IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 10, Issue 4, April 2020, ||Series -II|| PP 08-17

Biodiesel Production Using Coconut Oil Extract

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Received 07April 2020; Accepted 22 April 2020

ABSTRACT: Environmental concerns and diminishing reserves of fossil fuels has increased the demand for alternative sources of renewable diesel fuels. This paper validates the possibility of biodiesel production from low hydro-carbon content such as coconut oil. It focuses on oil extraction, physiochemical properties characterization, and trans-esterification of the extracted oil to obtain biodiesel. The biodiesel produced was characterized and compared with fossil-based diesel. Results showed the optimized reaction conditions for one stage trans-esterification of coconut oils at 0.20g/mol of ethanol to oil, the addition of 1% KOH catalyst, a 60 °C reaction temperature, and about 60mins of reaction time. Quality characterization of the diesel showed that it has excellent diesel characteristics. The measured parameters were within the American Society for Testing and Materials (ASTM) standard specifications for biodiesel production.

KEYWORDS: Biodiesel, Coconut oil, Characterization, Fermentation and Trans-esterification

I. INTRODUCTION

Energy is a vital infrastructure for economic development. Fossil fuels are essential for sustaining lives, economic activities, and stable, sustainable, energy supplies and prices are crucial for any society today [1]. However, fossil fuels are non-renewable energy sources. They that take millions of years to form and they are being consumed faster than they are being generated[2]. The supply of these fuels is limited, and they pollute the environment. Hence, it is necessary to adopt alternative renewable energy sources [3].

The use of renewable energies and biofuels contributes to environmental and socio-economic sustainability development. A Biofuel is any solid, liquid or gaseous fuel that is derived from biological materials or biomass such as food, crops, animal waste, algae, etc. Biofuels are a leading substitute for fossil fuels, and their production is continuously growing all over the world [1].Today, biodiesel is produced by transesterification of fatty acids in vegetable oils. The transesterification is achieved by using an alkaline catalyst (sodium or potassium hydroxide at 80 °C), a reaction that proceeds with very high yield [4]. Biofuels shields away from the dependence on the use of non-renewable fossil fuel that delivers high toxic emission, high greenhouse gases leading to global warming in the world. Various attempts have been made to make use of vegetable oils in diesel engines [5]. A possible remedy profound by many authors is the blending of the vegetable oil and diesel in some proportions[6].Biodiesel is an excellent alternative source of renewable energy that can be used in a conventional diesel engine without modification because of close fuel properties.

Coconut oil obtained from plants is one of the renewable sources which can be developed as a raw material for the manufacturing of biodiesel. Coconut oil extracted from the kernel of mature coconut has various applications as food, cosmetics, as a medication vector and in the production of biofuel. Because of its high saturated fat content, it is slow to oxidize and thus resistant to rancidification, lasting up to six months at 24 °C (75 F) without spoiling. Coconut oil is a clean liquid biofuel, relatively cheap, easy to extract, non-toxic and aromatic. [7] studied the properties and corrosion characteristics of biodiesel produced from coconut and fossil diesel blending.

II. METHODOLOGY

Matured coconuts were de-husked in a well-ventilated environment at room temperature. Size reduction was carried out before blending using a food grinder. The processes involved in oil extraction by fermentation method can be seen in figure 1.

