

Production of Biodiesel Fuel from Oleic Acid and Comparison of its Properties with Petroleum Diesel

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Abstract

Biodiesel define as the mono-alkyl esters of vegetable oil and animal fats is an alternative diesel fuel that is steadily gaining attention because the combustion of fossil fuels such as coal, oil and natural gas has been identify as a major cause of the increase in the concentration of carbon dioxide in the earth's atmosphere and causing global warming.

The present work concerns with estimating the physical properties experimentally such as kinematic viscosity, density, flash point and carbon residue of biodiesel that produced by the esterification reaction of methanol and oleic acid with homogeneous catalysts H_2SO_4 in a lab-scale packed reactive distillation column using the best operating conditions of methanol to oleic acid 8:1, catalyst amount 1.8 g sulfuric acid/g oleic acid, time 57 min and reaction temperature $130^\circ C$ that obtained from studying different variables such as molar ratio of methanol to oleic acid 4:1, 6:1 and 8:1, amount of catalyst 0.6, 1.2 and 1.8 g sulfuric acid/g oleic acid, reaction time 36, 57 and 75 minutes, and reaction temperature $100^\circ C$, $120^\circ C$ and $130^\circ C$.

The physical properties of biodiesel from the present work compared with those of ASTM (American Standard for Testing Material) standard for biodiesel, previous work and petrol diesel, from the results the biodiesel obtained can be used as alternative to diesel.

Keywords: biodiesel, physical properties, kinematic viscosity, density, flash point, carbon residue, esterification, oleic acid.

Introduction

The idea of using vegetable oil as fuel for diesel engines is over a century old. In 1911, Rudolph Diesel presented an engine based on compression-ignition is the diesel engine. At that time there was no specific fuel fed to this engine. Rudolph Diesel first used peanut oil (which is mostly in the form of triglycerides) at the turn of the century to demonstrate the patent for diesel engine. The rapid introduction of cheap petroleum made petroleum

the preferred source of diesel fuel, so that today's diesel engines do not operate well when operated on unmodified triglycerides. Natural oils, it turns out, are too viscous to be used in modern diesel engines [1-4]. In 1980s, a chemical modification of natural oils was introduced that helped to bring the viscosity of the oils within the range of current petroleum diesel. By reacting triglycerides with simple alcohols, a chemical reaction known as "transesterification" takes place in

industry to create a chemical compound known as an alkyl ester, which is the biodiesel [1].

There have been many problems associated with using vegetable oils directly in diesel engines, problems such as: decrease in power output and thermal efficiency of the engine, carbon deposits, oil ring sticking, thickening or gelling of the lubricating oil as a result of contamination by vegetable oils. Other disadvantages to the use of vegetable oils and especially animal fats are the high viscosity (about 11–17 times higher than diesel fuel) and lower volatility that result in carbon deposits in engines due to incomplete combustion.

Beside that, vegetable oils contain polyunsaturated compounds. Some chemical or physical modifications have been tested to overcome these problems: pyrolysis, micro emulsification, dilution and transesterification, so esters from vegetable oils are the best substitutes for diesel because they do not demand any modification in the diesel engine and less viscous and will easily flow through the fuel system of an engine, a high energetic yield, also vegetable oils naturally fix the solar energy and do not contain sulfur [5 & 2].

Biodiesel is the only alternative fuel currently available with an overall positive life-cycle energy balance as shown in fig. (1), producing 3.2 units of fuel product energy per unit of fossil energy consumed, compared to barely 0.83 units for petroleum diesel [3]. The presence of oxygen in biodiesel ($\approx 10\%$) improves combustion and reduces CO, soot, and hydrocarbon emissions while slightly increasing the NO_x emission. Biodiesel is generally considered to be renewable, since the carbon in the oil or fat originated mostly from carbon dioxide in the air, biodiesel is considered to contribute much less to global warming than fossil fuels. Diesel engines operated on

biodiesel have lower emissions of carbon monoxide, unburned hydrocarbons, particulate matter, and air toxics than when operated on petroleum-based diesel fuel [6].

