prepared by mixing oil and isopropanol in the ratio of 1:10 respectively to form the mixture.

The pH was determined to be 8.62 using pH meters; then 20ml of isopropyl/oil solution mixture was measured out into a 250cm³ conical flask and the NaOH solution was titrated against the mixture (isopropyl/oil solution). The titration test was repeated three times and the result of the average was determined as the percentage of free fatty acid (FFA) content of the Used Cooking Oil and the extra catalyst needed to neutralize the acid was computed using the expression (1) below:

$$X + 3.5g \text{ NaOH} \quad (1)$$

where X = the titrated value (NaOH/distilled water solution) and 3.5g NaOH is the standard catalyst required per 1000ml oil for transesterification reaction.

2.3.3 Sodium Methoxide Production

Six grams of sodium hydroxide pellet was measured into a 250ml beaker; 200ml of methanol was also measured out in a separate 250ml beaker. The methanol was gradually added to the sodium hydroxide, and the mixture was stirred for 13 minutes until the sodium hydroxide pellets completely dissolved to form sodium methoxide. Equation (2) below shows the formation of sodium methoxide solution.



2.3.4 Alkali Base Transesterification reaction

1000ml of Used Cooking Oil (UCO) was measured into a conical flask and was preheated to the temperature of 65°C. The prepared sodium hydroxide solution was poured into the Wet Mill Jar of the blender, and the preheated Used Cooking Oil was carefully added. The Wet Mill lid was securely tightened and the blender switched ON. The blender was operated at the highest speed for complete agitation of the reagents for 20 minutes before the blender was switched OFF. Figure 1 below represents the transesterification reaction for the conversion of 1mole of triglyceride and 3 moles of ethanol to 3 moles of methyl Ester and 1 mole of Glycerol respectively.

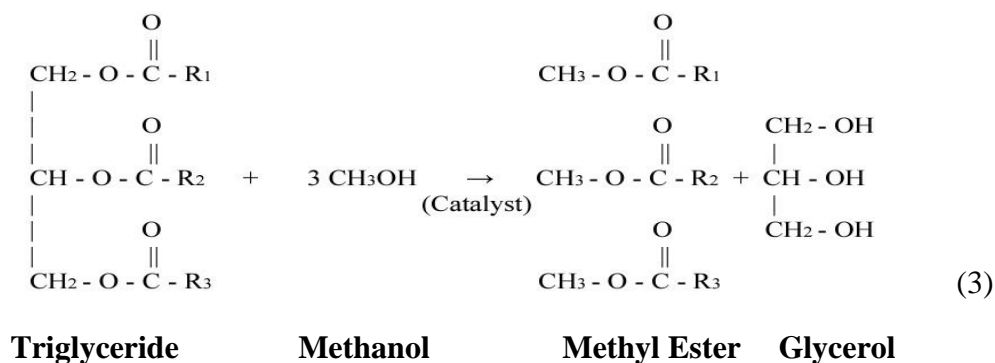


Figure 1: Equation for Transesterification Reaction

2.3.4 Settling and Separation

The mixture was poured from the Wet Mill of the blender into a separating funnel clamped on the retort stand and the lid was tightly secured. The mixture was allowed to stand overnight for complete separation and settling of the expected products (biodiesel and glycerol) respectively. The upper layer which is the methyl ester was a pale gold biodiesel while the lower layer of dark brown is the glycerol that settled at the bottom of the separating funnel. The valve separating the funnel was opened and the glycerol was discarded into the beaker.

2.3.5 Purification

The biodiesel produced was purified firstly, by washing it with warm distilled water. The distilled water used was warmed up to 40°C; equal ratio of biodiesel and warm distilled water was mixed in the separating funnel by first pouring the methyl ester, then adding the warm distilled water. The separating funnel was tightly secured and the separation funnel was shaken slowly for proper mixing and to

avoid emulsion of air bubbles that causes delay in separation of biodiesel from the washed impurities. The separating funnel was clamped on a retort stand and allowed to stand until proper separation was observed. The milkfish layer that contains the impurities at the bottom of the separating funnel was carefully drained by opening the tap of the separating funnel leaving the biodiesel that is the upper layer in the separating funnel. This sequence was repeated four times until a clear biodiesel with water was observed.

