

Optimized Biodiesel Production from Palm Kernel Oil Using a Bifunctional Catalyst from Cocoa Pod and Pig Bone

By

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Abstract

This study focused on enhancing the efficiency of biodiesel production from palm kernel oil (PKO) using a catalyst derived from a mixture of pig bone and cocoa pod doped with iron chloride and nickel nitrate. The catalyst was characterized using Brunauer-Emmett and Teller (BET), fourier transform infrared spectroscopy (FTIR), scanning electron microscope and energy dispersive X-ray (SEM-EDX), X-ray fluorescence (XRF), and X-ray diffraction (XRD) analysis. The impact of four variable input parameters (reaction temperature, time, catalyst loading, and oil to methanol ratio) on the biodiesel yield was analyzed using the Box Behken design (BBD) of Design Expert. From the obtained characterization result, the composition percentages of 41.426% calcium oxide, 15.265% phosphorus oxide, and 13.689% iron oxide were revealed. An optimal biodiesel yield of 92.4% was achieved at a temperature of 64.39°C, reaction time of 60.02 minutes with a methanol/oil ratio of 18:1 and catalyst loading of 5 wt%. The RSM model exhibited high effectiveness with R^2 value of 0.9754. Also, the biodiesel produced met established standards after analysis.

Keywords: Biodiesel, Box-Behnken design, Cocoa pod, Palm kernel oil, Pig bone

1. Introduction

The compounding factors of an exponential increase in the global population and the attainment of higher living standards have given rise to a profound escalation in energy consumption¹. Energy is a fundamental requirement for the overall well-being of humanity, enabling various essential activities in our daily lives. In the present scenario, the primary source of energy is predominantly derived from conventional petroleum sources like liquefied petroleum gas, diesel fuel, and natural gas. Fossil fuel, however, is non-renewable and possesses several eco-toxic effects upon usage, such as significant greenhouse gas emissions, acid rain, and even global warming.

Renewable energy plays a crucial role in ensuring energy security, fostering environmental protection, and generating employment opportunities in Nigeria and different other countries². The awareness of the limited supply of traditional energy sources and their environmental challenges

¹ Changmai, B., Vanlalveni, C., Ingle, A.P., Bhagat, R., & Rokhum, L. (2020). Widely used Catalysts in Biodiesel Production: A Review. *RSC Advance*. 10 (68), 41625–41679

² Li, L., Lin, J., Wu, N., Xie, S., Meng, C., Zheng, Y., Wang, X., & Zhao, Y. (2022). Review and Outlook on the International Renewable Energy Development. *Energy and Built Environment*. 3(2), 139–157

has led to an increased focus on finding alternative, renewable, and sustainable fuel resources. As a result, the production of biodiesel is rapidly growing as a substitute for fossil fuels³.

Biodiesel is an accepted alternative fuel, drawing considerable attention due to its potential to offer a sustainable energy solution in addressing the pressing challenge of global warming⁴. Biodiesel feedstock encompasses a variety of sources such as edible and non-edible oils such as palm oil, vegetable oils, palm kernel oil, soybean, rapeseed, jatropha, mustard, algae, flaxseed, sunflower, hemp, tallow, lard, yellow grease, and animal fats. Biodiesel is produced through the transesterification process and involves converting vegetable oils or other feedstock predominantly composed of triacylglycerol (such as animal fats or used frying oils) into monoalkyl esters by reacting them with monohydric alcohols⁵.

In this study, palm kernel oil (PKO) was used as a feedstock for biodiesel production as it holds significance in specific regions like Nigeria, where unrefined palm oil is readily available⁶. It offers several advantages, such as its abundance and cost-effectiveness, mitigation of food-for-fuel concern related conflict, hence, making it a viable alternative to traditional edible oils.

For biodiesel to gain wider acceptance globally, it needs to be produced at a more friendly economic condition than conventional fuel⁷. To boost the reaction rate and achieve a higher yield in the transesterification reaction, the presence of a catalyst is crucial⁸. Homogeneous catalysis typically yields faster reactions with lower catalyst requirements compared to heterogeneous catalysis. Despite the efficiency of homogeneous acid catalysts, they present challenges in terms of contamination, which require extensive separation and purification processes for the final product, hence, consequently results to higher production costs. Additionally, when heterogeneous catalysts are employed in transesterification, they can produce glycerin of higher purity with reduced dissolved ion content. This enhanced purity makes heterogeneous catalysts suitable for various industrial applications⁹.

