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Optimization of Biodiesel Production from Palm Kernel Oil Using Heterogeneous Catalyst: Physicochemical Characterization and Process Parameter Effects

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Abstract: ***This study investigated the production of biodiesel from palm kernel oil using heterogeneous catalyst. It involved characterization of the oil and production of biodiesel using palm kernel oil. Physicochemical properties of density, saponification, acid, free fatty acid, iodine and peroxide of the oil were determined. Biodiesel was produced by transesterification process using MgO as heterogeneous catalyst. Effects of process variables on biodiesel yield were evaluated, and the yield was optimized using response surface methodology (RSM). Properties of the biodiesel (specific gravity, kinematic viscosity, acid, flash point, pour point, cloud point, calorific value, moisture content and refractive index) were determined. Analysis of the results showed that palm kernel oil possesses physio-chemical properties suitable for biodiesel production. Moderate free fatty acid of 3.23 % oleic acid and saponification value 194.1 mg/g were obtained. Temperature, methanol/oil ratio, catalyst concentration and time influenced the biodiesel yield. Quadratic model adequately described the relationship between the biodiesel yield and the considered factors. Optimum biodiesel yield from palm kernel oil was recorded as 93.08% at temperature of 55oC, methanol/oil ratio of 5, catalyst concentration of 0.7 wt.% and time of 50 minutes. Specific gravity, kinematic viscosity, acid, flash point, pour point, cloud point, calorific value, moisture content, and refractive index values of the biodiesel are within the specified international standards.***

Keywords: Biodiesel, Characterization, Heterogeneous Catalyst, Palm kernel oil and Transesterification

I. INTRODUCTION

The escalating global population growth and the adverse environmental impact of fossil fuel consumption have spurred the exploration of alternative fuels. This endeavour has become increasingly urgent given the widespread reliance on fossil fuels across various sectors, including agriculture, manufacturing, domestic, and transportation.

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Moreover, concerns over rising fuel costs and the depletion of finite fossil fuel reserves have intensified the quest for sustainable energy sources. This shift aligns with the goals outlined in the United Nations Sustainable Development Goals (SDGs), which serve as a blueprint for addressing urgent global challenges by advocating for renewable energy sources, minimizing waste generation, and addressing climate change impacts. The creation of biodiesel from waste materials actively supports various SDGs, notably SDG 7 (affordable and clean energy), SDG 12 (responsible consumption and production), and SDG 13 (climate action) [1][28]. Biodiesel, a renewable and eco-friendly combustion fuel composed of long-chain methyl or ethyl esters of fatty acids, which is commonly derived from virgin or used agricultural oils such as vegetable oils and animal fats via transesterification reaction [2]. This reaction, involving oil and alcohol in the presence of a catalyst, is a common method employed by researchers for biodiesel production [3]. While numerous studies have investigated different methods for biodiesel production, attention has shifted towards the use of heterogeneous catalysts due to their advantages over homogeneous catalysts. Heterogeneous catalysts, such as those derived from agricultural waste materials or mineral sources, offer improved recoverability, reusability, and environmental compatibility [4][5].

Etim et al, [4] study claimed that flaxseed oil was converted into biodiesel using a bio-alkaline salt catalyst derived from Musa acuminata peels, achieving an experimental yield of 96.50 wt.% under optimized conditions, showcasing its potential as a sustainable fossil fuel alternative. Novita et al, [1] converted used palm cooking oil into biodiesel using a green and recyclable catalyst derived from palm kernel shell ash, achieving a high yield of 99.01% and meeting physiochemical standards, while also significantly reducing waste and production costs on a large scale.

Abdullahi et al, [6] KOH-modified metakaolin (KMK) was used as a new catalyst to produce biodiesel from allamanda seed oil (ASO), yielding up to 90.67%. The biodiesel met ASTM D6751 and EN 14214 standards, indicating its potential as an alternative to petroleum diesel. Ajala et al, [7][29] investigated the synthesis of chicken eggshell catalysts for palm kernel biodiesel production, finding that CEC900 exhibited optimal performance with a yield of 97.10%, making it a promising and cost-effective catalyst option [8].