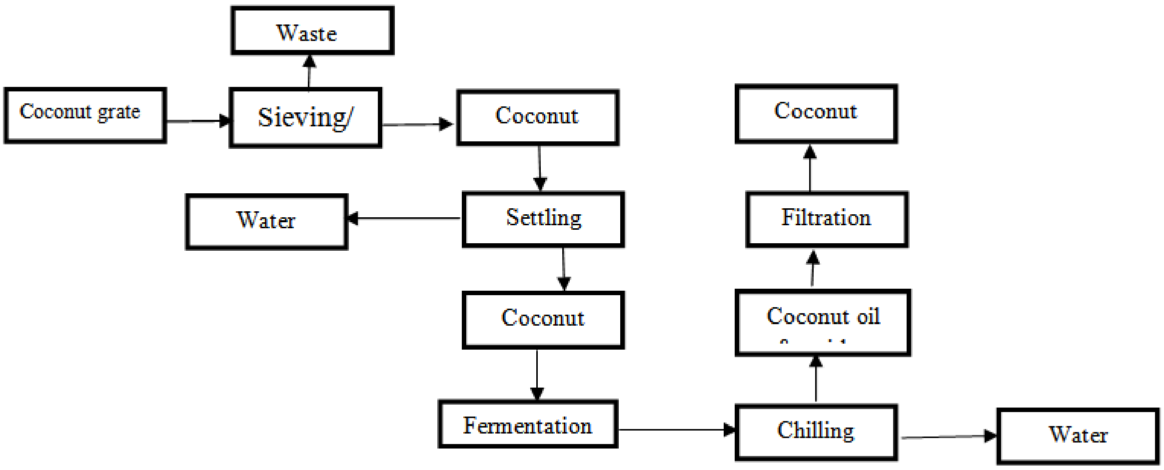

Figure 1. Flow Chat on Oil Extraction

The wet process was used to extract coconut oilfrom the coconut milk, then the physical and chemical characteristics of the oil obtained was determined.

The coconut oil ethyl ester was produced by transesteryfing coconut oil with ethanol in the presence of potassium hydroxide (KOH) as a base catalyst catalyst. Figure 2 shows the procedure involved in the trans-esterification. The reaction mechanism is a simple nucleophilic attack and there is a possible side reaction that will occur if there is an excess addition of potassium hydroxide that will produced a potassium carboxylate molecule (soap).

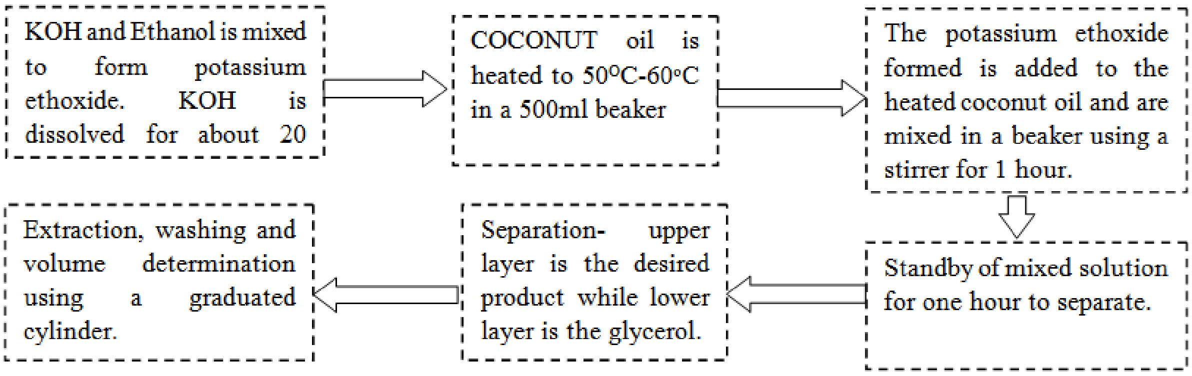

Figure 2. Schematic Diagram of Trans-esterification

In this study, the Central Composite design of RSM was used to determine the effect of interaction ofvarying temperatures ranges,alongside catalyst range and the oil/ethanol ratio on the yield of the trans-esterification process.The specific gravity/density (ASTM D1298), flash Point (ASTM D93), kinematic viscosity (ASTM D445), melting point, and combustion point of the biodiesel sample was also determined.

III. RESULTS

The result of the produced coconut oil are as follows. Color measurement by visual comparison gave Ivory white/water clear colour. The specific gravity of the oil was found to be 0.914g/mol, viscosity was 23Pa.S, flash point of the oil to be 267°C and the Iodine value of 123.1mgI2 /g. The acid value was 14mgKOH/g and saponification value was also determined to be 190mgKOH/g. Free fatty acid was 28 mg/g and Peroxide value was 191.89mg/g.