³ Talha, N.S., & Sulaiman, S. (2016). Overview of Catalysts in Biodiesel Production. *ARPJ Journal of Engineering and Applied Sciences*. 11 (1), 439–442

⁴ Odetoye, T.E., & Amusan, G.S. (2019). Cocoa Pod Ash as Biodiesel Catalyst for Biodiesel Production from Waste Chicken Fat. *CIGR Journal*. 21 (4), 141–151

⁵ Knothe, G. (2009). Improving Biodiesel Fuel Properties by Modifying Fatty Ester Composition. *Energy and Environmental Science*. 2 (7), 759–766

⁶ Ishola, F., Adelekan, D., Mamudu, A., Abodunrin, T., Aworinde, A., Olatunji, O., & Akinlabi, S. (2020). Biodiesel Production from Palm Olein: A Sustainable Bioresource for Nigeria. *Heliyon*. 6 (4), e03725

⁷ Obahiagbon, K., & Ahonkhah, D.O. (2023). Optimized Biodiesel Production from Waste Cooking Oil Using Nickel (II) Nitrate Doped Chicken Manure as Catalyst. *European Journal for Applied Sciences*. 11 (3), 812–824

⁸ Saxena, P., Jawale, S., & Joshipura, M.H. (2013). A review on prediction of properties of biodiesel and blends of biodiesel. *Procedia Engineering*. 51, 395–402

⁹ Lucia de Lima, A., Ronconi, C.M. & Mota, C.J.A. (2016). Heterogeneous Basic Catalysts for Biodiesel Production. *Catalysis Science Technology*. 6 (9), 2877–2891

The cost of producing biodiesel has also increased with modern technologies. As a result, various mathematical techniques are given more consideration for handling this issue¹⁰. Optimization of a production process is an essential and major factor as it allows us to boost product efficiency and minimize cost of production¹¹. The use of response surface methodology (RSM) in optimization studies is expanding and, it offers the specifics of the interaction impact of chosen variables with fewer tests¹². RSM stands out as a highly favorable statistical approach for optimizing the process parameters involved in biodiesel production. It minimizes the requirement for conducting numerous experiments in comparison to the conventional one factor-at-a-time method, even when dealing with an equivalent number of process factors. The key benefit of using RSM lies in its capacity to minimize the required number of experimental trials while still yielding statistically reliable results.

2. Materials and Methods

2.1 Material

The PKO utilized in this study was obtained from LUCO Chemical Laboratory, Benin city, Edo state in Nigeria. The PKO was then filtered to eliminate any impurity present. Pyrex-IG supplied an analytical grade of chemicals used for this work which includes; methanol, nickel nitrate, iron chloride, Phenolphthalein indicator, benzene, hydrochloric acid.

2.2 Catalyst Preparation

According to method employed by (Obahiagbon & Ahonkhai, 2023), wet impregnation method was used to craft a doped bi-functional catalyst. A slurry solution was created by adding calcined pig bone and cocoa pod to distilled water containing dissolved iron chloride and nickel nitrate. This mixture underwent stirring for approximately an hour to achieve complete blending. The resulting slurry solution was then placed on a heated magnetic stirrer, operating at 80 degrees Celsius, until all the water had evaporated, leaving a solid substance. This solid underwent sun drying for several hours and a subsequent one-hour drying period in an oven set at 100 degrees Celsius. Following these initial steps, the doped catalyst was subjected to a 6-hour calcination process at 900 degrees Celsius. After calcination, the catalyst was carefully transferred to a desiccator to prevent it from gaining moisture. Ultimately, it was stored in an airtight container, ready for future utilization.

¹⁰ Ozgur, C. (2021). Optimization of Biodiesel Yield and Diesel Engine Performance from Waste Cooking Oil by Response Surface Method (RSM). *Petroleum Science and Technology*. 39, 683-703

¹¹ Ozgur, C. (2022). Prediction and optimization of biodiesel production by using ANN and RSM. *International Journal of Automotive Engineering and Technologies*. 11 (2), 53-62

¹² Manojkumar, N., Muthukumaran, C., & Sharmila, G. (2020). A Comprehensive Review on the Application of Response Surface Methodology for Optimization of Biodiesel Production using Different Oil Sources. *Journal of King Saud University – Engineering Sciences*. 34 (3), 198-208

2.3 Catalyst Characterization

Following the calcination process, the resulting calcined sample went through extensive characterization procedure that includes the examination of its surface morphology utilizing Scanning Electron Microscopy (SEM). For an analysis of its crystalline structure, X-ray Diffraction Analysis (XRD) was conducted. Functional groups were identified, and the presence of characteristic absorption bands of major elements was confirmed through Fourier Transform Infrared Spectroscopy (FTIR). Additionally, the surface area of the catalysts was evaluated using the (BET) isothermal adsorption method and the Hammett indicator method. Finally, X-ray Fluorescence (XRF) analysis was utilized to ascertain the composition of oxides present within the sample. The integration of these various analytical techniques offered a comprehensive insight into the properties and composition of the catalysts.

2.4 Experimental Transesterification Setup and Biodiesel production

The experimental apparatus comprised a conical flask housing the reactants and a heated magnetic stirrer for ensuring a continuous and efficient mixing process. The adoption of a magnetic stirrer was crucial as it promoted a maximized surface area for the reaction, thereby enhancing its efficiency. Within this setup, a 250ml conical flask was placed on a magnetic stirrer. To mitigate methanol loss during the reaction, a rubber stopper was employed, allowing the temperature probe to pass through while minimizing vapor escape. The experimental procedure involved the introduction of 50g of PKO into a 250-ml conical flask, followed by placement on a hot plate magnetic stirrer. The oil was then heated to a specific temperature, and a carefully measured quantity of catalyst, dissolved in a precise volume of methanol, was subsequently introduced into the preheated PKO within the conical flask. These specific values were meticulously determined based on the values derived from the Box-Behnken Design (BBD) experimental data. Upon the conclusion of the reaction, the mixture within the conical flask was transferred to a separating funnel and allowed to stand undisturbed for several hours to facilitate phase separation. This yielded two distinct layers: a lower containing glycerol and an upper layer consisting of biodiesel. As part of this entire process, the biodiesel yield was also determined using equation 1.

