

Application of response surface methodology for optimization of biodiesel production process parameters

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Abstract:

The dwindling fossil fuel reserve and environmental damage due to emissions from fossil fuel necessitates the research for green fuel. The aim of this study is to find the optimal production parameters needed for giving a maximum biodiesel yield from two-step transesterification of neem (*Azadirachta indica*) seed oil using response surface methodology (RSM). The 2^k factorial central composite design RSM was used. The combined effects of temperature, catalyst amount, reaction time and molar ratio of alcohol in relation to biodiesel yield were optimized. Optimum conditions for the production of biodiesel are reaction temperature: 50.38 °C, reaction time: 106.67 minutes, molar ratio: 6.10:1 and catalyst amount: 5.34g with a predicted biodiesel yield of 86.78%. Under these optimized conditions, an actual biodiesel yield of 84.79% was achieved. The study shows that RSM is a reliable tool for optimization of production parameters which makes it suitable for use in production industries.

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1. Introduction

Currently fossil diesel fuels are the dominant fuels used in industries and transport sector of the developing and developed countries. In fact, more than 80% of energy obtains from three types of fossil fuels including oil, coal, and natural gas, and about 98% is generated through the carbon emission from fossil fuel combustion [1]. Serious depletion of fossil fuels and the increasing environmental pressure on green-house gases coming from the fossil fuels have led to search for biotechnological transformation of oils and fats, seeking the use of these raw materials in the production of high value added products such as renewable fuels [2]. Typical forms of renewable energy include wind power, hydropower, solar energy, biomass and biofuels. The contribution of all these resources is important because of the economic and environmental reasons, and biodiesel could be one of the solutions [3]. Biodiesel has become more attractive recently, because of its environmental benefits and the fact that it is made from renewable resources [3]. Biodiesel, either alone or in blends with fossil fuel, will help meet the world energy demands hitherto not yet sufficient. It is most commonly produced by transesterification of vegetable oils and animal fats by short chain alcohol such as methanol, ethanol, 1-propanol and butanol with the assistance of catalyst [1, 2, 3]. One of the challenges to widespread biodiesel adoption is its cost compared with petroleum diesel fuel. The relatively high price of biodiesel arises from the high cost of the refined edible oils that are predominant feed stocks for fuel production [4]. Among the vast non-edible oil seed species which could be used as a feedstock

for biodiesel production the neem plant has been attracting attention for its easy adaptability to tropical and subtropical climates in marginal and non-agricultural areas.

To increase the production of the biodiesel fuel during chemical reactions, an interaction between several substances must be considered. Optimizing the reaction parameters can considerably increase productivity [5]. To optimize the reaction variables for the higher conversion of biodiesel, the central composite design (CCD) matrix of response surface methodology (RSM) using Design Expert 6.6 software was applied for the design of the experiment. To find out the best model of the process, various reduced regression models were compared with the help of ANOVA, main effect plots, interaction plots, surface plots, and contour plots and finally, a modified polynomial model was developed to predict the conversion of triglycerides by the transesterification process. The model was also validated by performing additional experiments using the optimum values of variables. Optimization refers to improving the performance of a system, a process or a product to obtain the maximum benefit from it [6]. Response surface methodology (RSM) is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several independent variables or factors and the objective is to optimize this response [5,6]. According to Lateef, *et al.* [7], response surface designs are used to find improved or optimal process settings, troubleshoot process problems and weak points, and make a product or process more robust against external and non-controllable influences.

Central composite design (CCD) and Box-Behnken (B-B) designs are two of the most common RSM models used. Central composite designs consist of three types of design points: factorial points, star (or axial) points, and center points. In the usual orientation and scaling, the factorial points are a 2^k factorial design of at least resolution V with levels ± 1 , $2k$ axial points (Star points) two on each of k axes. The star points have each factor in turn at its high and low level ($\pm \alpha$), (α distance $\pm \alpha$ from the center of the design) and the other factors at their middle level (zero). Coding of variables in the range of (-1 to +1) is done according to the following equation:

$$xi = \frac{(Xi - Xcp)}{\Delta Xi} \quad (1)$$

Where

$i = 1, 2, 3, \dots, k$

x_i is the dimensionless coded value of an independent variable,

X_i is the real value of an independent variable,

X_{cp} is the real value of an independent variable at the central point, and ΔX_i is the step change of variable [8, 9 and 10].