The result of the effect of temperature, oil/ethanol and amount of catalyst on the yield of biodiesel are presented in table1. During the 6th run (temperature of 60^{o}C, catalyst wt of 1%, oil/ethanol ratio of 0.20g/mol) provides the greatest yield (79.34%). Whereas, the 17th yield (temperature of 70^{o}C, catalyst wt of 1%, oil/ethanol ratio of 0.25g/mol) gave the lowest percentage of biodiesel(48%).The quantity of biodiesel collected was measured and recorded. This process was repeated for all the formulation.

Table 1. Effect of temperature, oil/ethanol ratio and amount of catalyst on the yield of biodiesel

-	Factor 1	Factor 2	Factor 3	Response 1
Run	A: Temp	B: Catalyst	C: Oil/Eth. Ratio	Yield
	C	wt%	g/mol	%
1	60	0.8	0.2	76.50
2	60	1.2	0.3	70.20
3	70	0.8	0.2	58.52
4	60	0.8	0.3	72.88
5	70	1.2	0.3	51.24
6	60	1	0.2	79.47
7	70	0.8	0.25	55.45
8	70	1.2	0.2	54.80
9	50	1	0.3	56.12
10	60	1.2	0.2	72.80
11	50	0.8	0.25	60.22
12	50	1.2	0.3	62.59
13	50	1	0.25	65.92
14	50	0.8	0.2	64.21
15	60	0.8	0.25	75.69
16	60	1	0.3	72.59
17	70	0.8	0.3	48.00
18	50	0.8	0.3	62.27
19	50	1.2	0.2	58.72
20	60	1	0.2	75.10

3.1 Model Selection and Verification of Yield

The collected data was analyzed using design expert 10. Response surface method (RSM) was applied to optimize the process and to evaluate the influence of the process parameters of the trans-esterification process on the yield of biodiesel.

The responses selected were the methyl ester yield. A 2^3 CCD design of experiment was used (three factors each at two levels). All responses were analyzed using analysis of variance (ANOVA). The analysis of variance for the quadratic model of the yield is presented in table 2.

Table 2. ANOVA for Response Surface Quadratic model

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob> F**		
Model	1526.07	9	169.56	15.61	< 0.0001	significant	
A-Temperature	177.33	1	177.33	16.32	0.0024		
B-Catalyst	5.28	1	5.28	0.49	0.5016		
C-Oil/Ethanol Ratio	55.37	1	55.37	5.1	0.0475		
AB	2.97	1	2.97	0.27	0.6125		
AC	11.46	1	11.46	1.06	0.3285		
BC	12.77	1	12.77	1.18	0.3037		
A2	1090.55	1	1090.55	100.4	< 0.0001		
B2	2.54	1	2.54	0.23	0.6393		
C2	0.16	1	0.16	0.014	0.9071		

-Residual	108.62	10	10.86				
Lack of Fit	71.32	8	8.92	0.48	0.8141	not significant	
Pure Error	37.3	2	18.65				
Cor Total	1634.69	19					

The ANOVA demonstrated that the quadratic regression model of the yield is significant as the p-value has a very low probability value. The Model F-value of 15.61 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob> F" less than 0.0500 indicate model terms aresignificant.Values greater than 0.1000 indicate the model terms are not significant.If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

The "Lack of Fit F-value" of 0.48 implies the Lack of Fit is not significant relative to the pureerror as specified I Table 3. There is an 81.41% chance that a "Lack of Fit F-value" this large could occur dueto noise. Non-significant lack of fit is good.

Table 3. Correlation table

Std. Dev.	3.3	**R-Squared**	0.9336
Mean	64.66	**Adj R-Squared**	0.8737
C.V. %	5.1	**Pred R-Squared**	0.7634
PRESS	386.71	**Adeq Precision**	11.751
-2 Log Likelihood	90.60	**BIC**	120.56
		AICc	135.04

The analysis taken shows that the second-order polynomial model is an adequate representation of the actual relationship between the response and significant parameters with small p value (<0.05) and satisfactory coefficient of determination (R^2). The high value of R^2 = 0.9336 means that the quadratic regression model can be employed to explain the transesterification process.