This study explored the use of TiO2 and Cu impregnated TiO2 as heterogeneous catalysts for palm oil biodiesel production, achieving a maximum yield of 90.93% under optimal conditions, demonstrating promising potential for simplifying the process and reducing purification costs. Sai et al, [9] in his study demonstrated continuous biodiesel production from rubber seed oil (RSO) using eggshell-derived calcium oxide (CaO) as a heterogeneous catalyst, achieving a 97.84% conversion rate under optimized conditions determined by response surface methodology (RSM) and artificial neural networks (ANN). The ANN model exhibited better fitting with experimental data compared to RSM, suggesting its efficacy in predicting biodiesel production outcomes. Kolakoti et al, [10] utilized calcinated moringa oleifera leaves which were calcinated and utilized as a catalyst for palm oil biodiesel production, achieving a maximum yield of 92.82% under optimized conditions, with significant adherence to ASTM standards for fuel properties, and maintaining over 50% yield even after five cycles of catalyst reuse, Sai et al, [11] A novel heterogeneous catalyst, calcined fluorspar (CaF2), was applied in the biodiesel production process from rubber seed oil, achieving a high conversion rate of 95.95% under optimized conditions determined through response surface methodology (RSM), response surface methodology and artificial neural network models were used for optimization. Akhabue and Ogogo [12] used calcined eggshell-derived CaO catalyst optimized transesterification of palm kernel oil. Response surface methodology predicted a 96.395% biodiesel yield, aligning with ASTM standards. Akinfalabi et al, [13] used response surface methodology (RSM), optimal conditions for producing methyl esters from palm fatty acid distillate (PFAD) via esterification were determined. The study explored four reaction variables, highlighting the significant influence of reaction time and catalyst concentration interaction. With a maximum yield of 95%, the PFAD methyl ester exhibited promising fuel properties within international biodiesel standards, affirming its potential as a viable alternative fuel source. Ramli et al, [14] study explores waste cooking oil utilization for biodiesel production, addressing disposal issues. Bifunctional catalysts enable one-step esterification-transesterification, with optimal conditions yielding 81.1% biodiesel using Mo/γ-Al2O3-20 wt% CeO2 catalyst at 110°C, 7 wt% loading, 600 rpm, 30:1 methanol/oil, 270 min. Hadi et al, [15] examined biodiesel transesterification using CaO heterogeneous catalysts. They analysed process variables' impact on yield, identifying catalyst concentration as primary, methanol to oil ratio as secondary, and temperature as tertiary. Optimization yielded 98.56% biodiesel at 9.63 wt% catalyst, 15.30:1 methanol/oil, and 64.40°C.

Arumugam and Sankaranarayanan, [16] study explored sugarcane leaf ash as a catalyst for Calophyllum inophyllum methyl ester production. Through characterization and response surface methodology, optimal conditions of 19:1 methanol to oil ratio, 5 wt% catalyst, and 64°C temperature yield 97% FAME. Reusability data demonstrates 97.85% yield over 6 cycles, and blended B10 and B80 exhibit improved efficiency in backup energy usage. Margarette et al, [17] claimed that biodiesel production from palm kernel oil and groundnut oil using sodium methoxide as a catalyst. Optimal yields of 98% and 84% were achieved at 0.5% w/v CH_3ONa catalyst concentration and 55°C trans-esterification temperature with the analysis meeting ASTM standards. Anusi et al, [18] produced palm kernel oil biodiesel via alkali-catalysed transesterification of crude palm oil. After esterification and transesterification, biodiesel was characterized. Kinetic tests showed higher temperatures expedited the reaction rate, yielding 80-90% FAME content at 60°C.

While biodiesel production has attained significant advancements in research, there remains a notable gap in characterizing both the heterogeneous catalyst, MgO and palm kernel oil. Specifically, the physio-chemical properties of palm kernel oil, including density, saponification value, free fatty acid content, peroxide value, acid value, and iodine value, have not been thoroughly explored in the context of transesterification using MgO as a catalyst. Further research into these aspects is crucial to fully understand the suitability of palm kernel oil for biodiesel production. Nonetheless, preliminary analysis suggests promising potential for utilizing palm kernel oil as a feedstock in biodiesel synthesis.

II. MATERIALS AND METHODS

A. Materials

All chemical reagents utilized adhere to analytical grade standards. The materials and reagents employed in this experiment comprise palm kernel, methanol (CH3OH, 99.8% purity), MgO (utilized as a heterogeneous catalyst), and distilled water, all procured from the local market of Ogbete, Enugu State, Nigeria.