The washed biodiesel was heated to 110°C to evaporate off the water and methanol present in the fuel.

2.3.6 Biodiesel Blend Preparation

The biodiesel produced from UCO was blended with petroleum diesel oil using direct blending method. The biodiesel blends were prepared according to the measured percentage shown in Table 2, by placing the mixtures in a transparent bottle.

Table 2: Preparation of Biodiesel Blends

COMPOSITION OF BLENDS	VOLUME OF MIXTURE
B5	95ml of petroleum diesel + 5ml of methyl-ester
B10	90ml of petroleum diesel + 10ml of methyl-ester
B20	80ml of petroleum diesel + 20ml of methyl-ester
B30	70ml of petroleum diesel + 30ml of methyl-ester
B100	100ml of methyl-ester

2.4 Property Test for Biodiesel

These properties of the methyl-ester blends produced were tested in accordance with ASTM D6751 and EN14214 standards. They are:

- (a) Density
- (b) Flash and Fire points
- (c) Viscosity
- (d) Cloud and Pour Points

2.4.1 Test for Density

The densities of the samples were determined at ambient temperature (28°C) for each blend. A density bottle of mass 50ml was weighed on the analytical balance and the initial weight of the bottle was noted. The samples were put in the density bottle, the spill cleaned and dried, and the bottle weighed on the analytical balance. The densities were measured in triplicates and the average values were recorded as the results. The densities of the samples were computed using appropriate equations.

2.4.2 Test for Flash Point/Fire Point

The Flash point of the sample was determined using the setup comprising a hot – plate, beaker and thermometer. 80ml of the sample was placed in a transparent Pyrex beaker resting on a hot plate as the source of heat and a thermometer was introduced clamped on a retort stand. Heat was applied gradually by turning the knob of the hot plate until the observed movement of the particles increased. A flame was gradually brought close to the surface of the beaker until “a catch and disappearing” flame on the surface of the hot liquid was observed. The temperature at which this happens is noted. Further heating of the samples with gradual moving of the flame closer to the vapour was continued and the temperature at which the sample ignites without the flame disappearing from the surface of the sample was recorded as the Fire Point.

2.4.3 Test for Viscosity

The viscosities of the samples were determined using a glass capillary kinematic viscometer. The viscometer was tightly

clamped on a retort stand. 100g of each sample was collected into a Pyrex beaker and was gradually heated to a temperature above 40°C. The sample was then transferred into the viscometer through the larger opening of the capillary tube and the fluid was allowed to cool until a temperature of 40°C was reached. Thereafter, suction was applied to the other end of the capillary tube to draw the fluid to the mark on the upper meniscus level of the capillary tube. The fluid was allowed to run freely to the lower meniscus mark in the capillary tube. The efflux time for the fluid to flow from the upper meniscus mark to the lower meniscus mark was determined with the aid of a stopwatch. The test was triplicated for each sample and the kinematic viscosity was calculated from the formula below:

$$\text{Kinematic Viscosity} = kt$$

Where k = Calibrated value of the viscometer expressed in square millimetres per second *square (3.0)*

t = Flow time in seconds of the liquid.

The viscosities of the samples were determined using a simple viscometer setup as shown in figure 2:



Figure 2: Simple Viscosity Setup Apparatus

2.4.5 Test for Cloud and Pour Points

The cloud and pour points of the sample were analysed by reducing their temperature. The samples were introduced into transparent cylindrical glasses and placed in a cooling bath containing crushed ice.

The temperature of the samples was monitored as it decreased; the temperature at

which the clear sample loses its sharpness due to cloud formation was noted as the sample's cloud point. The sample was further cooled in order to pour it at every increase in temperature. The sample was inspected at every one-minute interval by tilting it horizontally. The temperature at which the samples cannot pour freely for five seconds was noted as the pour point.