The Box-Behnken design is an independent quadratic design in that it does not contain an embedded factorial or fractional factorial design. In this design the treatment combinations are at the midpoints of edges of the process space and at the center. These designs are rotatable (or near rotatable) and require 3 levels of each factor. Their primary advantage is in addressing the issue of where the experimental boundaries should be, and in particular to avoid treatment combinations that are extreme. The corner points and the star points are extreme points in terms of region in which experiment is done. The Box-Behnken design avoids all the corner points, and the star points. It has limited capability for orthogonal blocking compared to the central composite designs [9].

This study's main objective is to develop an approach for better understanding the relationships between the variables (methanol-to-oil ratio, catalyst concentration, reaction time and temperature) and the response (methyl esters) to obtain the optimum conditions for biodiesel production using central composite design (CCD) and response surface methodology (RSM).

The aim of this study is to find the optimal production parameters needed for giving a maximum biodiesel yield from transesterification of neem seed oil using response surface methodology.

2. Materials and methods

Neem seed oil from a Soxhlet extraction process was acquired for the work. The methanol and potassium hydroxide used throughout this study were of technical grade.

2.1 Procedure

A 100 ml of required refined neem or neem oil was poured into the flask and heated up to 60 °C. The 45% v/v methanol was added to the preheated neem or yellow oleander oil and stirred for a few minutes. A quantity of

0.5% Sulphuric acid (H_2SO_4) was added to the mixture. Heating and stirring continued for about 45 minutes at atmospheric pressure. After completion of this reaction, the mixture was poured into a separating funnel for separating the excess alcohol, impurities and Sulphuric acid which moved to the top layer and was discarded. The lower layer, esterified oil was kept for further processing into methyl ester. This process is to reduce the free fatty acid content of neem seed oil to less than 1%

The esterified oil was poured into a flask and heated up to 60°C, a 1% quantity of KOH was dissolved in 30% (6:1 M) methanol. The dissolved solution was poured into the flask. The mixture was then heated and stirred for 1 hour. On completion of reaction, the mixture was poured into separating funnel over 12 hours. The glycerol and impurities settled in lower layer. The impure biodiesel which contain some traces of catalyst, glycerol and methanol remained in upper layer had to be washed. The upper layer is pure biodiesel and lower layer was drawn off. The biodiesel was then washed and dried.

2.2 Single factor experiments

Single factor experiments in which one factor was varied while the other factors were kept constant to determine appropriate ranges of the independent variables to be used in design of experiments was carried out. The results of the experiments were used to fix the range of each independent variable which influence biodiesel yield.

2.3 Experimental Design

A 2^k (number of factors $k = 4$) factorial central composite design (CCD) RSM was employed for the optimization of the amount of catalyst (A), methanol- oil molar ratio (B), process temperature (C) reaction time (D) for high biodiesel production. Catalyst concentration, methanol-to-oil ratio, temperature and reaction time are independent variables while biodiesel yield is the dependent variable. Thirty experimental runs made up of 16 factorial experiments, 8 star points and 6 center points were carried out.

3. Results and Discussion

It was found from the preliminary production of biodiesel from neem seed oil that biodiesel yield will be most effective in the range of catalyst amount from 0.75 to 15 g, methanol- oil molar ratio 3: 1 to 12: 1, reaction temperature 40°C to 60°C and processing time in the range from 30 to 180 minutes (Figures 1 to 4). The range values were coded to lie at ± 1 for the factorial points, 0 for center points, and $\pm \alpha$ for axial points. The codes were calculated as functions of the range of interest of each factor using central composite circumscribed (CCC) method as shown in Table 1.

The relationship between independent variables and the response is calculated using the second order polynomial equation (2). The analysis of variance (ANOVA) for the experimental data and the model coefficients were calculated using the software Design-Expert 6.6 (Stat-Ease Inc., Minneapolis, MN, USA).

Table 1: Ranges and Levels of Independent Process Variables using Central Composite Circumscribed (CCC) Method of CCD

Factor	$-\alpha$	-1	0 (middle)	+1	$+\alpha$
Catalyst (A) (g)	0.75	4.31	7.88	11.44	15.00
Molar ratio (B)	3.00	5.25	7.50	9.75	12.00
Temperature(C) (°C)	40.00	46.25	52.50	58.75	65.00
Time (D) (minutes)	60.00	90.00	120.00	150.00	180.00

The experimental data were analyzed by the response surface regression procedure to fit to the

following second-order polynomial equation of Equation. (2):

$$Y = \beta_0 + \sum_{i=1}^k \beta_i x_i + \sum_{i=1}^k \beta_{ii} x_i^2 + \sum_{i=1}^k \sum_{j=1}^k \beta_{ij} x_i x_j \quad (2)$$

Where Y is the predicted oil yield, β_0 model constant, $\beta_i, \beta_{ii}, \beta_{ij}$ are linear, quadratic and interaction coefficient, respectively. k is number of factors considered in the study. Table 2 shows the design summary for the optimization of biodiesel yields and production parameters for neem and yellow oleander.