B. Equipment Utilized

The equipment/devices utilized encompass a range of items: beakers, a stopwatch, a weighing balance, a water bath, a viscometer, a glass measuring cylinder, filter paper, an electronic weighing balance, a conical flask with cork, an Erlenmeyer flask, beakers of 250ml and 500ml capacities, a spatula, an oven, a 1000ml volumetric flask, and a separating funnel.

C. Characterization of the Palm Kernel Oil

a. Determination of Density

The weight of a 100ml empty bottle was measured using an electronic weighing balance. Subsequently, the bottle was filled to the brim with the oil, and the combined weight of the bottle and oil was recorded. This process was replicated, and the density was calculated employing the formula provided below.

$$Density\ (\rho) = \frac{W_2 - W_1}{V}$$

W2=weight of bottle and oil, W1=weight of bottle, V =volume of oil.

b. Saponification Value (S.V)

A 30ml sample of palm kernel oil was introduced into a 250ml conical flask, followed by the addition of 25ml of 0.5M ethanol potassium hydroxide solution.

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Subsequently, a reflux condenser was attached, and the flask's contents were refluxed for 30 minutes on a water bath, with continuous swirling until it reached a simmer. The excess potassium hydroxide was then titrated with 0.5M hydrochloric acid, employing phenolphthalein as an indicator while the mixture remained hot. Additionally, a blank determination was conducted using distilled water under identical conditions, and the saponification value was determined using the provided equation.

$$Saponification\ value\ (S.V) = \frac{(B-R)\times 28.05}{Weight\ of\ oil}$$

c. Determination of Free Fatty Acid (FFA) Reagent

A 40ml sample of the oil was carefully transferred into a 250ml conical flask and gently warmed. Subsequently, 25ml of methanol was added with thorough stirring, followed by the introduction of two drops of phenolphthalein indicator and a single drop of 0.14M sodium hydroxide solution. The mixture was then titrated with 0.14M sodium hydroxide solution while vigorously shaking until a consistent, light pink coloration, which persisted for one minute, was observed. The endpoint was noted and utilized to compute the Free Fatty Acid (FFA) value using the following methodology:

$$\%\ FFA\ (as\ oleic) = \frac{Titre \times N \times 28.2}{Weight\ of\ sample}$$

Where, N = molarity of base

d. Determination of Peroxide Value

2.0g of palm kernel oil was introduced into a solution mixture consisting of 12cm³ of chloroform and 10cm³ of acetic acid. To this mixture, 0.5cm³ of saturated potassium iodide was added, and the flask was corked, allowing it to rest with occasional shaking for one minute. Subsequently, 30cm³ of distilled water was added, and the mixture was titrated against 0.1M Na_2SO_3 until the yellow coloration almost disappeared. Following this, 0.5cm³ of starch indicator was swiftly added, and the titration was continued until the blue coloration just vanished. Additionally, a blank titration was conducted under identical conditions.

Peroxide value = ((S – B) X N x 1000)/W

Where Peroxide value = Meq peroxide per 100g of sample

S = volume of titrant (cm^3) for sample

B = volume of titrant (cm^3) for blank

N = molarity of Na_2SO_3 solution (mEq/cm3)

1000 = conversion of units (g/kg)

W = Weight of oil sample

e. Determination of Acid Value (A.V)

The oil sample (40ml) was placed in a 250ml conical flask and warmed. Methanol (25ml) was added with through stirring followed by two drop of phenolphthalein indicator and a drop of 0.14M sodium hydroxide solution while shaking vigorously until a permanent light pink colour, which persisted for 1 minute, was observed, recorded as end the point and used in the calculation of the FFA value as indicated below:

$$Acid\ value = \%FFA\ (as\ oleic) \times 1.99$$

f. Determination of Iodine Value

15ml of the sample was placed in a 250ml conical flask stopper and left for exactly 30 minutes. Potassium iodine solution (10ml of 15% W/V) was added to the flask washing down any iodine that may be found on the stopper. This was titrated against 0.14M Na_2SO_3 until the sodium become light yellow. Starch indicator (1%, 2ml) was added and the titration continued until the blue colour disappeared. A blank (Distilled water) determination was carried out under the same conditions. The titre value was recorded and used to calculate the iodine value as indicated below.

$$Iodine\ value = \frac{(B-R) \times molarities\ of\ Na2So3 \times 12.69}{Weight\ of\ sample}$$

B= Titre value of Blank (Distilled water), R=Titre value for real determination.