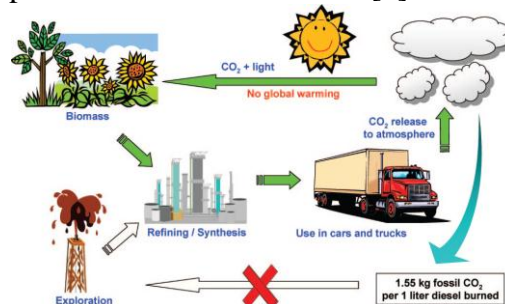


Fig. 1, Life cycle of diesel vs. biodiesel as an environmentally friendly fuel, The CO_2 cycle is closed for biodiesel but not for diesel [3 & 7]

There are six ways of producing biodiesel:

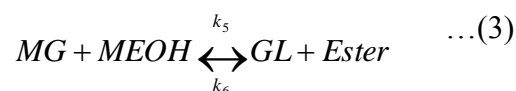
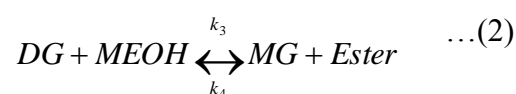
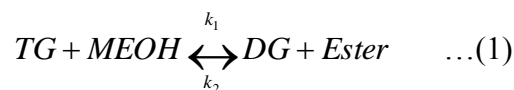
1. Direct use and blending of vegetable oil.
2. The usage of micro emulsions with short-chain alcohols.
3. Thermal cracking (Pyrolysis) of vegetable oils.
4. Transesterification of triglycerides catalysed by acids, bases or enzymes.
5. Esterification of free fatty acids with alcohols, using acids catalysts, solids acids or bioenzymes.
6. Two-stage process (transesterification and esterification).

Using transesterification reaction, biodiesel production is normally catalyzed by alkaline homogeneous catalyst to form a mixture of fatty acid methyl esters. Alkaline catalyst could result soap formation if the feedstock used contains substantial amount of free fatty acids (FFA). In the present work esterification of oleic acid (FFA) with methanol using acids catalyst has been consider the acid catalyzed esterification reaction is one of the suitable routes to solve the problem of soap formation [2,3,5& 8].

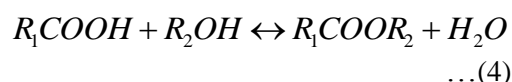
The principal ways of making biodiesel are by transesterification of

triglycerides and esterification of free fatty acids.

In the transesterification reaction, a tri-ester (triglycerides, TG) is converted to three individual esters. The three reactions of the transesterification reaction of triglycerides with alcohol to esters and glycerol (GL) are in the following equations:



In the esterification reaction, a new ester is produced.



The catalyst used in these processes can be enzymatic (lipases: *Candida*, *Pseudomonas*) [9], homogenous acids (H_2SO_4 , HCl , H_3PO_4) [10 & 11], heterogeneous acids (zeolites, sulfonic resins) [7, 12, 13 & 15], heterogeneous bases (MgO , CaO) and or homogenous bases (KOH , $NaOH$) [15 & 16], the latter being commonly used at industrial scale because it operated at moderate conditions (ambient pressure and a temperature of 60-70°C) and it gives a shorter reaction time.

Also the biodiesel can be produced without a catalyst using supercritical method, this was developed to solve the problem of miscibility of oil and alcohol that hinders the kinetics of transesterification, as well as to take advantage of not using catalyst at all. However, the operating conditions are severe ($T > 240^\circ C$, $P > 80 \text{ bar}$) and

therefore require special equipments [17 & 18].

The higher cost of biodiesel is due to its production mostly from expensive high-quality feedstock [19 & 20]. To solve these problems, producing biodiesel from economic feedstock non-edible oils are suitable for biodiesel production, because edible oils are already in demand and too expensive than diesel fuel. As non-edible oil is considered to be the wonder biodiesel feed stock because of rapid in growth, higher seed productivity, suitable for tropical regions.

Despite the chemical differences of biodiesel and diesel fuels, these two fuels have similar properties and performance parameters as given in table (1) [21, 22 & 23].

An important characteristic of diesel fuels is the ability to autoignite, quantified by the cetane number. Biodiesel has a higher cetane number and higher flash point than petroleum diesel, as given in table (1), this means it has better and safer performance. Along with its technical advantages over petroleum diesel, biodiesel brings several additional benefits to the society: rural revitalization, creation of new jobs, and less global warming.

Blends of biodiesel and petroleum diesel are designated by a "B" followed by the vol % of biodiesel. B5 and B20, the most common blends, can be used in unmodified diesel engines [2].

The present work concerns with the estimation of the physical properties of biodiesel experimentally such as kinematic viscosity, density, flash point and carbon residue for the biodiesel produced by esterification of oleic acid with methanol using sulfuric acid as a catalyst experimentally and compare with the physical properties of petrol diesel fuel.