$$\text{Yield} = \frac{\text{mass of biodiesel produced (g)}}{\text{initial mass of oil (g)}} \quad (1)$$

2.5 Experimental Design and Optimization Parameter

The optimization of biodiesel production was obtained by adopting the BBD using Design Expert 13. Table 1 presents the four variable parameters utilized in optimizing the experiment: Catalyst loading, methanol-to-oil ratio, reaction time, and reaction temperature, coded as A, B, C, and D respectively, all selected as independent variables to enhance the conditions for biodiesel production.

Table 1: Experimental variable parameters

Factor	Variable	Unit	Minimum	Mean	Maximum
A	Methanol to oil ratio	-	6.00	12.00	18.00
B	Catalyst loading	Wt %	1.0000	3.00	5.00
C	Reaction time	min	60.00	75.00	90.00
D	Reaction temperature	°C	50.00	60.00	70.00

3 Result and Discussion

3.1 Characterization of PKO

The physiochemical qualities of PKO were tested before changing its chemical composition, and the results obtained are shown in Table 2.

Table 2: Physiochemical properties of PKO

Property	Value	Unit
Acid value	10.40	Mg KOH/g
FFA	5.20	Mg KOH/g
Saponification value	206	Mg KOH/g
Density	887	kg/m ³
Specific gravity	0.903	-
Kinematic viscosity	115.55	mm ² /s
Moisture content	0.28	%

3.2 Characterization of catalysts

3.2.1 XRF Analysis

Table 3 shows the XRF analysis of pig bone, cocoa pod, and the doped catalyst indicating the oxides present in the material. From the result, K₂O is the major constituent of cocoa pod while pig bones and the doped catalyst had CaO as their major constituent. The doped catalyst had as constituent oxides majorly; CaO, P₂O₅, Fe₂O₃, SiO₂ and NiO which makes it a good bi-functional

catalyst for biodiesel production. The presence of Fe_2O_3 and NiO in the doped catalyst is as a result of doping.

Table 3: XRF analysis

Constituents	Concentration (%)		
	Pig bone	Cocoa pod	Catalyst
Silicon oxide (SiO_2)	0.093	1.612	9.055
Vanadium pentoxide (V_2O_5)	0.026	0.021	0.071
Chromium oxide (Cr_2O_3)	0	0.023	0.026
Manganese oxide (MnO)	0.032	0.181	0.04
Iron (iii) oxide (Fe_2O_3)	0.262	0.609	13.689
Cobalt tetraoxide (Co_3O_4)	0.07	0.022	0.046
Nickel oxide (NiO)	0.004	0.023	5.448
Copper oxide (CuO)	0.03	0.138	0.05
Niobium pentoxide (Nb_2O_3)	0.005	0.052	0.01
Molybdenum trioxide (MoO_3)	0.023	0.043	0.024
Tungsten oxide (WO_3)	0.01	0	0.125
Phosphorus oxide (P_2O_5)	31.638	1.725	15.265
Trioxosulphate (SO_3)	0.3	1.862	0.265
Calcium oxide (CaO)	63.797	19.542	41.426
Magnesium oxide (MgO)	0.498	1.078	1.069
Potassium oxide (K_2O)	0.254	63.573	2.501
Barium oxide (BaO)	0.027	0	0
Aluminum oxide (Al_2O_3)	1.779	5.128	2.221
Tantalum pentoxide (Ta_2O_5)	0.018	0.043	0
Titanium oxide (TiO_2)	0	0.128	0.341
Zinc oxide (ZnO)	0.027	0.129	0.008

Chlorine (Cl)	0.759	0.749	7.982
Zirconium oxide (ZrO ₂)	0.019	0.056	0.013
Tin oxide (SnO ₂)	0.328	3.262	0.324

3.2.2 XRD Analysis

XRD results of the catalyst reveal the crystallinity of the materials. Fig 1 shows major peaks at 32.438° and 33.528°, indicating the predominance of hydroxylapatite, which is mainly present in bones. Minor peaks were observed at 29.53° showing the presence of hatrurite, indicating the presence of calcium, oxygen and silica. Also, the presence of other crystals like quartz was observed from the plot. The presence of these crystalline phases in the catalyst suggests the transformation of its precursors. This can be attributed to the interactions between the pig bones, cocoa pod and the dopants at elevated temperature level.

