Optimization of Experimental Conditions for Biodiesel Production

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***Abstract*-- This study is based on optimizing the experimental conditions of biodiesel production by base-catalyzed transesterification using waste cooking oil (WCO). In this study, the key parameters varied were methanol (20, 25, 30, 35, and 40%), sodium hydroxide (0.4, 0.6, 0.8, 0.9 and 1.0g), reaction time (40, 60, 90, 100 and 120 minutes) and reaction temperature (50, 52, 55, 58, and 60 ^{o}C). Maximum biodiesel yield of 86% was obtained at optimum conditions of 30% methanol concentration, 0.4g of NaOH concentration, 60^{o}C reaction temperature and 90 minutes of operation. Biodiesel produced meets American Standard of Testing and Materials (ASTM) standards of biodiesel fuel: viscosity (4.0564 – 4.9824cSt), density (0.8790 – 0.8819g/cm^{3}), flash point (157 – 168^{o}C), pour point (0 to -3^{o}C) and calculated cetane index (7.45 – 8.26).**

***Index Term*-- Biodiesel, fossil fuel, methanol, transesterification, waste cooking oil.**

1. INTRODUCTION

Majority of the world's energy needs is met through petrochemical sources, coal, and natural gases; these sources are not infinite and at current usage rates will be consumed shortly.[1,2,3] Diesel fuel is largely utilized in the transport, agriculture, commercial, domestic, and industrial sectors for the generation of power/mechanical energy. The increasingly high energy demand in the industrialized world and associated pollution problems resulting from the widespread use of fossil fuels make it essentially necessary to develop renewable energy sources with lesser environmental pollution challenges, when compared to the conventional fossil fuels. This has stimulated recent interest in alternative sustainable sources of energy.[4] An alternative fuel must be technically feasible, economically competitive, environmentally acceptable, and readily available. One possible alternative to fossil fuel is the use of derivatives of oils of plant origin such as vegetable oils. This alternative diesel fuel can be termed biodiesel.[4]

Increasing uncertainty about global energy production and supply, environmental concerns due to the use of fossil fuels, and the high price of petroleum products are the major reasons to search for alternatives to petro-diesel. Global supply of oil and natural gas from the conventional sources is unlikely to meet the growth in energy demand over the next 25 years.[2,5] In this perspective, considerable attention has been given towards the production of biodiesel as a diesel substitute. A growing environmental concern is the effect of green house gases on the environment in recent decades and this places the biodiesel production at an advantaged position for many environmental friendly policies, countries and industries. The ability to use biodiesel directly in diesel engines with little or no modifications, with similar fuel economy and with reduced greenhouse gas emissions are the primary advantages of biodiesel in addition to its qualities of being non toxic and biodegradable.[6]

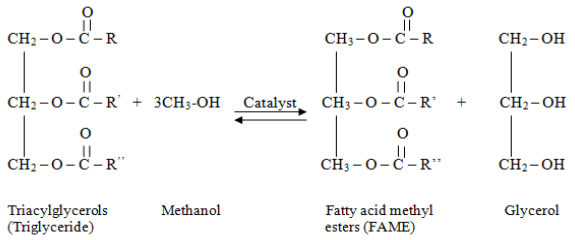
Biodiesel, an alternative diesel fuel, is produced from renewable biological sources such as vegetable oils and animal fats.[7,8] The American Society for Testing and Materials (ASTM) defines biodiesel fuel as monoalkyl esters of long chain fatty acids derived from a renewable lipid feedstock, such as vegetable oil or animal fat. ''Bio'' represents its renewable and biological source in contrast to traditional petroleum-based diesel fuel; ''diesel'' refers to its use in diesel engines. As an alternative fuel, biodiesel can be used in neat form or mixed with petroleum-based diesel.[9,10]

Biodiesel, as an alternative fuel, has many merits. It is derived from a renewable, domestic resource, thereby relieving reliance on petroleum fuel imports. It is biodegradable and non-toxic. Compared to petroleum-based diesel, biodiesel has a more favourable combustion emission profile, such as low emissions of carbon monoxide, particulate matter and unburned hydrocarbons. Carbon dioxide produced by combustion of biodiesel can be recycled by photosynthesis, thereby minimizing the impact of biodiesel combustion on the greenhouse effect.[9]

At present, the high cost of biodiesel is the major obstacle to its commercialization. Biodiesel usually costs more compared to the cost for petroleum based diesel. It is reported that the high cost of biodiesel is mainly due to the cost of the vegetable oil.[6,10,11,12] Exploring ways to reduce the high cost of biodiesel is of much interest in recent biodiesel research, one way of reducing the biodiesel production costs is to use the less expensive feedstock containing fatty acids such as inedible oils, animal fats, waste cooking oil and by-products of the refining vegetable oils.[12,13]