Table 1, Petroleum Diesel vs. Biodiesel [21, 22 & 23]

Fuel Property	Petrol Diesel	Biodiesel
Fuel standard	ASTM D975	ASTM D6751
Fuel composition	C10-C21 HC	C12-C22 FAME
Kinetic viscosity, mm ² /s (at 40 °C)	1.3–4.1	1.9–6.0
Specific gravity, kg/L	0.85	0.88
Boiling point, °C	188–343	182–338
Flash point, °C	60–80	100–170
Cloud point, °C	-15 to 5	-3 to 12
Pour point, °C	-35 to -15	-15 to 10
Cetane number (ignition quality) min	40–55	48–65
Stoichiometric air/fuel ratio (AFR)	15	13.8
Life-cycle energy balance (energy units produced per unit energy consumed)	0.83/1	3.2/1

The esters were extensively characterized for their physical properties such as viscosity, heating value, cloud point, pour point, boiling point distribution, flash point and lubricity property.

Viscosity is the most important property of biodiesels since it affects the operation of fuel injection equipment, particularly at low temperatures when an increase in viscosity affects the fluidity of the fuel, high viscosity leads to poorer atomization of the fuel spray and less accurate operation of the fuel injectors. The lower the viscosity of the biodiesel, the easier it is to pump and atomize and achieve finer droplets. The conversion of triglycerides into methyl or ethyl esters through the transesterification process reduces the molecular weight to one third that of the triglyceride and reduces the viscosity by a factor of about eight. Biodiesels have a viscosity close to that of diesel fuels. As the oil temperature increases its viscosity decreases the ester content determined through kinematic viscosity at 40°C using the correlation of Felizardo et.al., (2006) [24]:

$$FAME\% = -45.055 * \ln \nu + 162.85 \dots (5)$$

The biodiesel kinematic viscosity according to ASTM must be between the ranges 1.9 - 6 cst (ASTM D 445).

Flash point is the minimal temperature where enough vapors of the liquid form an inflammable mixture with the air. Biodiesels have flash points 160 to 170°C. the minimal flash point regulated for biodiesel, ASTM norm D6751, is the most restrictive, as it fixes the minimal temperature at 130°C, whereas the European norm, EN 14214, regulates the minimal flash point at 120°C and the Brazilian ANP 07/2008 at 100°C. Very small quantities of residual alcohol present in biodiesel provoke a significant decrease in the flash point [25].

The carbon residue is a measure of how much residual carbon remains after combustion. Carbon residue is formed by decomposition and subsequent pyrolysis of fuel components can clog the fuel injectors. The maximum allowable carbon residue for biodiesel is 0.05wt% [26].

Experimental Work

The experiments were carried out using laboratory scale batch reactive distillation column as shown in Fig. (2). The unit consists of a still pot (D), which is heated using glycerin bath (C) that takes heat from a magnetic stirrer .

The distillation column is located above the still pot, packed with raschig

rings. The still pot consists of a three neck-round flask connected to the distillation column through its central opening. A thermometer was inserted in the first neck in order to measure the temperature of mixture at the bottom.

Heat for the still pot was supplied by a glycerin bath, the controller for heating rate by magnetic stirrer was used to change the power of the heating and hence change the heating rate in order to obtain the reaction temperature. The reaction takes place in the still and in liquid phase at atmospheric pressure, because of the high boiling point of oleic acid and the mixtures is heated by glycerin oil bath until the reaction temperature has been reached.

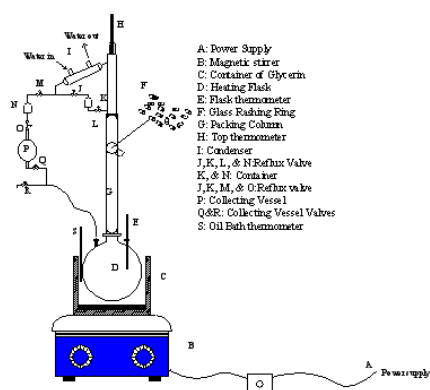


Fig. 2, Flow Diagram of Experimental Plant

The distillation column is made of a heat resistance glass column insulated with rubber insulation to avoid the heat loss. The inside diameter of column is 3.5 cm, packed with glass raschig rings of 10 mm length, 6 mm outside diameter, and 3 mm inside diameter.

The upper part of distillation column was connected to a double pipe condenser, which worked for condensing methanol and returning it to the column as recovery in startup period. This reflux of methanol resulted in the high ratio of methanol to oleic acid in the reboiler that helped to displace the reaction to the right. Water at room temperature was

circulated counter currently through the external pipe of condenser to condense the vapor out from the upper part of distillation column totally. Both portions of condensate were passed through graduated containers before reaching the column and the collecting vessel, the liquid distillate is collected in the collecting vessel P.