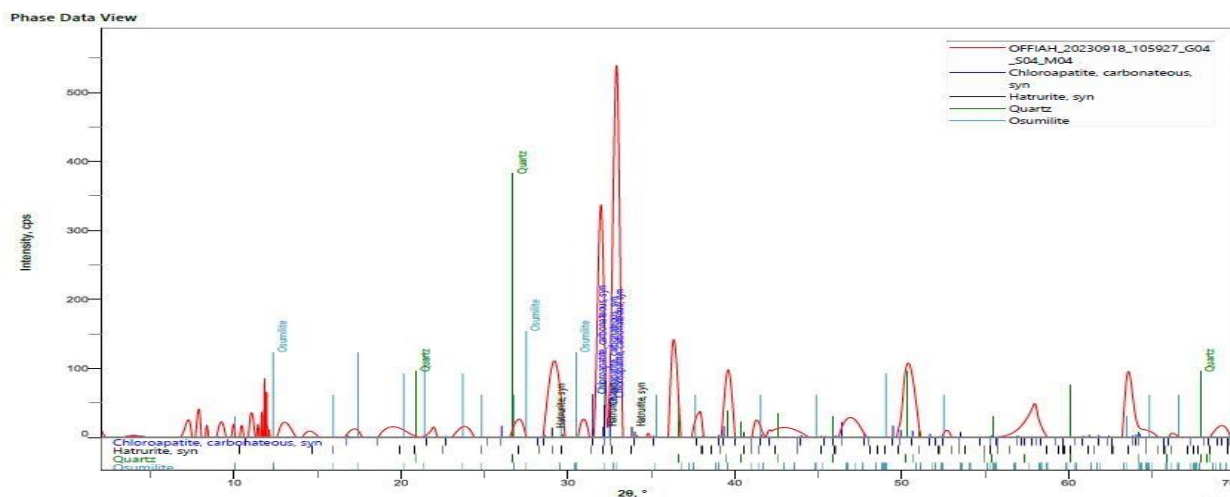


Fig 1: XRD plots for catalyst

3.2.3 SEM/EDX Analysis

The morphology of the catalyst is shown in the SEM image presented in Fig 2. The SEM image shows a fine-grained morphology much like that of hydrated sand. The structure is much aggregated with pores. This aggregated distribution usually occurs due to inter-particle interactions of the catalyst precursors. The catalyst surface experienced transformation from a much denser rough irregular pellet and partial forms of agglomerations to a mix of much finer grain-like aggregates obtained by blending both pig bones and cocoa pod and this can be seen in the SEM images of the catalyst. The resultant micro-structure of the catalyst indicates surface area adequate and required of a catalyst for improved catalytic activity and reaction, confirming its ability to be used as an effective heterogeneous catalyst.

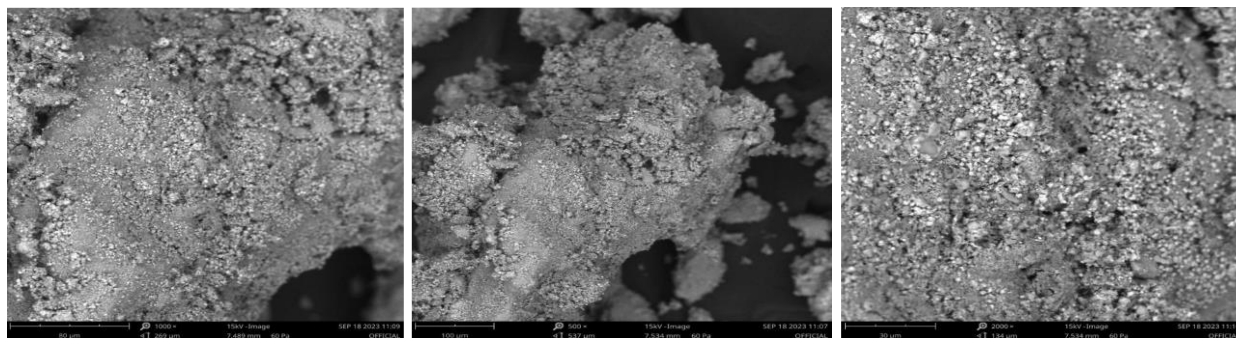


Fig 2: SEM images for catalyst

The EDX patterns shown on Fig 3 indicate that the catalyst is composed of metals like calcium, iron and phosphorus as its major content; the presence of iron could be as a result of doping. The actual weight concentration of these metals and other elements present in the catalyst is shown on Table 4. The metals present in the catalysts are very reactive and this thus explains their strong catalytic behavior. The result also agrees with the XRD analysis results.