D. Production of the Biodiesel through Transesterification Process

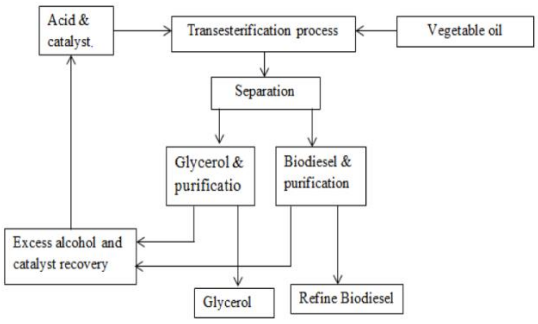

Fig 1. Transesterification process

Table 1.0: Experimental Design Matrix

Std	Run	Factor 1 A: Methanol / Oil ratio	Factor 2 B: Catalyst Dosage (%)	Factor 3 C: Temperature (°C)	Factor 4 D: Time (min.)	Response Yield %
20	1	5	0.9	55	50	
16	2	7	0.9	75	70	
23	3	5	0.7	55	30	
2	4	7	0.5	35	30	
12	5	7	0.9	35	70	
10	6	7	0.5	35	70	
26	7	5	0.7	55	50	
25	8	5	0.7	55	50	

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5	9	3	0.5	75	30	
3	10	3	0.9	35	30	
19	11	5	0.5	55	50	
13	12	3	0.5	75	70	
4	13	7	0.9	35	30	
7	14	3	0.9	75	30	
30	15	5	0.7	55	50	
27	16	5	0.7	55	50	
14	17	7	0.5	75	70	
1	18	3	0.5	35	30	
18	19	7	0.7	55	50	
24	20	5	0.7	55	70	
8	21	7	0.9	75	30	
17	22	3	0.7	55	50	
11	23	3	0.9	35	70	
6	24	7	0.5	75	30	
9	25	3	0.5	35	70	
22	26	5	0.7	75	50	
28	27	5	0.7	55	50	
29	28	5	0.7	55	50	
15	29	3	0.9	75	70	
21	30	5	0.7	35	50	

E. Characterization of the Biodiesel

a. Determination of Pour Point

The heated biodiesel sample underwent a cooling process within a cooling bath to facilitate the formation of wax crystals. Gradually reducing the temperature to slightly above the anticipated pour point, the test jar was periodically removed and tilted to observe any surface movement. Once the specimen ceased to flow upon tilting, the jar was held horizontally for a duration of 5 seconds. If the biodiesel did not flow during this horizontal positioning, the resulting temperature was recorded as the pour point temperature.

b. Determination of Cloud Point

The procedure began by pouring the sample into a 50ml test jar, filling it to approximately half of its capacity. A cork, housing a test thermometer, was employed to seal the jar, with the thermometer bulb positioned at the jar's bottom. Subsequently, the test jar, with its contents, was positioned within a constant temperature cooling bath, atop a gasket to prevent excessive cooling. At intervals of 1°C, the sample was withdrawn from the bath and inspected for cloudiness before promptly returning it. Depending on the cloud point, progressively cooler cooling baths may be utilized.

c. Determination of Flash Point

The Cleveland Open Cup (COC) method was employed to ascertain the flash point. In this approach, the sample was placed in an open cup and subjected to heat. At specified intervals, a flame was introduced above the surface of the oil. The observed flash point temperature fluctuated depending on the distance between the flame and the oil surface. Once the flame reached a height sufficient to ignite vapors above the oil, the corresponding flash point temperature was recorded.

d. Determination of Kinematic Viscosity

The kinematic viscosity was assessed in accordance with the ASTM D7042-04 standard. This involved analyzing the sample by injecting it into a digital automatic viscometer analyzer set to operate at a temperature of 40°C.

e. Determination of Calorific Value

The calorific value of the biodiesel was determined using a bomb calorimeter following the ASTM D2015 standard method. In this process, an oxygen bomb was pressurized to 3 MPa using an oxygen container. The bomb was then automatically ignited once the temperatures of the jacket and the bucket equilibrated within an acceptable accuracy range of each other.

f. Determination of Moisture Content

A measured quantity of the sample was precisely weighed in an aluminum weighing dish and subjected to drying until a constant weight was achieved in a sealed oven set at 40-45°C for approximately 48 hours. After 45 hours, the sample was removed from the oven, weighed, returned to the oven, and reweighed at the 48-hour mark. Once the difference in weights fell within 2%, indicating a state of dryness, the sample was deemed dry. The weight of the dried sample was then determined, allowing for the calculation of moisture content in the sample, as follows:

$$Initial\ weight\ of\ the\ sample\ (wet)\ =\ Xgm,$$

After drying the sample;

$$Final\ weight\ of\ the\ sample\ (dry)\ =\ Ygm,$$

$$Moisture\ content\ (Z\ \%) = \left(1 - \left(\frac{Y}{X}\right)\right) \times 100$$