3.0 RESULTS AND DISCUSSION

Table 3: Titration Results

TEST	TITRE VALUE (ml)
1 st Run	2.40
2 nd Run	2.5
3 rd Run	2.5
4 th Run	2.6
Average	2.5

The results from the titration test were determined from the average of the titre values as shown in Table 3.

2.5g of NaOH was added to 3.5g NaOH as the required catalyst, while 6.5g NaOH was used to react with 1litre of UCO and 250g of methanol to convert the free fatty acid (FFA) into methyl – ester known as biodiesel.

The alkali base transesterification reaction of the Used Cooking Oil and Sodium Methoxide at a ratio of 4:1 of UCO to methanol as stated previously, yielded 93.71% increase in biodiesel production after 20 minutes. The collected by-product (glycerol) was determined to be 177.23g that could be further processed to produce soap. It was observed also that 142.13g of the total reacting masses accounted as losses which could be due to unreacted methanol, residual catalyst and the emulsion removed at the water washing stage of the production process. The results stated are averages of three different experimental runs. Detailed results for each of the experimental runs are presented in Table 4

Table 4: Results of Experimental Runs

EXPERIMENTAL CONDITIONS	1 ST RUN	2 ND RUN	3 RD RUN	AVERAGE
Reaction Temperature (°C)	65	65	65	65
Reaction Time (min)	20	20	20	20
Used Cooking Oil (UCO) quantity (g)	1000	1000	1000	1000
Methanol Quantity (g)	250	250	250	250
NaOH (Catalyst) concentration (g)	6.5	6.5	6.5	6.5
UCO Biodiesel obtained (g)	925.20	955.80	930.40	937.13
Glycerol obtained (g)	188	164.70	179	177.23
Losses (g)	143.3	136	147.10	142.13
UCO Biodiesel Yield %	92.52	95.58	93.04	93.71

Table 5 Properties of Biodiesel Blends and Used Cooking Oil

PROPERTIES	UCO	B100	B30	B20	B10	B5	ASTM D6751	EN 14214
Kinematic Viscosity @ 40°C	36.94	8.344	5.690	5.309	5.309	5.073	1.9 – 6.0	3.5 – 5.0
Specific Gravity @ 28°C	0.910	0.882	0.847	0.846	0.840	0.834	0.860 – 0.9	0.860 – 0.9
Flash Point (°C)	259	210	145	136	132	126	130min	120min
Fire Point (°C)	263	238	165	153	143	138	-	-
Cloud Point (°C)	7.2	3.6	2.9	2.7	2.6	2.4	Reported	Reported
Pour Point (°C)	5.4	2.4	1.6	1.5	1.4	1.2	Reported	Reported

3.1 Properties of Biodiesel Blends

The physical properties of the biodiesel blends such as its Viscosity, Density, Cloud Point, Pour Point, Flash Point, and Fire Point were determined and compared with the ASTM D6751 Standard and EN 14214 Standard for biodiesel as shown in Table 5. It is seen that the fuel properties of biodiesel blends are in agreement with the ASTM D6751 and EN14214 Standards, and other reports from some authors.

3.2 Flash Point

The flash point of a fuel is the lowest temperature at which the fuel will ignite when exposed to a flame or spark. Biodiesel fuel has a higher flash point over conventional diesel fuel (74°C – 80°C). The biodiesel produced from UCO (B100) has a flash point of 210°C and this satisfies the minimum requirement of ASTM D6751 and EN14214 standard as provided in the table 4.4.