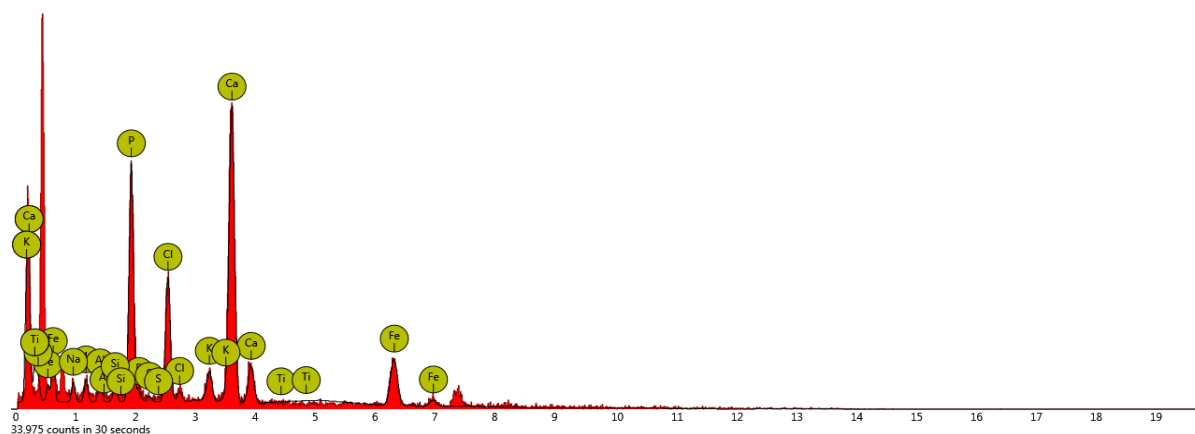


Fig 3: EDX pattern of the catalyst

Table 4: Elemental composition of doped catalyst obtained from EDX

Element	Element	Atomic	Weight
20	Calcium	38.90	40.43
26	Iron	15.20	22.01
15	Phosphorus	20.33	16.33
17	Chlorine	12.12	11.14
19	Potassium	3.48	3.53
11	Sodium	3.33	1.98

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12	Magnesium	2.75	1.73
13	Aluminium	1.98	1.39
14	Silicon	1.33	0.97
16	Sulfur	0.58	0.48
22	Titanium	0.00	0.00

3.2.4 BET Analysis

The surface area, pore volume and pore size the catalyst was analyzed using BET analysis. The surface area of the catalyst was found to be 367.3 m²/g. The catalyst was also characterized by a good pore size and diameter of 0.184 cc/g and 3.040 nm. Fig 4 shows the isotherm (a) and pore distribution data (b) of the catalyst respectively.