Oleic acid was charged into the still pot (reactor flask), the acid catalyst (H_2SO_4) of 98% purity was added to methanol and the mixture was charged to reactor flask. The reactants (oleic acid, methanol and the catalyst) were mixed in 2L flask, heated in a glycerin bath and kept at reaction temperature and atmospheric pressure. During this period, samples were taken at the specified time to test the kinematic viscosity.

At the end of the distillation process the content in the column is removed in graduated cylinder to separate water phase from the methyl oleate (biodiesel) phase if water is available, where esterification of fatty acid is a reversible reaction and water is formed. Removal of water can drive the reaction equilibrium to the completion and therefore increase the conversion. By removing water as by product the equilibrium is shifted towards ester methyl oleate (biodiesel) formation. The biodiesel will always be separated at the bottom of the reactive distillation column. Water is present as a side product and typically is removed as top product due to its lower boiling point, together with the methanol.

In order to determine the best conditions for methyl oleate (biodiesel) production by batch reactive distillation, the experiments were carried out using different variables such as molar ratio of methanol to oleic acid 4:1, 6:1 and 8:1, amount of catalyst 0.6, 1.2, and 1.8 g sulfuric acid/g oleic acid, reaction time 36, 57, and 75 minutes and reaction

temperature 100°C, 120°C, and 130°. The design of experiments by the Taguchi method was considered for performing the minimum numbers of experiments of 9 [27 & 28]

The functional groups of biodiesel were examined by FTIR spectrum this was by measuring the energy associated with the vibration of atoms that are connected together [26]. FTIR has been used to elucidate structures in biodiesel.

The methyl oleate (biodiesel) samples were analyzed by FTIR with IR- Prestige-21 spectrometer with Detuterated Triglycine Sulfate (DTGC) sampling attachment and a resolution of 8° per cm⁻¹. The spectra were taken at room temperature and in a range of 4000 – 400 cm⁻¹, air spectrum was

used as the background. Analysis and samples were carried out in Iben Sina Company / Ministry of Industry and Minerals.

The functional group composition of methyl oleate (Biodiesel) was confirmed by FT-IR as shown in Fig. (3) sharp band at 2924.09 cm⁻¹ is due to C–H stretching vibration of methylene groups. A sharp band 1743.65 cm⁻¹ is attributed to C=O stretching frequency. Absorption at 1435.04 cm⁻¹ and 1458.18 cm⁻¹ is assigned to asymmetric –CH₃ or –CH₂ bending vibrations. Bands at 1242.16 cm⁻¹, 1195.87cm⁻¹ and 1172.72 cm⁻¹ are due to C–O stretching of ester. The bands obtained at 1118.71cm⁻¹, 1018.41cm⁻¹ and 875.68 cm⁻¹ are due to C–C stretching.

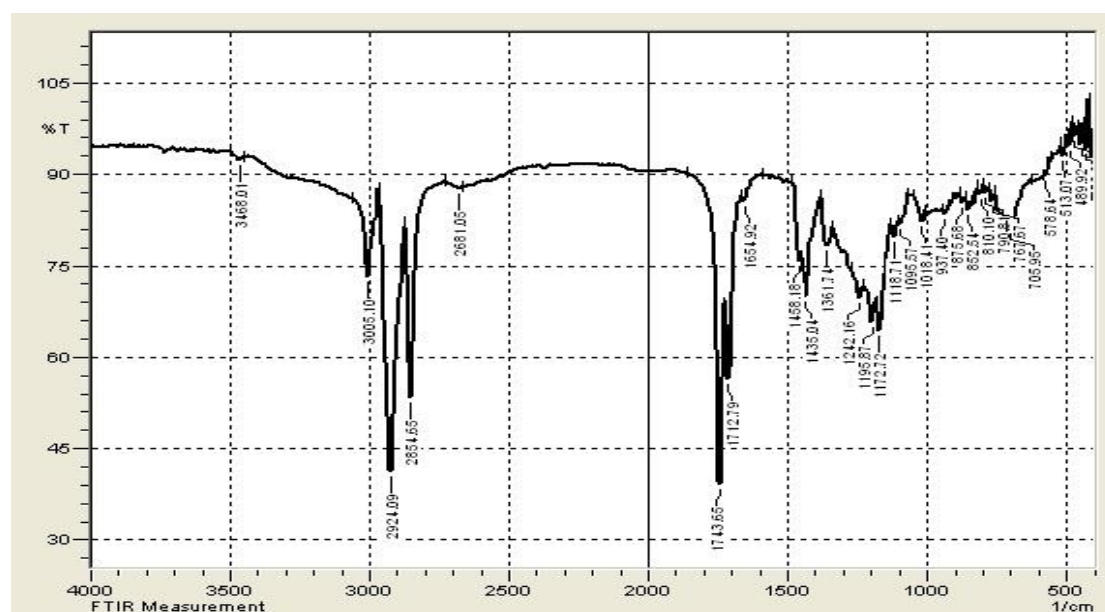


Fig. 3, FT-IR spectrum of produced methyl oleate (Biodiesel)