The flash point of the biodiesel produced is higher than those reported by Samuel et al (139°C), Igbokwe and Nwafor (150°C) and Alamu et al (167°C) as shown in the table 4.4. B20 (123°C) of Ibekwe and Nwafor is lower than the minimum requirement as reported by ASTM D6751 (130°C) compared to the B20 (136°C) of this work which is within the range of the required standard. However, B5 indicates the lowest flash point 126°C which is slightly below the minimum requirement of ASTM D6751 standard and above that of EN14214 standard as shown in Table 5

Furthermore, UCO displays a great rise in flash point compared to the biodiesel blends as shown in Figure 3. In addition, the high flash point of UCO biodiesel and biodiesel blends compared to petroleum diesel makes it safer to handle and for storage.

Table 6: Characterization of experimental Used Cooking Oil Methyl-Ester in comparison with other standards

PROPERTIES	UCO METHYL ESTER (B100)	B20	IBEKWE AND NWAFOR		SAMUEL ET AL	ALAMU ET AL	ASTM D6751
			B100	B20	METHYL ESTER	METHYL ESTER	
Kinematic Viscosity @40°C	8.344	5.309	2.99	2.04	4.72	4.839	1.9 – 6.0
Specific Gravity @ 28°C	0.882	0.846	0.865	0.846	0.879	0.883	0.860 – 0.90
Flash Point (°C)	210	136	150	123	139	167	130min
Fire Point (°C)	238	153	-	-	-	-	-
Cloud Point (°C)	3.6	2.7	7.5	3.0	-	6	Reported
Pour Point (°C)	2.4	1.5	0.0	-12	-	2	Reported

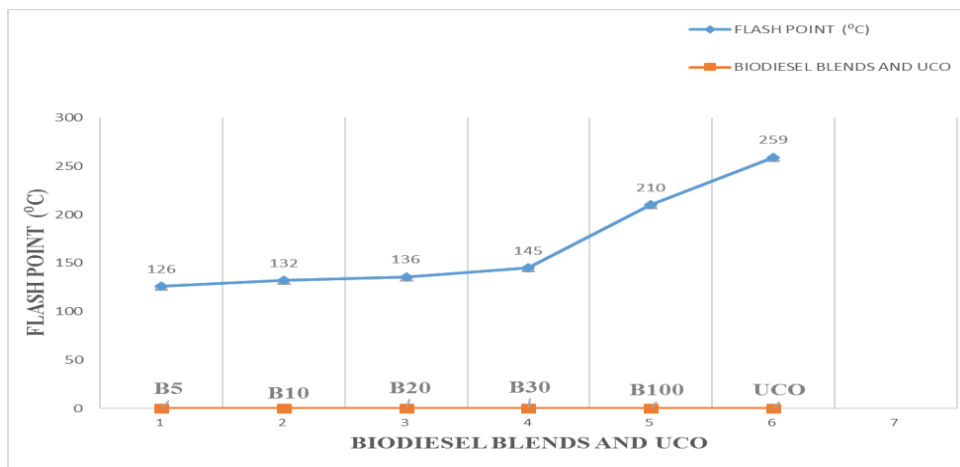


Figure 3: Flash Point of Biodiesel Blends and Used Cooking Oil

3.3 Fire Point

The fire point of a fuel is the lowest temperature at which the vapour produced by that given fuel will continue to burn for at least five seconds after ignition by an open flame. The fire point of the samples were determined and found to be more than 10°C higher than the flash point as shown in Table 5. The fire point for biodiesel is significantly higher than that of conventional fuel; this is more reason why biodiesel is safer than petroleum diesel.

3.4 Density

Density is one of the desirable properties of a fuel; it is an important parameter for diesel fuel injection system. Fuel density affects engine performance, as the density increases the energy content of the fuel also increases. Higher density of fuel results to low volatility and poor atomization of biodiesel during fuel injection in combustion chamber causing incomplete combustion and carbon deposits in combustion chamber.