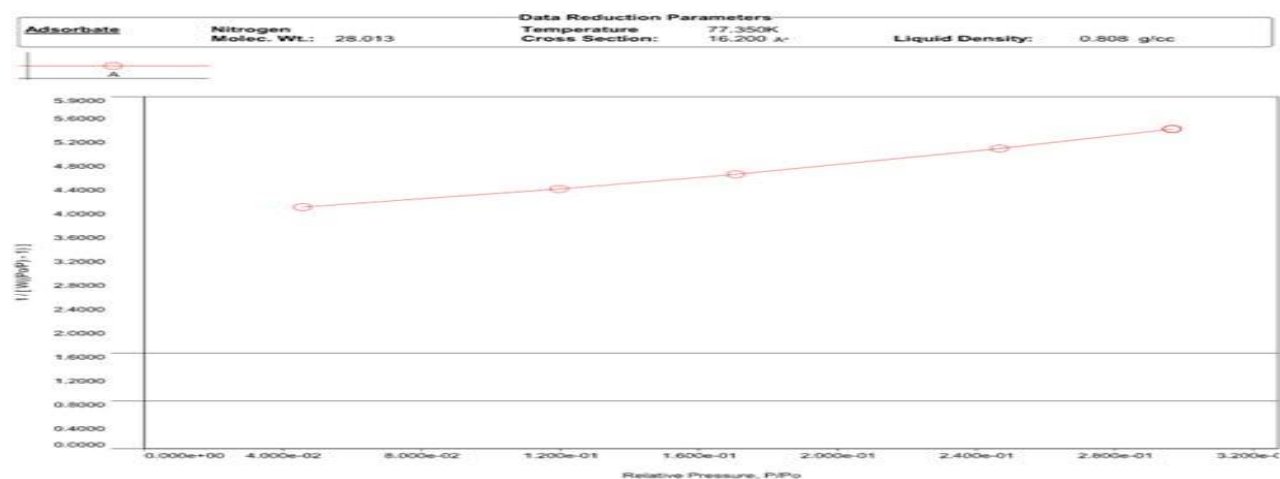


Fig 4a: Nitrogen Physisorption isotherm for the catalyst

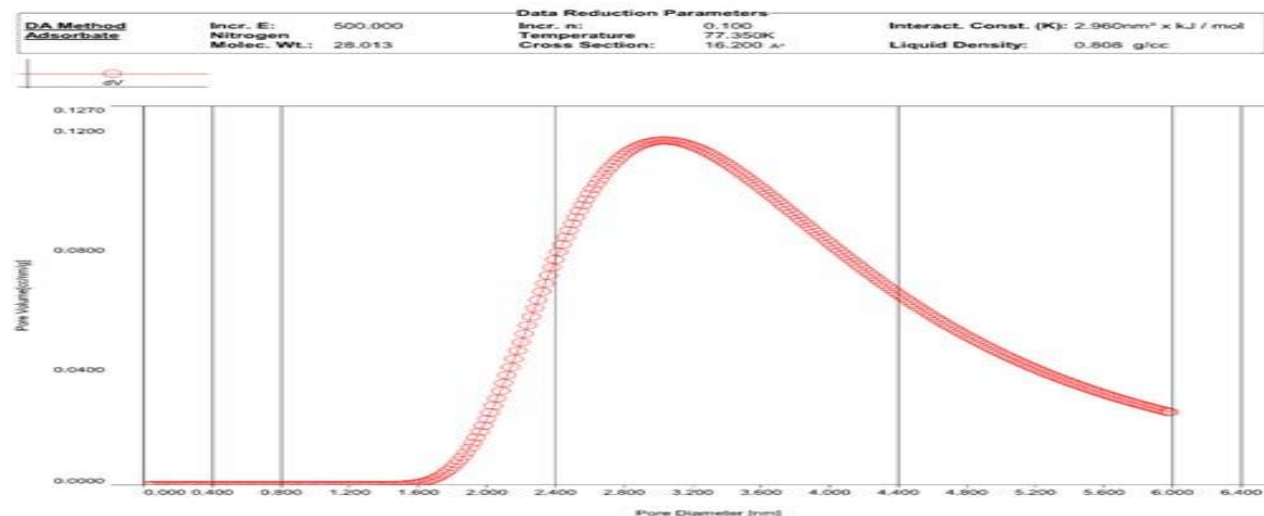


Fig 4b: Pore size distribution for the catalyst

3.2.5 FTIR Analysis

From the FTIR image shown in Fig 5, the catalyst observed peaks at 3397.65, 1079.74, 1022.69, 960.70, 602.16, 557.46, 473.04, 426.72 and 402.42 cm^{-1} . Peak area observed around 3397.65 cm^{-1} for the catalyst represents the O-H stretch bond cm. Peaks observed around 2300-2000 cm^{-1} , 1900-1700 cm^{-1} , 1400-1100 cm^{-1} , 1000-800 cm^{-1} could be attributed to the presence of metallic oxides such as calcium oxides (CaO), silicon oxides (SiO_2), and others such as magnesium and phosphorus oxides.

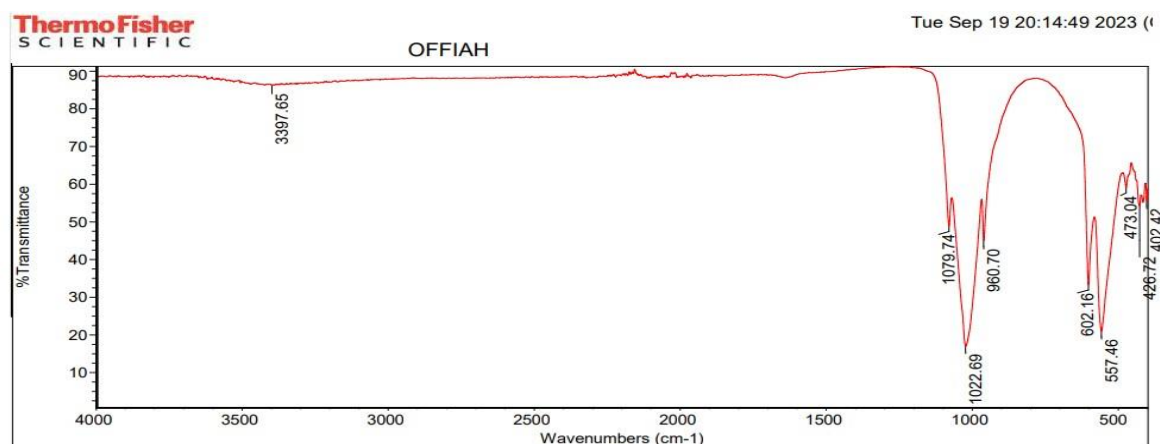


Fig 5: FTIR image of the catalyst

3.2.6 Optimization by RSM

The optimization of biodiesel production was obtained by adopting BBD. The design of experiments involved parameters such as methanol/oil ratio, catalyst loading, reaction time, and reaction temperature which were coded as A, B, C, and D respectively, as shown in Table 5.

Table 5: Design of experiment based on BBD showing Actual and Predicted Results

Run	A:Methanol/oil ratio	B:Catalyst loading	C:Reaction time	D:Reaction temp	Actual	Predicted
		wt%	mins	°C	%	%
1	12.00	5.00	60.00	60.00	76.9	77.93
2	6.00	3.00	75.00	70.00	69.5	68.07
3	18.00	3.00	75.00	50.00	72	74.67
4	12.00	3.00	60.00	70.00	72.4	72.85
5	18.00	5.00	75.00	60.00	88.4	87.35
6	12.00	1.00	90.00	60.00	74	74.20
7	12.00	3.00	75.00	60.00	64.2	64.18
8	12.00	3.00	75.00	60.00	63.8	64.18
9	12.00	5.00	75.00	50.00	75.3	74.55
10	18.00	3.00	90.00	60.00	82.8	82.33
11	6.00	3.00	60.00	60.00	71.8	71.00
12	6.00	3.00	90.00	60.00	76.5	76.13
13	12.00	3.00	75.00	60.00	65	64.18
14	12.00	5.00	75.00	70.00	72.7	73.60
15	18.00	1.00	75.00	60.00	76.5	76.68
16	18.00	3.00	60.00	60.00	85.5	84.60
17	12.00	3.00	90.00	50.00	71.4	70.98
18	12.00	3.00	60.00	50.00	72.6	71.60
19	6.00	5.00	75.00	60.00	72.1	71.95
20	12.00	1.00	60.00	60.00	69.8	71.02
21	18.00	3.00	75.00	70.00	85.3	84.87
22	12.00	3.00	75.00	60.00	63.5	64.18
23	12.00	5.00	90.00	60.00	77.6	77.62
24	6.00	3.00	75.00	50.00	70	71.67
25	12.00	1.00	75.00	70.00	73.2	72.68