Physical Properties Analysis

Flash Point Analyzer

The biodiesel flash point is tested using open and close cup flash point. The flash points were measured using Cleveland open cup Flash Point tester (Koehler Instrument Company, Inc. K13900) and for obtaining a more accurate result a close cup method was also used by Pensky-Martens close cup tester (Koehler Instrument Company,

Inc. K16200), using ASTM D93 Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester. The apparatus and method consist of the controlled heating of the biodiesel in a closed cup, introducing an ignition source, and observing if the heated biodiesel flashes, the temperature at which the biodiesel flashes is the flash point.

For a flash point below 93°C means that biodiesel obtained is out of specification, if the biodiesel has not flashed at 160°C, the test is finished and the result is reported as >160°C.

Viscosity Testing

IUbbelohde viscometer was used for transparent liquids (Koehler Instrument Company, Inc.) size 1, the viscometer constant is 0.00933 (mm²/s)/s [cst/s], water bath is used to maintain the biodiesel at 40°C.

The kinematic viscosity (ν), [(mm²/s), or cst] is calculated from mean measure flow time t and the viscometer constant C using the following equation:

$$\nu = C * t \quad \dots(6)$$

The ester content was determined at 40°C using the following equation [24]:

$$FAME\% = -45.055 * \ln \nu + 162.85 \quad \dots(5)$$

Density

Density is the mass per unit volume of a substance at a given temperature. Fatty acid alcohol esters (biodiesel) have a density of about 0.88 g/ml was measured using a pycnometer of 50 ml and at room temperature.

Carbon Residue

The test basically involves heating the fuel to a high temperature in the absence of oxygen. Most of the fuel will vaporize and be driven off, but a portion may decompose and pyrolyze to hard carbonaceous deposits. This is particularly important in diesel engines because of the possibility of carbon residues clogging the fuel injectors.

The carbon residue for biodiesel was measured in Petroleum Engineering laboratory/Baghdad University. The samples were heated to 550°C in a furnace and tested using a Ramsbottom carbon residue manufactured by glass

unit. The carbon residue (wt %) is calculated as weight of carbon after combustion divided by the weight of total sample before combustion.

Results and Discussion

Operating Variables

-Effect of Molar Ratio

Molar ratio of methanol to oleic acid is one of the most important variables that are affecting the ester content. As the molar ratio of methanol/oleic acid increases the biodiesel (methyl oleate) content wt% increases, as shown in Fig. (4) and the numerical value of the maximum point indicates the best molar ratio of methanol to oleic acid. Thus the best condition for the maximum biodiesel (methyl oleate) content wt% is 8:1.

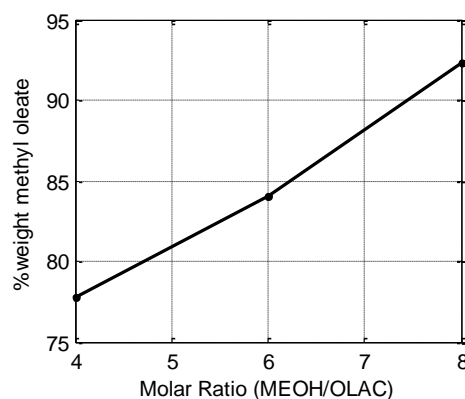


Fig. 4, Effect of molar ratio on the biodiesel (methyl oleate) content wt%

-Effect of Catalyst Amount

Different amounts of catalyst of 0.6, 1.2 and 1.8 g sulfuric acid/g oleic acid have been used. The amount of catalyst increases as the biodiesel (methyl oleate) content wt% increases, as shown in Fig. (5). The catalyst enhanced the reaction rate and conversion. Therefore, the best amount of catalyst for the maximum biodiesel (methyl oleate) content wt% is 1.8 g sulfuric acid/g oleic acid.