III. RESULTS AND DISCUSSION

The physicochemical characteristics of the palm kernel oil are summarized in table 2.0. The density, saponification, acid, free fatty acid, iodine, and peroxide values fall within the standard range [19] (Koh and Ghazi, 2011). Specifically, the saponification value was measured at 194.1 mg/g, indicating a moderate value that suggests the oil's suitability for biodiesel production.

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It's worth noting that higher saponification values can hinder biodiesel yield due to increased soap formation in the presence of sodium hydroxide catalyst [20] (Minodora et al., 2010). The recorded free fatty acid content of 3.23% oleic acid is within the standard range of 2.4 to 4.2%. Additionally, the iodine value was determined to be 23.72 g/100g, indicating the presence of double bonds in the oil.

Table 2.0: Physicochemical Characteristics of the Oil

Properties	Values of this Experiment
Density (g/cm^3)	0.889
Saponification Value (mg/g)	194.1
Acid Value (mg/g)	6.46
Free Fatty Acid (% oleic acid)	3.23
Iodine Value (g/100g)	23.72
Peroxide value (meq/kg)	0.35

A. Effects of Process Variables on the Biodiesel Yield

The effects of process variables including temperature, methanol/oil ratio, catalyst concentration, and time on biodiesel yield are detailed in the respective tables below. Table 5.0 illustrates biodiesel yield across various temperatures ranging from 35°C to 75°C. The yield exhibited an increasing trend with rising temperature until reaching a peak at 55°C, yielding 94.49%. However, beyond this point, the yield decreased to 93.15% at 65°C. This observed variation in biodiesel yield with temperature can be attributed to alterations in the thermal energy required for the transesterification process [21][22] (Tanguy et al., 2006; Samart et al., 2010).

In Table 4.0, biodiesel yield increased with an elevated methanol/oil ratio until reaching its peak at 6:1. The surplus of methanol aids in accelerating methanolysis rates. A higher methanol concentration facilitates the generation of methoxy species on the catalyst surface, thereby shifting the equilibrium towards the forward direction and consequently enhancing biodiesel yield [23] (Buasri et al., 2013). Analogous trends were observed in the effects of catalyst concentration and time on biodiesel yield, as depicted in Tables 2.0 and 3.0, respectively. Beyond the maximum point, the reaction initiates a reversal towards reactants. This phenomenon is attributed to the reversibility of the transesterification reaction [22][24] (Samart et al., 2010; Mostafa and Gelareh, 2016).

Table 3.0: Effect of Methanol/Oil Ratio on the Biodiesel Yield

Methanol/Oil Ratio	Biodiesel Yield (%)
3	48.27
4	79.61
5	94.49
6	86.62
7	85.04

Table 4.0: Effect of Catalyst dosage (Catalyst/Oil, wt%) on the Biodiesel Yield

Catalyst Dosage (%)	Biodiesel Yield (%)
0.5	80.77
0.6	88.71
0.7	94.49
0.8	92.52
0.9	91.13

Table 5.0: Effect of Temperature on the Biodiesel Yield

Temperature (^{0}C)	Biodiesel Yield (%)
35	83.40
45	88.73
55	94.49
65	93.15
75	92.44

Table 6.0: Effect of Time on the Biodiesel Yield

Time (Minutes)	Biodiesel Yield (%)
30	68.58
40	81.43
50	94.49
60	87.50
70	86.34

B. Result of the Response Surface Methodology

The Response Surface Methodology results are depicted in Table 7.0, illustrating the interactive effects of process variables on biodiesel yield. A maximum yield of 94.42% was achieved at the midpoint values of methanol/oil ratio, catalyst concentration, temperature, and time. As elaborated in subsequent sections, a comprehensive understanding of the relationship between biodiesel yield and the considered factors necessitates analysis of variance, mathematical modeling, and graphical analysis.