The use of Waste Cooking Oil (WCO) instead of fresh vegetable oil is an effective way to reduce the raw material cost because it is estimated to be about half the price of virgin oil.[14] In addition using waste cooking oil could also help to solve the problem of waste oil disposal.[15]

Simple chemical reaction during the production of biodiesel (Fatty acid methyl esters) through transesterification of WCO (Triglyceride) is shown below:



The overall aim of the study is to establish the optimum conditions for producing biodiesel from alkali-catalyzed transesterification using waste cooking oil as the major raw material. This will be achieved by considering the effects of variation in certain parameters, such as weight of NaOH, methanol, temperature and reaction time on the production of biodiesel. And by considering the properties of the biodiesel (density, viscosity @ 40^0C, pour point, flash point and cetane index number) to determine the quality of biodiesel (using ASTM standards).

2. Materials and Methods

Waste cooking oil, the main feed, was obtained from Covenant University cafeteria in Ota, Ogun State Nigeria. The equipment used in this study include: density meter (DMA 38), thermostatic viscosity bath, flash point tester (NPM 440) and pour point tester. While the chemical reagents include: methanol, NaOH, KOH, HCl and benzene.

2.1 WCO Acid Value Determination

To address the challenge of oil rancidity, acid value determination was carried out to determine the quantity of Free Fatty Acid (FFA). 10g of WCO was accurately weighed, 95% alcohol was taken and neutralized with dilute NaOH solution. 50ml of this neutral alcohol and 50ml benzene were added to the WCO in the flask. The contents of the flask were shaken well to dissolve the FFA. This was immediately titrated using KOH solution and phenolphthalein as indicator.

2.2 Determination of NaOH needed (catalyst)

1g of Sodium Hydroxide pellets was dissolved completely in 1000ml of distilled water and 1ml of WCO was dissolved in 10ml of isopropyl alcohol. Two drops of phenolphthalein was added to the WCO solution. Titration was carried out using an eye dropper. The number of millilitres derived from the titration was taken and multiplied by the number of litres of WCO to be transesterified to determine the quantity of NaOH needed for the reaction.

2.3 Experimental Procedures on Biodiesel Production

100g of WCO was used during each of the experiments. The effects of temperature, percentage weight of methanol, weight of NaOH (catalyst) and reaction time were considered by varying one of the factors and keeping the other factors constant.

100g of WCO was put in a flat bottomed flask. The required amount of catalyst (NaOH) was weighed and dissolved completely in the required amount of methanol, using the hot plate and magnetic stirrer to form sodium methoxide solution. This was added into warm oil and then mixed vigorously using the magnetic stirrer. The required temperature for the reaction was maintained throughout the reaction time. Loss of reagents (especially methanol) to the atmosphere was prevented. The reacted mixture was poured into a separating funnel. The mixture was left for 24 hours to allow separation by gravitational settling into a clear golden liquid biodiesel on top and light brown glycerol at the bottom (Fig. 1). Glycerol layer was drained off from the separating funnel leaving only crude biodiesel. The crude biodiesel was then purified by washing with warm water to remove residual catalysts or soaps and to bring down the pH of the biodiesel to about 7. This was carried out by first weighing the biodiesel, the half weight of biodiesel is the weight of warm water (together with little quantity of Hydrochloric Acid, HCl) added to the crude biodiesel. The mixture was left for 12 hours to separate into a top layer of biodiesel and layer of impure water (Fig. 2). Water was drained off first and then the biodiesel, the washing process was repeated until the water layer became clear. Acid was only added to the water during the first washing. The pure biodiesel was dried by heating it to 130^oC (to ensure that any trace of water present is evaporated) and then cool.

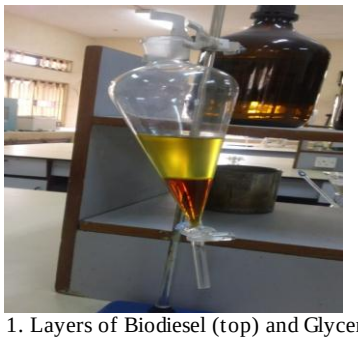


Fig. 1. Layers of Biodiesel (top) and Glycerol

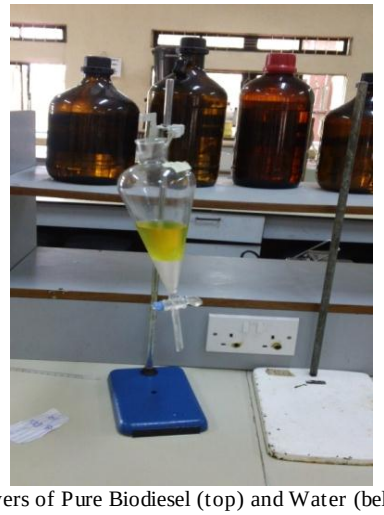


Fig. 2. Layers of Pure Biodiesel (top) and Water (below).