3.3 Mathematical Modelling

A model equation was generated to fit the experimental data using design expert 10. From the experimental data obtained from the response surface experimentation. The best fitting of response function can be described by Equation 1.

$$Y (\%) = + 73.72 - 4.32A - 1.14B - 0.92C - 0.12AB - 1.21AC + 0.98BC - 16.97A^2 + 0.39B^2 + 0.068C^2 \quad (1)$$

where Y is the yield in percentage of biodiesel produced, and A, B, C are the temperature, catalyst weight and oil/ethanol molar ratio respectively.From the above equation it can be said that the factors with positive coefficients have greater effect on the yield than the negative value coefficients, that is to say that the BC (catalyst and oil/ethanol ratio interaction), B^2(second power of the catalyst) and C^2 (second power of the oil/ethanol ratio) have greater effect on the yield.

3.4 Analysis of the Response Surface

To study the effect of the three parameters as well as their interactions on the transesterification of coconut oil, response surface, and contour plots are generated using Design Expert 10, as shown in Figures3 to 8. The 3D response surface plots and contour plots of the combined effects of the independent variables on the yield are shown in the figures below. The 3D responses were obtained by keeping the variables constant at zero level while varying the other two variables.

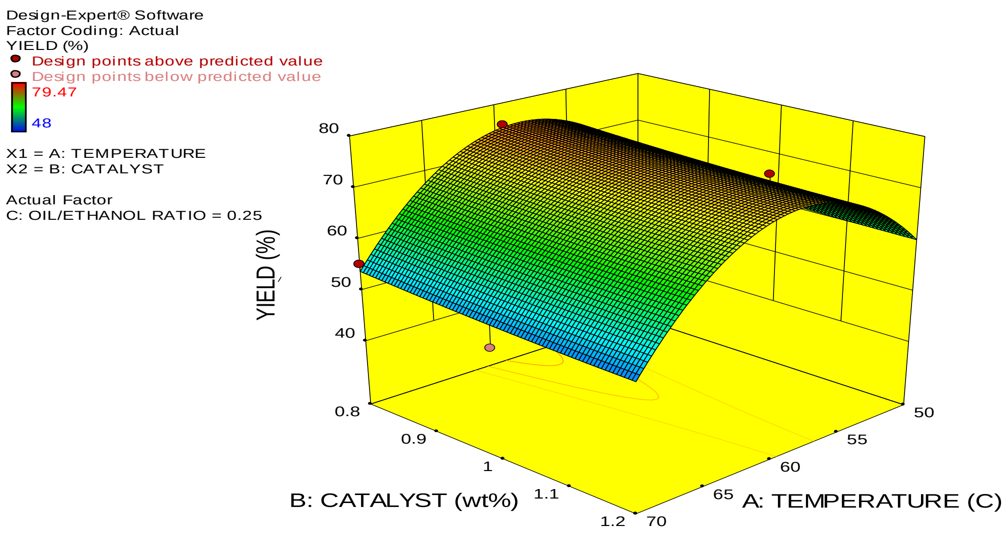

Figure 3. 3D plots of the effect of catalyst ratioand temperature on yield

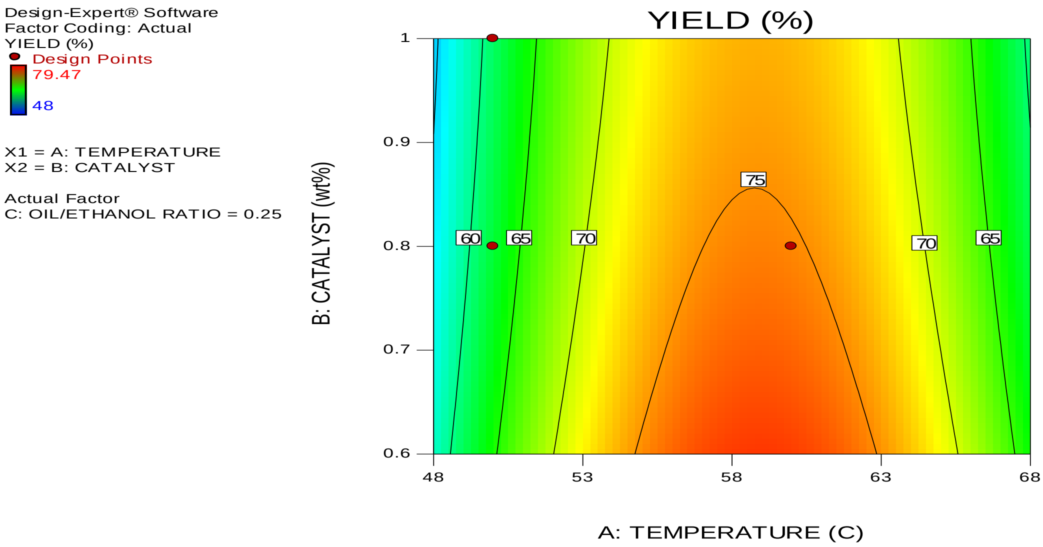

Figure 4. Contour plots of the effect catalyst and temperature on yield

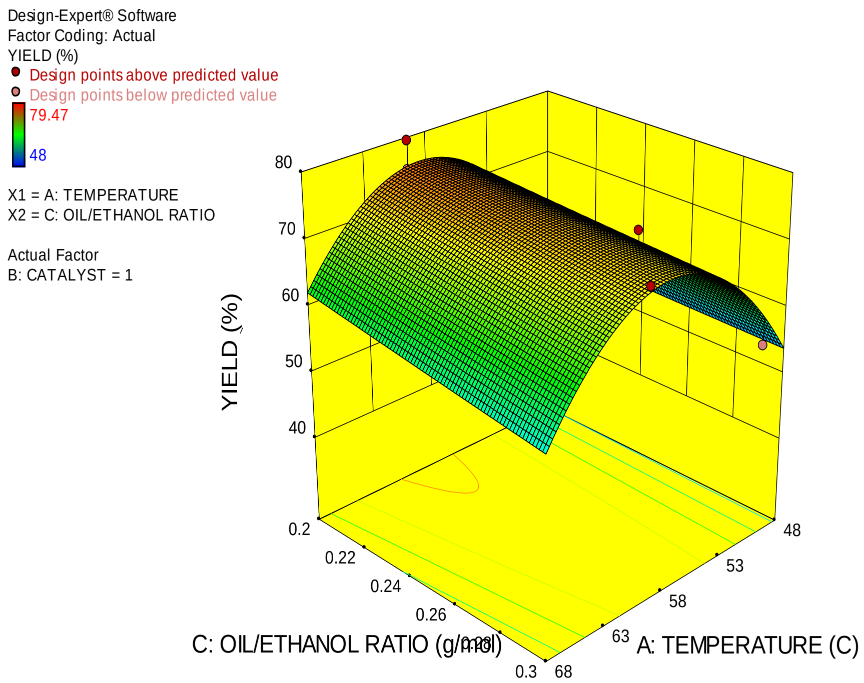

Figure 5. 3D plots of the effect of temperature and oil/ethanol ratio and temperature on yield