Table 7.0: Response Surface Methodology Results

Std	Run	Factor 1 A: Methanol /Oil Ratio	Factor 2 B: Catalyst Dosage (%)	Factor 3 C: Temperature (ºC)	Factor 4 D: Time (Min.)	Response Yield %
20	1	5	0.9	55	50	91.68
16	2	7	0.9	75	70	85.75
23	3	5	0.7	55	30	69.95
2	4	7	0.5	35	30	41.68
12	5	7	0.9	35	70	70.86
10	6	7	0.5	35	70	45.64
26	7	5	0.7	55	50	94.42
25	8	5	0.7	55	50	94.42
5	9	3	0.5	75	30	22.21
3	10	3	0.9	35	30	25.64
19	11	5	0.5	55	50	82.90
13	12	3	0.5	75	70	24.37
4	13	7	0.9	35	30	56.29

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7	14	3	0.9	75	30	28.32
30	15	5	0.7	55	50	94.42
27	16	5	0.7	55	50	94.42
14	17	7	0.5	75	70	56.14
1	18	3	0.5	35	30	21.68
18	19	7	0.7	55	50	84.25
24	20	5	0.7	55	70	81.27
8	21	7	0.9	75	30	64.35
17	22	3	0.7	55	50	48.24
11	23	3	0.9	35	70	32.53
6	24	7	0.5	75	30	48.45
9	25	3	0.5	35	70	27.97
22	26	5	0.7	75	50	92.52
28	27	5	0.7	55	50	94.42
29	28	5	0.7	55	50	94.42
15	29	3	0.9	75	70	42.37
21	30	5	0.7	35	50	83.41

a. Analysis of Variance (ANOVA) for Quadratic Model

The analysis of variance (ANOVA) for the biodiesel yield model is presented in Table 8.0. The model's F-value of 236.62 indicates its significance, with only a 0.01% probability of such a large F-value occurring due to random variation. Model terms with p-values less than 0.0500 are considered significant, and in this case, terms A, B, C, D, AB, AC, BD, A^2, B^2, C^2, and D^2 are all significant. The predicted R^2 value of 0.9752 closely aligns with the adjusted R^2 value of 0.9913, differing by less than 0.2, suggesting a reasonable agreement. Adequate precision, which measures the signal-to-noise ratio, is desirable with a ratio greater than 4. The ratio of 41.530 indicates adequate signal strength. The generated Equation 4.1 model can effectively guide exploration within the design space. The equation, expressed in terms of coded factors, enables predictions regarding the response for given levels of each factor. Utilizing the coded equation facilitates the identification of the relative impact of factors by comparing their coefficients.

Table 8.0: ANOVA of the Model for Biodiesel Yield

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	21069.03	14	1504.93	236.62	< 0.0001	**Significant**
A-Methanol/oil ratio	4358.04	1	4358.04	685.22	< 0.0001	
B-Concentration dosage	892.53	1	892.53	140.33	< 0.0001	
C-Temperature	191.95	1	191.95	30.18	< 0.0001	
D-Time	433.45	1	433.45	68.15	< 0.0001	
AB	173.65	1	173.65	27.30	0.0001	
AC	59.17	1	59.17	9.30	0.0081	
AD	20.77	1	20.77	3.27	0.0908	
BC	28.28	1	28.28	4.45	0.0522	
BD	84.69	1	84.69	13.32	0.0024	
CD	11.54	1	11.54	1.81	0.1979	
A^2	1684.33	1	1684.33	264.83	< 0.0001	
B^2	51.35	1	51.35	8.07	0.0124	
C^2	36.96	1	36.96	5.81	0.0292	
D^2	674.26	1	674.26	106.01	< 0.0001	
Residual	95.40	15	6.36			
Lack of Fit	95.40	10	9.54			
Pure Error	0.0000	5	0.0000			
Cor Total	21164.43	29				
Std. Dev.	2.52		R^2		0.9955	
Mean	63.17		Adjusted R^2		0.9913	
C.V. %	3.99		Predicted R^2		0.9752	
			Adeq Precision		41.5297	

$$\text{Biodiesel yield} = +93.08 + 15.56A + 7.04B + 3.27C + 4.91D + 3.29AB + 1.92AC + 2.30BD + 0.8494CD - 25.50A^2 - 4.45B^2 - 3.78C^2 - 16.13D^2 \quad (4.1)$$

b. Graphical Analysis of the Results

Graphical analyses of the results are depicted in Figures 4.1 through 4.7. In Figure 4.1, the plot of predicted versus actual biodiesel yield forms a straight-line graph, with data points closely clustered around the line of best fit. This alignment indicates that the model effectively describes the experimental data. Figures 1.0 through 7.0 present 3-D plots showing parabolic curves, characteristic of quadratic equations. These observations are consistent with the findings reported by [20] (Minodora et al,2010), suggesting a quadratic relationship between biodiesel yield and the considered factors.