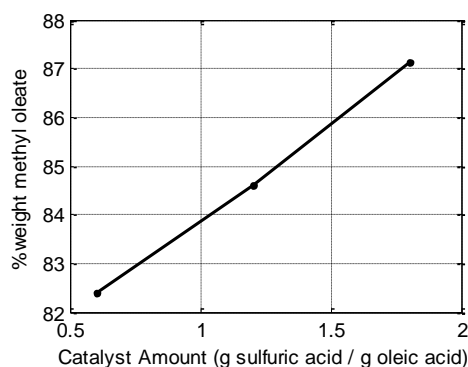


Fig. 5, Effect of catalyst amount on the biodiesel (methyl oleate) content wt%

-Effect of Reaction Time

Different reaction times of 36, 57 and 75 minutes have been studied, when the reaction time increases the biodiesel (methyl oleate) content wt% increases up to 57 min but decreases for further increases in time, as shown in Fig. (6). Thus, the best reaction time for the maximum biodiesel (methyl oleate) content wt% is 57 min.

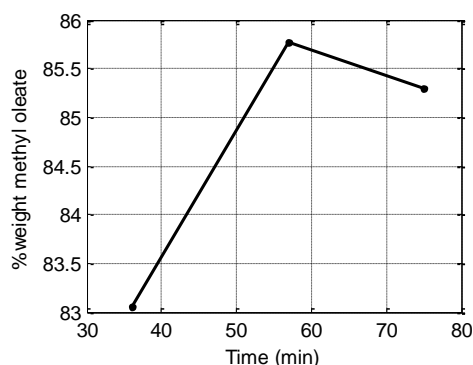


Fig. 6, Effect of time on the biodiesel (methyl oleate) content wt%

-Effect of Reaction Temperature

Reaction temperature is another critical variable, the reaction is endothermic and when the temperature increases the biodiesel (methyl oleate) content wt% increases too, as shown in Fig. (7). The best reaction temperature that gives maximum biodiesel (methyl oleate) content wt% is 130°C.

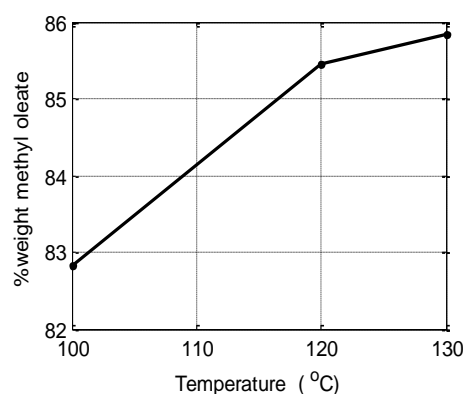


Fig. 7, Effect of reaction temperature on the biodiesel (methyl oleate) content wt%

Physical Properties

From the above studied variables and for the best operating conditions of molar ratio of methanol to oleic acid 8:1, catalyst amount 1.8 g sulfuric acid/g oleic acid, time 57 min and reaction temperature 130°C the physical properties of the produced biodiesel have been studied.

-Flash Point

The flash point measures the tendency of the sample to form a flammable mixture with air under controlled conditions. This property must be considered to assess the overall flammability hazard of a material. The flash point of FAME (B100) is greater than or equal to 130°C according to ASTM. The results of the flash point at different variables is given in table (2).

The methyl oleate flash point was significantly higher than that of diesel fuel and thus would be quite safe for use in transportation compared to diesel which has a flash point of 52-66°C. The higher flash point of biodiesel is important advantage. Therefore, by including a flash point specification of 130°C or higher, the ASTM standard limits the amount of alcohol to a very low level (<0.1%). Residual alcohol left in biodiesel will generally be too small to have a negative effect on fuel performance [25].

Table 2, Flash points of the biodiesel from the experimental results

Exp. runs	Molar ratio (MeOH/olac)	Catalyst Amount	Reaction Temperature (°C)	Flash point (°C) Open	Flash point (°C) Close
1	4:1	0.6	100	175	-
2	4:1	1.2	120	-	160
3	4:1	1.8	130	-	162
4	6:1	0.6	130	179	-
5	6:1	1.2	100	177	-
6	6:1	1.8	120	180	-
7	8:1	0.6	120	179	-
8	8:1	1.2	130	190	-
9	8:1	1.8	100	-	161

Kinematic Viscosity

The viscosities of the biodiesel produced at lower temperature are higher than that of the corresponding experiments conducted with the same feed ratio but at higher temperatures. Esterification reaction is responsible for minimizing the viscosity of free fatty acid in order to apply it as a fuel for engines because high viscosities of free fatty acid leads to operational problem such as engine deposit [29].

In the present work, the kinematic viscosity of methyl oleate was determined at 40°C (ASTM D445) as this is the temperature prescribed in biodiesel and petro diesel standards.