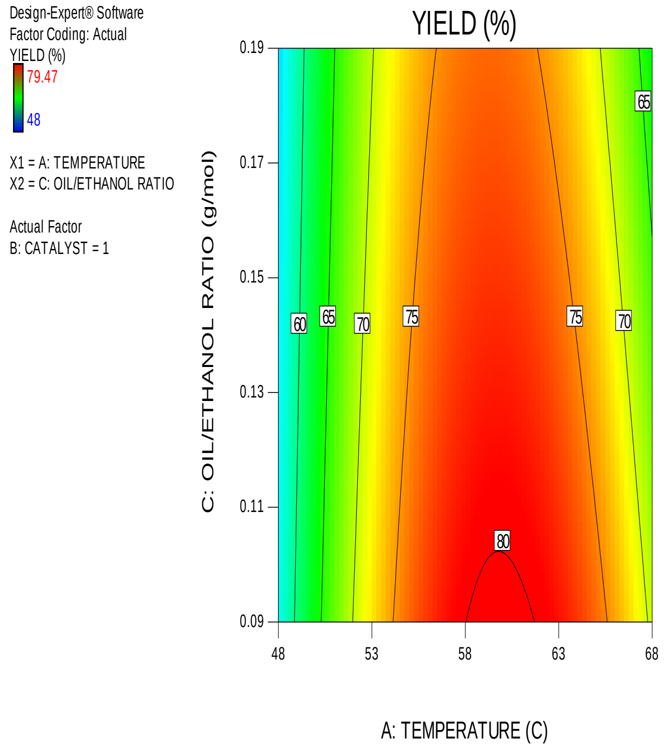

Figure 6. Contour plots of the effect of and oil/ethanol ratio and temperature on yield

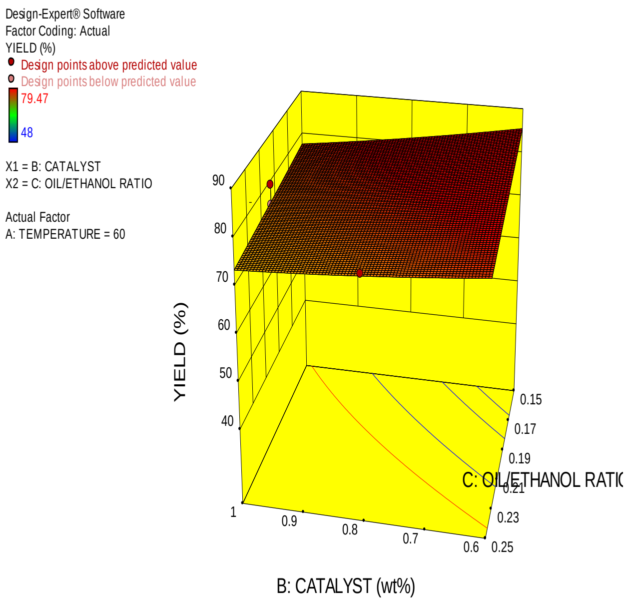

Figure 7. 3D plots of the effect catalyst ratioand oil/ethanol on yield

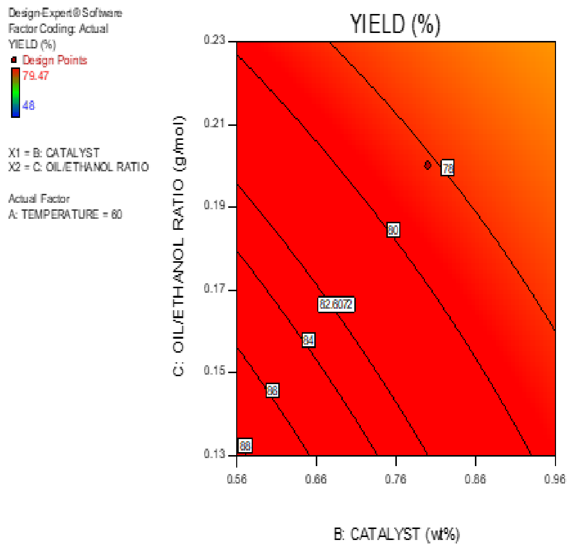

Figure 8. Contour plots of the effect ofoil/ethanol ratio and catalyst on yield

3.5 Result of Effects of Individual Process Variables on Yield.

i. **Effect of ethanol-to-oil molar ratio:** The use of excess ethanol improves FAEE yield, but beyond a particular value, the excess ethanol causes dilution.

ii. **Effect of Reaction Temperature**. Temperature influences the reaction and yield of the biodiesel product. A higher temperature of 70^{o}C resulted in a decrease in conversion to biodieselby causing evaporation of ethanol and reducing the overall ester yield.

iii. **Effect of Catalyst Mass/Concentration.**The biodiesel yield increased as the catalyst concentration increased up to an optimum level. Further increase in catalyst concentration beyond optimum values caused a decreased biodiesel yield.