26	12.00	3.00	90.00	70.00	75.3	76.33
27	12.00	3.00	75.00	60.00	64.4	64.18
28	6.00	1.00	75.00	60.00	71.2	72.28
29	12.00	1.00	75.00	50.00	67.3	65.13

From Table 5, the result obtained shows that the biodiesel yield ranged between 63.5% and 88.4%. Based on the data, the identified response surface model that relates biodiesel yield to the process input variables in terms of the coded equation is given in Equation 2.

$$Y = 64.18 + 4.95A + 2.53B + 0.7176C + 1.6D + 2.75AB - 1.85AC + 3.4AD - 0.8750BC - 2.13BD + 1.02CD + 8.11A^2 + 4.78B^2 + 6.23C^2 + 2.53D^2 \quad (2)$$

Where: Y = Biodiesel yield, A = methanol/oil ratio, B = catalyst loading, C = reaction time, D = reaction temperature.

The coded form of the equation is valuable for assessing the relative influence of each factor through coefficient comparisons and when articulated in relation to actual factors with their respective units, permits the prediction of the response at specified levels for each factor. Within Equation 2, factors A, B, C, D, AB, AD, CD, A^2 , B^2 , C^2 , and D^2 positively contribute to an augmented biodiesel yield. Conversely, factors AC, BC, and BD have an adverse impact on the reaction, resulting in a decrease in biodiesel yield.

The focus of the model summary statistics is on the model maximizing the R^2 and predicted R^2 values. A higher R^2 value indicates a stronger model and good prediction of the responses. In this case, the value of R^2 was found to be 0.9754, which accounts for up to 97.54% of the response variability.

Table 6: ANOVA for the quadratic model

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	1147.65	14	81.97	39.63	< 0.0001
A-methanol oil ratio	294.03	1	294.03	142.14	< 0.0001
B-catalyst loading	80.08	1	80.08	38.71	< 0.0001
C-Reaction time	6.16	1	6.16	2.98	0.1063
D-Reaction temp	32.67	1	32.67	15.79	0.0014
AB	30.25	1	30.25	14.62	0.0019
AC	13.69	1	13.69	6.62	0.0221

AD	47.61	1	47.61	23.02	0.0003
BC	3.06	1	3.06	1.48	0.2438
BD	18.06	1	18.06	8.73	0.0104
CD	4.20	1	4.20	2.03	0.1760
A ²	426.19	1	426.19	206.03	< 0.0001
B ²	148.26	1	148.26	71.67	< 0.0001
C ²	251.83	1	251.83	121.74	< 0.0001
D ²	41.55	1	41.55	20.08	0.0005
Residual	28.96	14	2.07		
Lack of Fit	27.63	10	2.76	8.32	0.0279
Pure Error	1.33	4	0.3320		
Cor Total	1176.61	28			

The Model F-value of 39.63 underscores the model's significance, suggesting an incredibly low 0.01% probability of such a substantial F-value occurring due to random noise. . If a considerable number of model terms are deemed insignificant (excluding those necessary for hierarchy), optimizing the model through reduction could enhance its efficacy. The Lack of Fit F-value of 8.32 indicates that the Lack of Fit isn't markedly significant relative to pure error.

The predicted biodiesel yield values and actual yield values are shown on a parity plot in Fig 6. It can be seen from both plots that the data points are close to the diagonal line which indicates that the predicted and actual responses were very close, and this justifies the fitness of the model to accurately predict biodiesel yield.