Table 2: Design Summary for the Optimization of Neem Biodiesel Yields

Factor Name	Units	Type	Low Actual	High Actual	Low Coded	High Coded
A Catalyst	g	Numeric	4.31	11.44	-1.000	1.000
B Molar ratio		Numeric	5.25	9.75	-1.000	1.000
C Temperature	°C	Numeric	46.25	58.75	-1.000	1.000
D Time	minutes	Numeric	90.00	150.00	-1.000	1.000

Initial Design: Central Composite
Design Model: Quadratic

Blocks:

No Blocks

StudyType: Response Surface

3.1 Validation of predictive model

The optimized conditions generated during response surface methodology implementation were validated by conducting biodiesel production experiments with the generated optimal setting conditions.

3.2 Single Factor Preliminary Experiment

The influence of each of the four factors selected for optimization on biodiesel yield as found from the preliminary experiments is discussed here. Figures 1 to 4 show the variation in biodiesel yield with increase of each factor.

3.2.1 Influence of catalyst on conversion efficiency

A range of 0.75 to 16 g KOH was chosen for the experiment. The conversion efficiency at different catalyst amount is shown in Figure 1. Transesterification of yellow oleander gave the highest yield of biodiesel of 85% with

about 4.57 g of potassium hydroxide catalyst. With further increase in catalyst quantity, there was steep decrease in the biodiesel yield. Excess amount of catalyst was apt to form emulsion which increased the viscosity and led to the formation of gels. The formation of emulsion will therefore block the reaction thereby resulting in decreased yield of biodiesel. Due to this observed trend, a range of 0.75 to 15 g of catalyst was chosen for the optimization.

3.2.2 Influence of methanol on biodiesel yield efficiency

The Influence of methanol-oil molar ratio on biodiesel conversion efficiency was determined and the amount of biodiesel produced at different methanol- oil molar ratios is shown in Figure 2. It showed proportional increase with increasing amount of methanol. An optimum yield of 75.85% neem biodiesel was achieved when the molar reached 9:1.

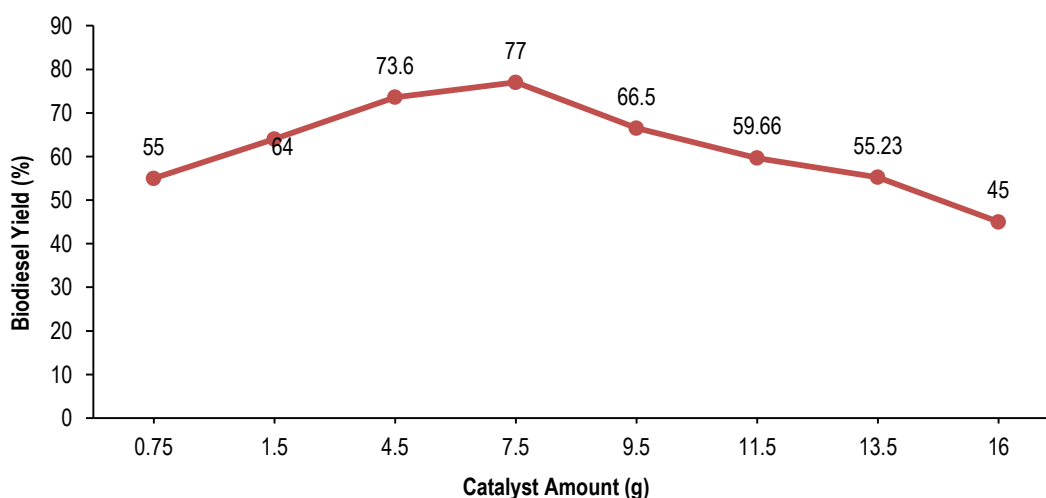


Figure 1: Effect of Catalyst Amount on Biodiesel Conversion

However, when the molar ratio was over these values, the increment of biodiesel yield reduced considerably. Higher molar ratio of alcohol to oil makes separation of glycerin from biodiesel difficult due to increase insolubility [11, 12]. When glycerin remains in the

solution, it causes a shift in equilibrium to the left, resulting in the lower yield of biodiesel. The range of values chosen in the case of methanol-oil molar ratio for optimization experiment 3:1 to 12:1