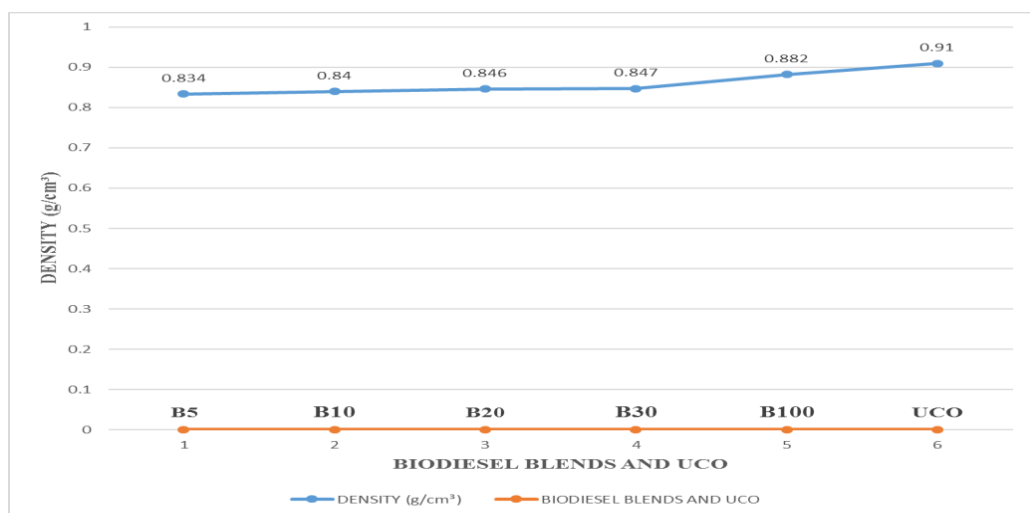


Figure 4: Density for the Biodiesel Blends and UCO

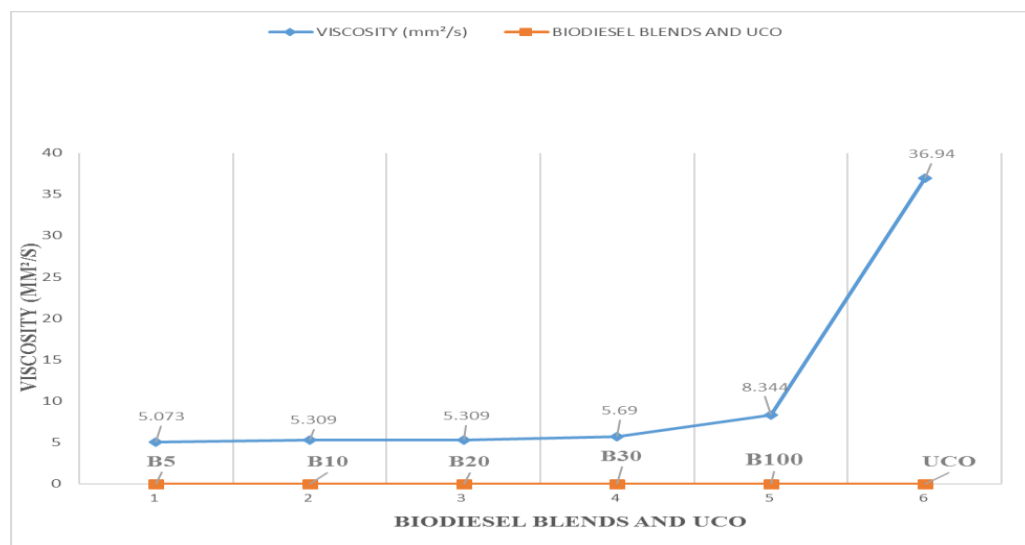


Figure 5: Viscosity of Biodiesel Blends and Used Cooking Oil

From the results presented in Figure 4, the density recorded for B100 is within the range limit for both ASTM D6751 and EN 14214 standards for biodiesel. From Figure 4, UCO has a density 0.910g/cm^3 , which is above the range of ASTM D6751 and EN 14214 Standards for biodiesel, which when used may result to engine ignition delay. Moreover, the density of Used Cooking Oil B100 (0.882g/cm^3) was observed to be in good agreement with that of Samuel et al and Aluma et al. However, the remaining blends (B5, B10, B20, and B30) were slightly lower than the given standards for biodiesel. The B20 of this research work is of the same value (0.846g/cm^3) with that of Igbokwe and Nwafor (9999), this value 0.846g/cm^3 compared to ASTM D6751 and EN 14214 (i.e. 0.883 and $0.860 - 0.90$) g/cm^3 respectively for biodiesel indicates the lower density of petroleum diesel.