2.4 Biodiesel Analysis

To ascertain the quality of the biodiesel produced, the following properties of biodiesel were determined: viscosity (carried out in accordance with ASTM D445), pour point (in accordance with ASTM D97), flash point, density (in

accordance with ASTM D1298) and cetane index (calculated). Properties of the biodiesel obtained were shown in Table I.

3. Discussion of Results

The effects of factors considered on biodiesel yield were illustrated in Fig. 3, 4, 5 and 6. To consider the effect of variation in the reaction temperature, the reaction temperature must be kept below the boiling point of methanol (65^0C) and also, methanol, NaOH and reaction time were kept constant. The results from Fig. 3 show that maximum biodiesel yield of 86% was obtained at 60^oC temperature and that biodiesel yield increased as the temperature increased.

TABLE I
PROPERTIES OF BIODIESEL PRODUCED

Exp	BIODIESEL PROPERTIES				
	Density at 15^oC [g/cm^3]	Viscosity at 40^oC [cSt]	Flash Point [^0C]	Pour Point [^0C]	Cetane Index
1	0.8796	4.2331	158	-3	8.09
2	0.8798	4.2431	160	-3	8.04
3	0.8795	4.2909	162	-3	8.12
4	0.8817	4.9720	165	0	7.15
5	0.8819	4.9980	168	-3	7.50
6	0.8812	4.0564	157	0	7.70
7	0.8817	4.3904	163	-3	7.51
8	0.8819	4.1045	163	-3	7.45
9	0.8794	4.1642	164	0	8.15
10	0.8790	4.0493	159	-3	8.26
11	0.8792	4.1504	161	0	8.21
12	0.8795	4.0321	158	-3	8.12
13	0.8815	4.3234	165	0	8.12
14	0.8777	4.3879	162	-3	7.56
15	0.8816	4.2634	160	0	8.62
16	0.8813	4.4687	158	0	7.54
17	0.8818	4.3987	168	0	7.62
18	0.8810	4.5028	159	-3	7.48
19	0.8813	4.7528	160	-3	7.71
20	0.8815	4.9824	162	-3	7.62

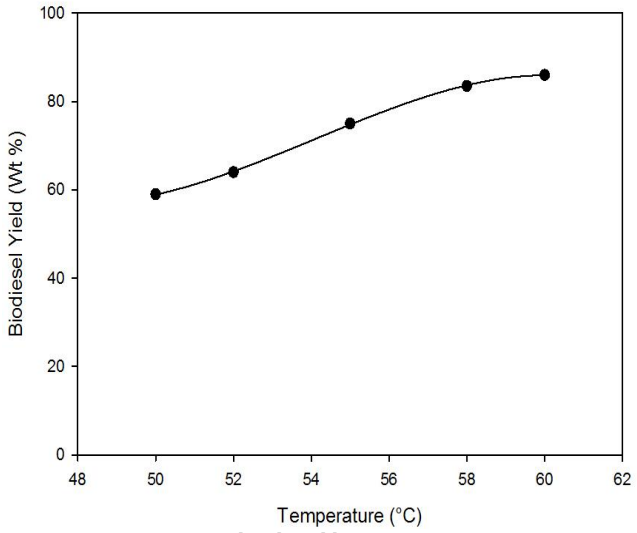
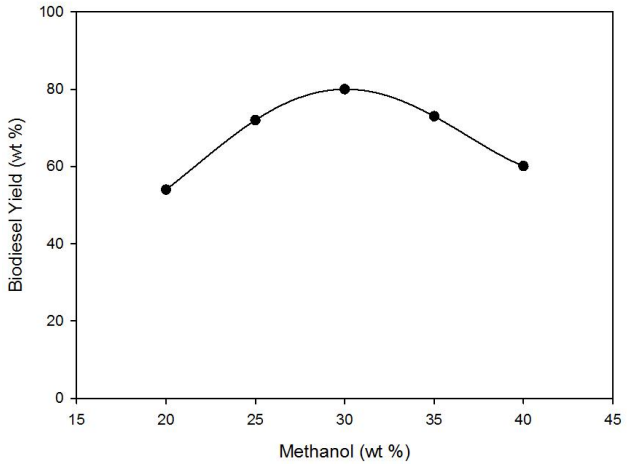


Fig. 3. Biodiesel Yield against Temperature

From Fig. 4, the optimum methanol weight percent of 30% produced maximum biodiesel yield of 80%. An increase in the quantity of methanol resulted in decrease in biodiesel yield and increase in glycerol (byproduct).