The 3-D plots also illustrate the optimal biodiesel yield of 93.08%, which occurs at a temperature of 55°C, a methanol/oil ratio of 5, a catalyst concentration of 0.7 wt%, and a reaction time of 50 minutes.

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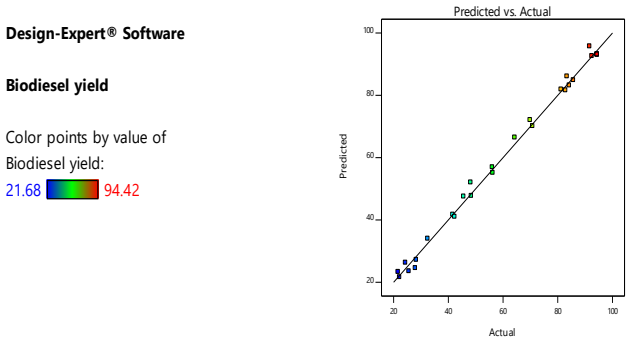

Figure 1.0: Graph of Predicted Versus Actual Biodiesel Yield

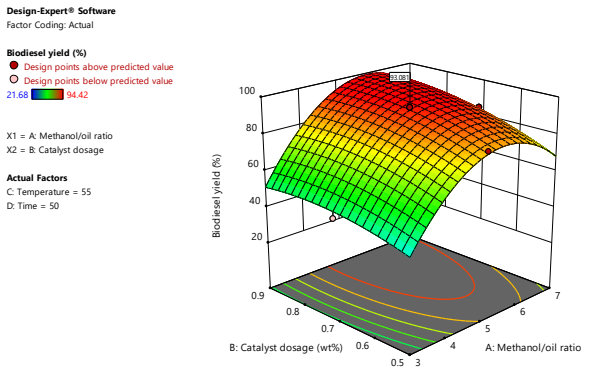

Figure 2.0: Graph of Biodiesel Yield Versus Catalyst Dosage and Methanol/Oil Ratio