3.5 Viscosity

Viscosity is a measure of the internal flow resistance of a liquid. The viscosity of biodiesel should be low for good atomization of fuel spray. This is the primary reason why biodiesel is used as an alternative fuel instead of neat vegetable oil and animal fat that will ultimately lead to engine operational problems when used directly as fuel. The kinematic viscosity of B100 measured at 40°C was $8.344\text{mm}^2/\text{s}$ and was found to be high compared to the acceptable standards. However, the viscosity of the blends (B5, B10, B20, and B30) falls within the ASTM D6751 Standards and slightly above EN 14214 Standard for biodiesel. The viscosities comparison for the produced biodiesel blends and Used Cooking Oil as shown in Figure 5 revealed that UCO at 40°C has a viscosity of $39.944\text{mm}^2/\text{s}$ which is very high compared with that recorded for ASTM D6751 and EN 14214 Standards. This is the major reason why vegetable oil or UCO cannot be used directly in an engine due to its high viscosity.

3.6 Cold Flow Characteristics

The cold flow properties of the UCO methyl ester blends were measured by determining the cloud point and pour point. The cloud point and pour point are important low-temperature

fuel parameters. The cloud point as a desirable fuel property indicates the temperature at which the solidification of heavier components of biodiesel result in the formation of cloud of crystals. It is observed from Table 6 that the cloud point of B100 (3.6) is lower than those reported by Alumu et al (6°C), Igbokwe and Nwafor (7.5°C). In addition, the B20 of Igbokwe and Nwafor (3.0°C) is slightly higher than the B20 (2.7°C) of this study. While the pour point of a fuel indicates the lowest temperature, at which the wax becomes visible when the fuel is cooled to a certain temperature. It is the lowest temperature at which the fuel can flow. Specifications for cloud point and pour point are not in the biodiesel standards, although ASTM D6751 and EN 14214 requires that the cloud point be reported, this is because each country has different climatic conditions. As presented in Table 6, the UCO methyl ester (B100) has a satisfactory cloud point (3.6°C) and pour point (2.4°C) compared to Alumu et al, 6°C and 2°C respectively for cloud point and pour point. However, the cloud point and pour point reported by Igbokwe and Nwafor (0.0°C and -12°C) respectively is significantly lower than the determined cloud and pour points.

4.0 CONCLUSION

Biodiesel was successfully produced from Used Cooking Oil through alkali catalysed transesterification reaction using methanol in the presence of NaOH at a reaction time of 20 minutes. The produced methyl-ester was characterised and from the obtained results, the methyl esters produced can be effectively used in a diesel engine since they fulfil the requirement of ASTM D6751 and EN 14214 Standards for biodiesel fuel. The UCO has been proved to be a good feedstock for biodiesel as high yield of 93.71% was obtained and fuel properties were within the standard prescribed by ASTM and EN. The densities of the blends (B30, B20, B10, and B5) are closer to that of petroleum diesel but they have higher viscosity compared to petroleum diesel.

4.2 RECOMMENDATION

Biodiesel produced from Used Cooking Oil could be used in a diesel engine without engine

modification. However, it is advisable to use biodiesel in its blended form. The blends B20 and B30 from this study have satisfactory properties compared to petroleum diesel and therefore should be recommended for use in any diesel engine.

In addition, for the purpose of mass production, a better separation technique should be used in order to reduce the separation time such as a commercial centrifugal separating machine.

The production of biodiesel should be encouraged in order to increase employment opportunities, reduce over dependency on petroleum diesel, and reduce global warming.

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