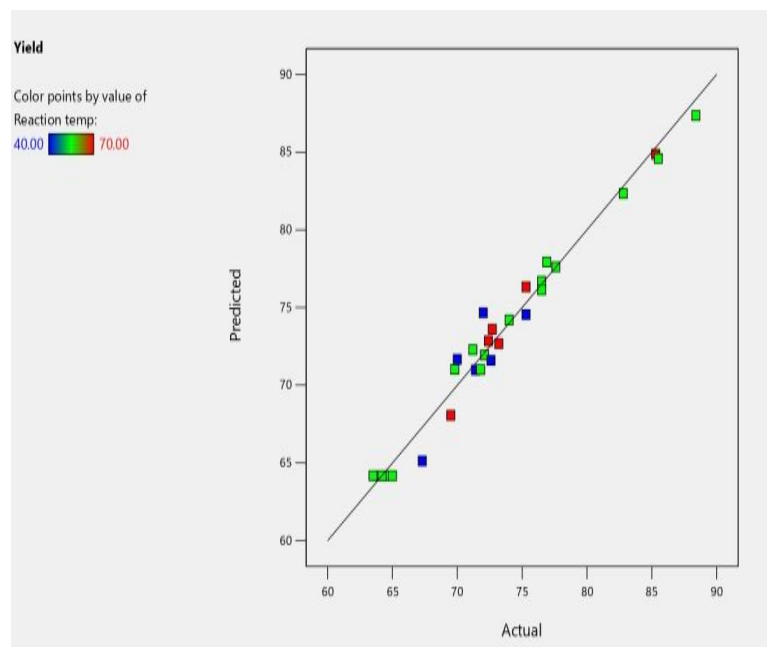


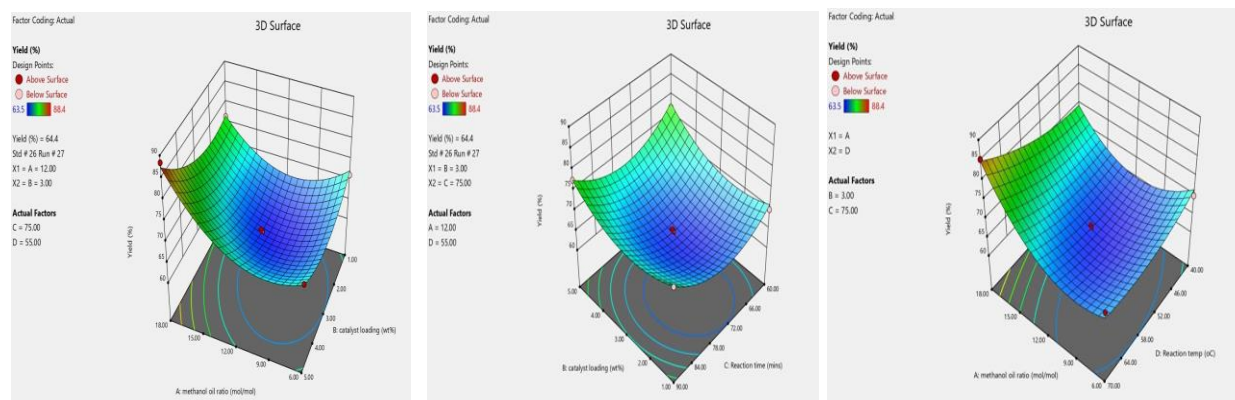
Fig 6: Predicted and actual biodiesel yield comparison

Effect of Input Variables on Biodiesel Yield

Fig 7 (a) depicts the relationship between biodiesel yield, methanol/oil ratio and catalyst loading (wt%) based on the 3D surface model. From the plot, it is clear that with the gradual increase in the methanol/oil ratio resulted in an increase in biodiesel production. Optimum yield of biodiesel was achieved with methanol/oil ratio of 18:1.

Also, from Fig 7 (b), it can be seen that with an increase in catalyst loading, yield of biodiesel observed an increase indicating the availability of more active sites for transesterification to occur. Optimum biodiesel yield was achieved with catalyst loading of 5 wt%.

Fig 7 (c) depicts the relationship between biodiesel yield, catalyst loading (wt%) and reaction time (mins) based on the 3D surface model. From the 3D plot, an increase in reaction time resulted in an increase in biodiesel yield; although after 75 minutes, increase in yield was not observed by the reaction. Optimum biodiesel yield was achieved with reaction duration of 60 minutes.



(a) (b) (c)

Fig 7: 3D surface plots showing effects of (a) methanol/oil ratio and catalyst loading (b) catalyst loading and reaction time (c) methanol/oil and reaction temperature on biodiesel yield

Optimum Parameters for Biodiesel yield using RSM

From the numerical optimization studies carried out on the biodiesel production process, the optimum yield of biodiesel of 92.4% was achieved with a methanol/oil ratio of 18:1, catalyst loading of 5 wt%, reaction time of 60 minutes and reaction temperature of 64.39°C.

3.2.7 Characterization of PKO Biodiesel

The acid value, density, kinematic viscosity, cetane number and flashpoint characteristics of PKO biodiesel were tested and the results of the analysis were obtained and compared with ASTM as shown in Table 7. The low viscosity indicates good fuel as high viscosity leads to insufficient fuel atomization, which can result in the development of soot and engine deposits. High flash point value contributes to the fuel susceptibility to ignition upon exposure to an open flame or spark

Table 7: PKO biodiesel characterization

Property	PKO Biodiesel	ASTM D6751
Viscosity @40°C (mm ² /s)	4.89	Min 1.97
Density @60°F (kg/m ³)	874	860-900
Acid value (mg KOH/g)	0.437	Max 0.5
Cetane number (-)	61.2	Min 47
Flash point (°C)	166.00	Min 130

4 Conclusion

Biodiesel was produced from palm kernel oil using catalyst synthesized from a mixture of pig bones and cocoa pod doped with iron chloride and nickel nitrate. Optimization of the biodiesel production was carried out using RSM and a high R² value of 0.9754 was observed, indicating that RSM can be used as an optimization tool for facilitating the biodiesel production process. The optimum reaction conditions for the maximum yield of 92.4% was achieved with a methanol/oil ratio of 18:1, catalyst loading of 5 wt%, reaction time of 60.02 minutes and reaction temperature of 64.39°C. The physicochemical properties of the biodiesel obtained using the catalyst produced were within the appropriate range of ASTM D6751 specifications for biodiesel.

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