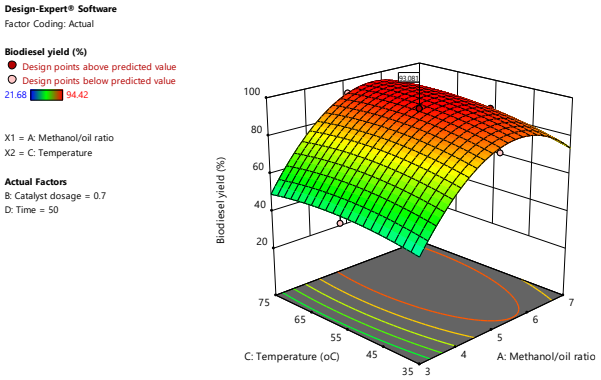

Figure 3.0: Graph of Biodiesel Yield Versus Temperature and Methanol/Oil Ratio

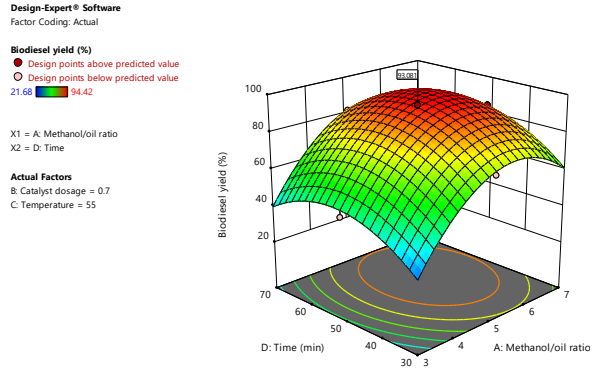

Figure 4.0: Graph of Biodiesel Yield Versus Temperature and Concentration Dosage

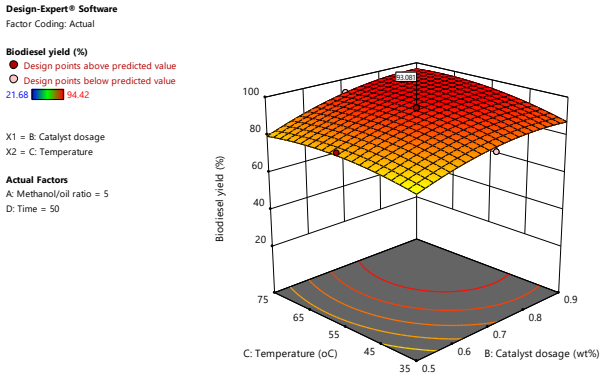

Figure 5.0: Graph of Biodiesel Yield Versus Temperature and Catalyst Dosage

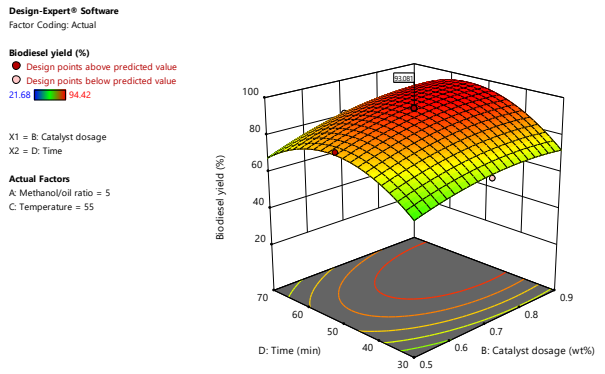

Figure 6.0: Graph of Biodiesel Yield Versus Time and Concentration Dosage

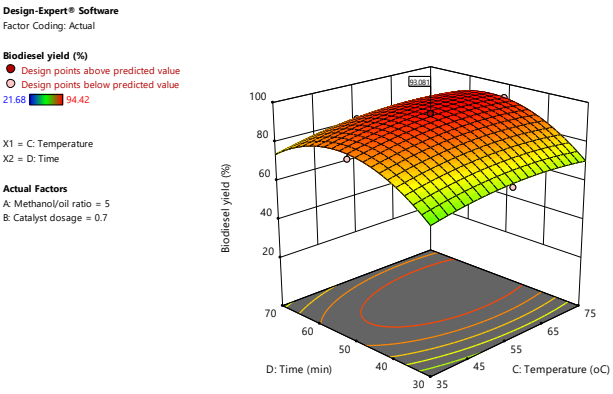

Figure 7.0: Graph of Biodiesel Yield Versus Time and Temperature

C. Properties of Biodiesel

The biodiesel's properties, detailed in Table 9.0, align with specified international standards for biodiesel as referenced by [25][30][31][32] (Sakthivel et al, 2018). It showed moisture content of 0.02 %, which is within the permissible value of less than 0.05%. Flash point was obtained as 164^{o}C. It showed the level of flammability of the biodiesel. Flash point is vital in determining storage and handling processes [26] (Atabani et al, 2013). The flash point value of the biodiesel produced was within the range (157 – 168 ^{o}C) which conforms to ASTM standard, >130 ^{o}C [27] (Ayoola et al, 2012).

Table 9.0: Properties of the Biodiesel

Properties	Biodiesel
Specific Gravity	0.887
Kinematic viscosity (mm^2/s)	3.92
Acid Value (mg/g)	0.23
Flash Point (°C)	164
Pour Point(°C)	-7.7
Cloud Point(°C)	-5.1
Calorific Value (MJ/kg)	35.6
Moisture content (wt%)	0.02
Refractive Index	1.261

IV. CONCLUSION

The palm kernel oil exhibits properties falling within the standard range for density, saponification, acid, free fatty acid, iodine, and peroxide values. The recorded free fatty acid content of 3.23% oleic acid aligns with the standard range of 2.4 to 4.2%. Notably, the saponification value, measured at 194.1 mg/g, indicates a moderate level, suggesting the oil's suitability for biodiesel production. Successful biodiesel production was achieved using waste palm kernel oil, with key process variables including temperature, methanol/oil ratio, catalyst concentration, and time exerting significant influence on the biodiesel yield. The relationship between biodiesel yield and these factors was effectively described by a quadratic model, revealing an optimal yield of 93.08% under conditions of 55°C temperature, 5 methanol/oil ratio, 0.7 wt.% catalyst concentration, and 50 minutes' reaction time. Furthermore, the biodiesel meets specified international standards for specific gravity, kinematic viscosity, acid content, flash point, pour point, cloud point, calorific value, moisture content, and refractive index, reaffirming its quality and suitability for various applications.

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Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material	Not relevant.
Authors Contributions	All authors have equal participation in this article.

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