The viscosity of the biodiesel decreased as the operating temperature increased, as shown in Fig. (8) this is because as the temperature increases the esterification reaction is facilitated.

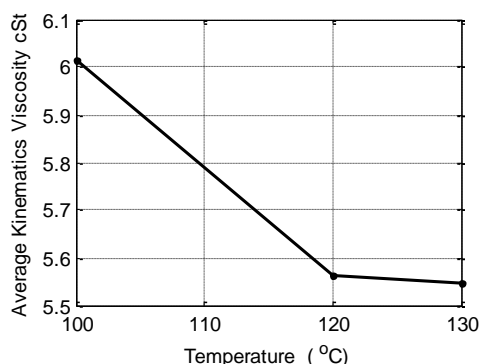


Fig. 8, Effect of reaction temperature on biodiesel kinematics viscosity

The viscosity decreases with increase in feed molar ratio of oleic acid to methanol for experiment conducted at

a given temperature, , as shown in Fig. (9) this is due to the increase in the conversion of oleic acid. The conversion of oleic acid increases with increasing the excess methanol.

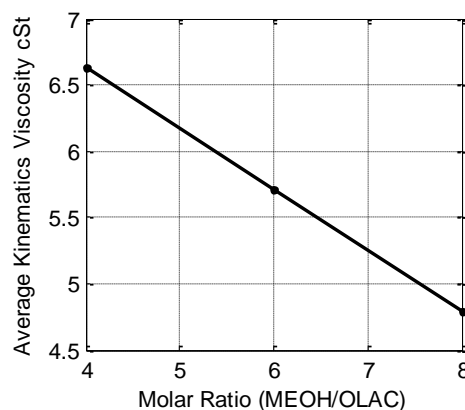


Fig. 9, Effect of Molar ratio on biodiesel kinematics viscosity

Increasing the amount of catalyst the viscosity of biodiesel decreases, this is due to an increase in the conversion of oleic acid, as shown in Fig. (10).

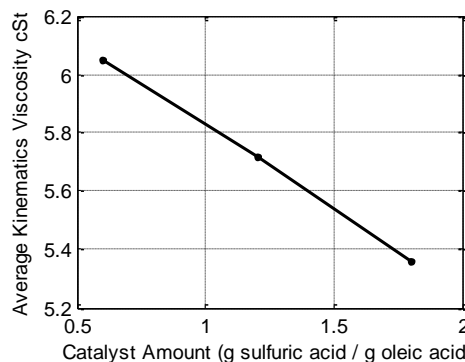


Fig. 10, Effect of catalyst amount on biodiesel kinematics viscosity

The viscosity decreases with increasing the time of reaction up to 57min, for further increase in time there is no significant decrease in the viscosity as shown in Fig. (11).

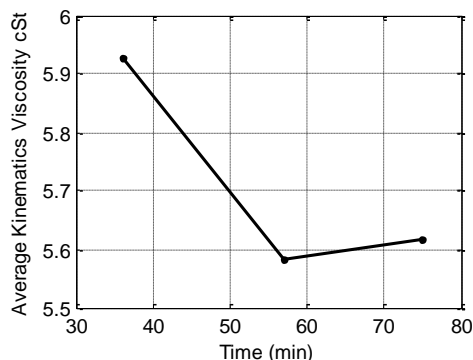


Fig. 11, Effect of time of reaction on biodiesel (Methyl oleate) kinematics viscosity

Density

The density of the biodiesel produced was conducted and found to be in the range 0.87-0.88 g/ml. When comparing the average of the results 0.8787 g/ml with the ASTM D6751 for biodiesel 0.870–0.890 g/ml which is acceptable.

Decreasing the density of biodiesel with increasing the molar ratio, this is due to the decrease in the amount of oleic acid, as shown in Fig. (12).

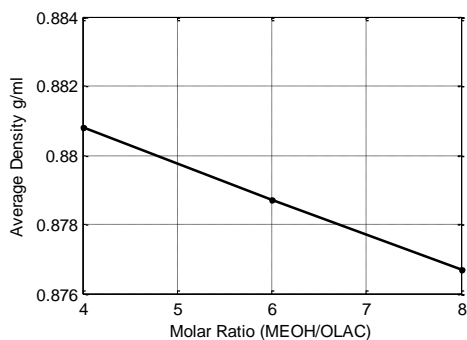


Fig. 12, Effect of Molar ratio on biodiesel density

Increasing the amount of catalyst the density of biodiesel decreases, this is due to an increase in the conversion of oleic acid, as shown in Fig. (13).