1.6 Result of the Effects of Interaction of Process Variables on Percent Yield of Biodiesel.

The three-dimensional plots of interaction effectsof process variables over the FAEE yield are shown. Each plot representsthe effect of two process variables while holding the third ata constant level.

i. **Effect of Temperature and Catalyst Mass on Biodiesel Yield.**It can be observed in Figures 3 and 4 that the initial increase in boththe temperature and the catalyst increases the yield of FAEE.As both the temperature and the catalyst increase the FAEE catalyst and ethanol to oil molar ratio. Further increase in both the ethanol and the catalyst decreases the percent yield. This might be because increasing catalyst mass favours formation of soap than the biodiesel and an increase in ethanol beyond the limit will hinder the conversion of fatty acids to FAEE. This might be due to the inactivation of the catalyst or emulsification of the glycerol by the alcohol.

ii. **Effect of Ethanol to Oil Molar Ratio and Temperature on Yield**. The plot in figures 5 and 6 shows the effect of varyingtemperature and ethanol to oil molar ratio. The catalystconcentration; weight by weight catalyst to oil is at 1.Initially the effect of the low level of ethanol to oil molar ratio,and temperature produces a low level of FAEE percentage yield. Further increase in both process variables will enable the optimum amount of yield. In contrast, an increase beyond some levels decreases the yield. The effect of increasing temperature beyond the boiling point of ethanol will decrease the interaction of the oil with ethanol which leads to a decreased yield.

iii. **Effect of Ethanol to Oil Molar Ratio and Catalyst on Biodiesel Yield**.It is possible to see from the plot in figure 7 and figure 8 thatthe initially percentage FAEE yield increases with increasing catalyst and ethanol to oil molar ratio. Further increase in both the ethanol and the catalyst decreases the percent yield. This might be because increasing catalyst mass favors formation of soap than the biodiesel and an increase in ethanol beyond the limit will hinder the conversion of fatty acids to FAEE. This might be due to the inactivation of the catalyst or emulsification of the glycerol by the alcohol.

Table4comparesthe properties of the biodiesel produced with commercial diesel as to ascertain the differences in fuel properties.

Table 4. Values of fuel properties of Produced biodiesel

S/N	Properties	Produced biodiesel	Commercial diesel
1	Colour	Greyish Brown	Brown
2	Viscosity (mm^2/s)	2.8	2.6
3	Specific gravity (g/mol)	0.87	0.74
4	Acid Value (mgKOH/g)	0.3	0.35
5	Free fatty acid(mg/g)	0.4	0.5
6	Saponificationvalue (mg/g)	155.7	150.9
7	Iodine Value (gI^2 /l00g)	127.37	130
8	Flash point (^oC)	115	50
9	Fire point (^oC)	126	70
10	Boiling point (^oC)	80	110

The result of the characterization of the produced biodiesel was compared with commercial biodiesel using a bar chart as demonstrated in figures9 and 10.