.Fig. 4. Plot of Biodiesel Yield against Methanol Quantity

From Fig. 5, it can be deduced that the optimum concentration of 0.4g NaOH was required for effective transesterification of WCO, maximum biodiesel yield of 82.3% was obtained. The figure also shows reduction in biodiesel yield as the catalyst concentration (NaOH) increases, this resulted in increased formation of glycerol.

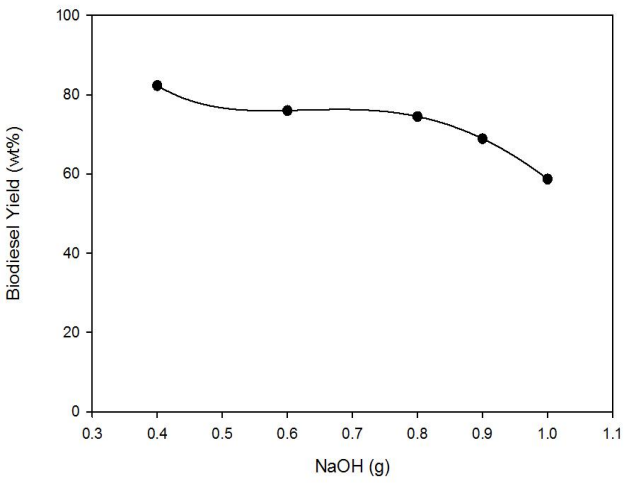


Fig. 5. Biodiesel Yield against NaOH

In order to optimize the reaction time, experiments were conducted using conditions that gave best yield of biodiesel so far: that is, methanol concentration of 30 wt%, 0.4g NaOH and temperature of 60 ^{o}C. The results (Fig. 6) show the optimum biodiesel yield was obtained at optimum condition of (90 – 100) minutes, although the yield at 120 minutes is the maximum yield.

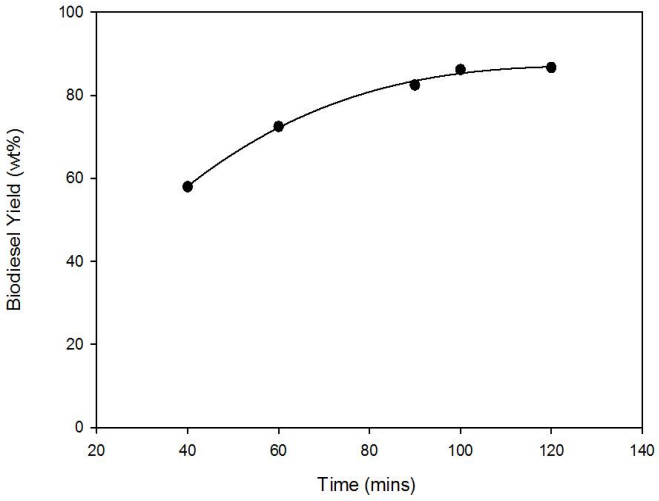


Fig. 6. Biodiesel Yield against Reaction Time

4. CONCLUSION

Easy availability and inexpensive of Waste Cooking Oil (WCO) make it a reliable source of biodiesel for sustainable energy generation. The use of WCO reduces biodiesel production cost by about (60 – 70)% because the feedstock cost constitutes approximately (70 – 95) % of the overall biodiesel production cost.[12]

Optimum biodiesel yield was obtained at optimum conditions of 30% methanol concentration, 0.4g of NaOH concentration, 60^{o}C reaction temperature and 90 minutes of operation. Biodiesel produced meets American Standard of Testing and Materials (ASTM) standards: viscosity (4.0564 – 4.9824cSt), density (0.8790 – 0.8819g/cm^3), flash point (157 – 168^{o}C), pour point (0 to -3^{o}C) and cetane index (7.45 – 8.26).

The viscosity values obtained were within the range (4.0564 – 4.9824 cSt) which conforms to ASTM standard (1.9 – 6.0 cSt). The flash point values of the biodiesel produced were within the range (157 – 168 ^{o}C) which conforms to ASTM standard (>130 ^{o}C). The density values of the biodiesel produced were within the range (0.8790 – 0.8819) g/cm^3 which conforms to ASTM standard (0.88 – 0.9 g/cm^3).[16,17] The pour point values of the biodiesel produced were within the range (0 to -3 ^{o}C) and this conforms to ASTM standard (-3 to 5 ^{o}C). Also, using WCO for biodiesel production is cost effective[11] and it is the solution to the challenge of WCO disposal.[10]

Further work that can be considered include: the effect of KOH (as catalyst) instead of NaOH, the effect of acid catalyst (e.g HCl), and the determination of other properties of the biodiesel produced.

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