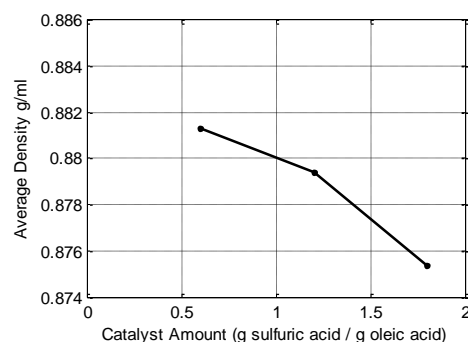


Fig. 13, Effect of catalyst amount on biodiesel density

The density of biodiesel increasing with time of reaction as shown in Fig. (14).

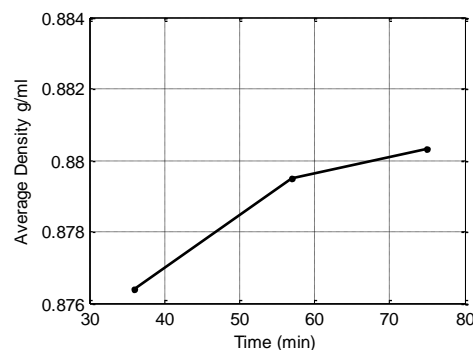


Fig. 14, Effect of time of reaction on biodiesel density

The density of the biodiesel decreased as the operating temperature increased up to 120°C, for further increase in temperature, the density increased, as shown in Fig. (15).

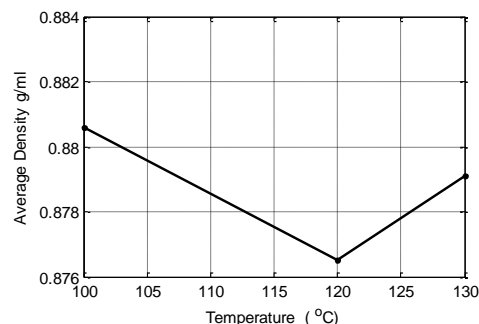


Fig. 15, Effect of reaction temperature on biodiesel density

Carbon Residue

The carbon residue of the biodiesel obtained in is 0.0392wt%, which is satisfied with the standard biodiesel

(the maximum allowable of carbon residue for a biodiesel is 0.05 wt %).

The Comparison between Different Biodiesel and Petrodiesel Fuels

The physical properties of biodiesel obtained from the present are compared with other works of [30, 31] and diesel oil [23], as given in table (3). The operating conditions of [30] are methanol to oleic acid 8:1, catalyst amount 1.8 wt% oleic acid, time 90 min and reaction temperature 180°C in a batch reactive distillation, and for [31] that use jatropha carcus oil and hydroxide sodium as a catalyst the operating conditions are methanol to oil acid 5.5:1, catalyst amount 2 wt% oil, time 24 min and reaction

temperature 50°C in a continuous reactive distillation,

The flash point and specific gravity of biodiesel obtained from the present work are similar to that from previous work [30] and diesel oil from petroleum [23]. The kinematics viscosity is important indicator the quality of fuel, high value of viscosity gives rise to poor fuel outomization, incomplete combustion and carbon deposition on the injectors. Therefore, the biodiesel viscosity must be low. The viscosity of biodiesel obtained from the present work are 4.457 cSt which is slightly greater than that of petro diesel viscosity of 1.9-4.1cSt, as given in table (3)

Table 3, Comparison of different biodiesel and diesel oil

Fuel Properties	Present work	Biodiesel from oleic acid [28]	Biodiesel from WVO acid [29]	Diesel Oil [23]	Method
Flash point, °C (close cup)	165	172	177	52-66	ASTM D 93
Kinetic Viscosity, mm ² /s, (at 40 °C)	4.457	4.537	4.8	1.9-4.1	ASTM D445
Density g/ml	0.875	0.8798	0.89	0.82	ASTM D 1298
Carbon residue. wt%	0.0392	0.035	-	-	ASTM D 189
Ester Content, wt%	95.516	-	-	-	-

Conclusion

The comparison between different biodiesel and petrodiesel fuels at the best conditions to produce biodiesel and according to Tanguchi method are the molar ratio of methanol to oleic acid 8:1, catalyst amount 1.8 g sulfuric acid/g oleic acid, time 57 min and reaction temperature 130°C. From this comparison one can conclude that the flash point, kinematics viscosity, density and carbon residue that experimentally estimated in the present work for the biodiesel that produced from the esterification reaction of oleic acid and methanol are similar to those of diesel fuel, so the biodiesel (methyl oleate) has the quality required to be a diesel substitute.

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