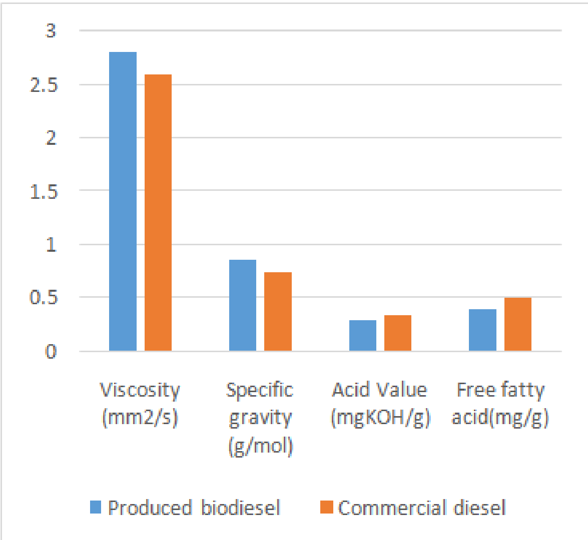

Figure 9.Diesel characterization comparism chart 1

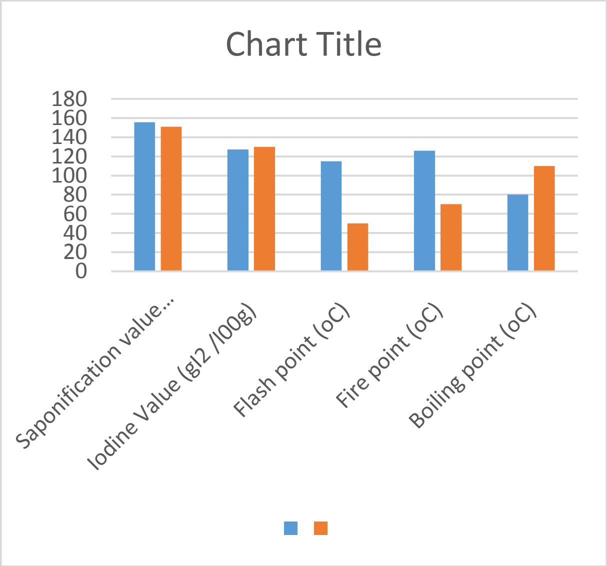

Figure 10. Diesel characterization comparism chart 2

IV. DISCUSSION

The biodiesel obtained was characterized to know their fuel properties. Density, specific gravity, viscosity, acid, iodine and saponification values were also determined. The specific gravity of the coconut oil reduced from 0.914 to 0.87 after transesterification process to produce its biodiesel. In comparison, the specific gravity of the biodiesel is slightly higher than that of diesel of 0.85.Viscosity is one of the essential criteria for evaluating diesel quality. High viscosity leads to operational problems, including engine deposits. The viscosity of the coconut oil before transesterification was 23mm^2/s. It reduced drastically after transesterification to 2.8 mm^2/s. However, the viscosity of the biodiesel is 0.2 mm^2/s higher than that of diesel but in the range of ASTM standard.

The free fatty acid and acid value of the coconut oil dropped considerably from 28.025 mg/g and 14.025 mgKOH/g to 0.40 mg/g and 0.20 mgKOH/g for its biodiesel. This perhaps showed an effective transesterification process of producing the biodiesel. The acid value of the biodiesel, which is 0.30mgKOH/g is lower than that of commercial diesel which is 0.35mgKOH/g but in the range of ASTM specification. It should be noted that acid value measures the FFA contents of the biodiesel directly, it helps to state the corrosive nature of the fuel, its filter clogging tendency and the amount of water. This parameter can also be used to measure the freshness of the biodiesel.

The iodine value of the oil was found to be 123.1, and that of biodiesel was found to be 27.37. High iodine value shows high unsaturation of the oil. In this regard, the low iodine value of the oil and the biodiesel depict low unsaturation of the oil and biodiesel.

Flash Points, which is the temperature at which the fuel can ignite when exposed to a heat source, is essential for safe handling, storage and transportation. The flashpoints of 267°C and 115°C for coconut oil and biodiesel respectively compared to 50°C for diesel fuel. Coconut oil biodiesel compared to the ASTM standard can be classified as a non-hazardous fuel because of its high flash point.

It is to note that the addition of higher amounts of alcohol could prolong the required separation time since biodiesel lay separation from water layer becomes more complicated in the presence of a huge quantity of alcohol.

V. CONCLUSION

The study showed that biodiesel of better quality and yield could be produced from coconut oil by a trans-esterification reaction.The procedure was familiarized in a small-scale. A high yield of 79.47% was obtained.

The optimized reaction conditions for one stage transesterification of coconut oils were a 1:3 molar ratio of ethanol to oil, the addition of 1% KOH catalyst, at 60°C reaction temperature, and about 60mins of reaction time. The results on the total glycerin content of the biodiesel emanated from coconut are impressive and conform favourably to standard. Finally,coconut oil is a suitable feedstock for environmentally friendly biodiesel production. Hence is study recommendsfurther research on biodiesel production on a larger scale. Besides, policies and useful infrastructures that support biodiesel production should be put in place.

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