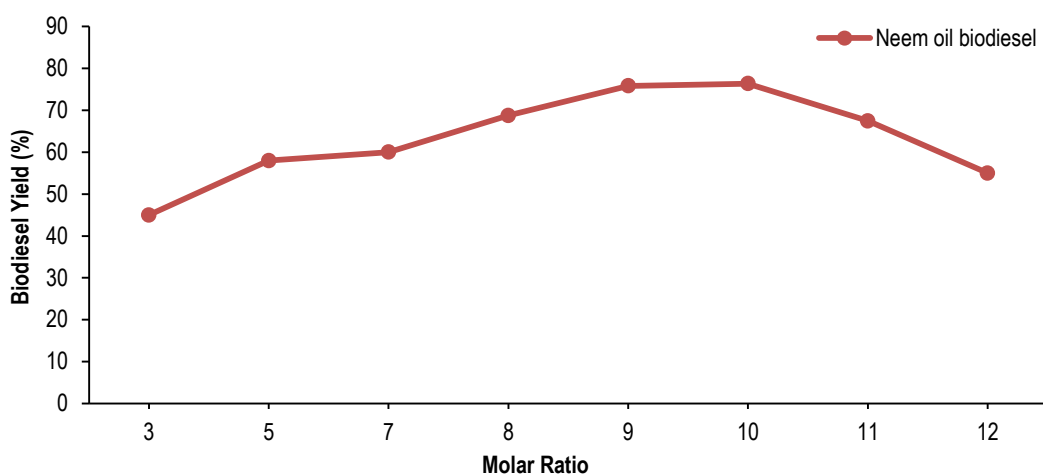


Figure 2: Influence of Methanol-Oil Molar Ratio on Biodiesel Conversion Efficiency

3.2.3 Effect of reaction temperature on biodiesel conversion

Figure 3 shows the effect of temperature on biodiesel yield. Maximum biodiesel yields of 85% and 79.40% for neem seed oil was obtained at 61.5°C; further temperature increase decreased biodiesel yield. The reaction temperature above boiling point of methanol (65°C) was

avoided in the choice of suitable range since at higher temperatures; methanol evaporates leading to formation of soap by the alkaline catalyst before completion of the transesterification [14]. Therefore, the range of temperatures taken for subsequent experiment on optimization is 40 to 65°C.

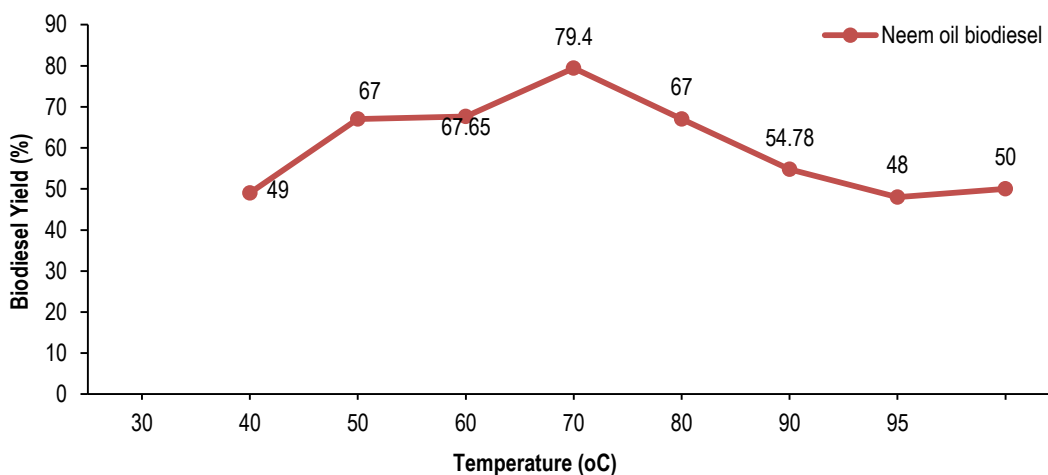


Figure 3: Effect of Reaction Temperature on Biodiesel Conversion

3.2.4 Effect of reaction time on biodiesel conversion

For the experiment with time in the range of 30 to 180 minutes, the influence of reaction time on conversion efficiency is shown in Figure 4. The reaction was slow during the first few minutes. This is due to time taken for mixing and dispersion of methanol and the neem and yellow oleander triglycerides [13]. However the reaction increased steadily from 40 minutes of reaction. As depicted, optimal biodiesel yield of 76.53% was achieved in 120 minutes. The outcome to this end may perhaps be

attributed to the imperfect transesterification response amid methanol and oil [15]. The experimental showed that 150 minutes is sufficient for the completion of the reaction for conversion neem seed oil to biodiesel.

3.3 Statistical analysis and model fitting

The experimental design matrices of the independent reaction parameters optimized in this study on the basis of the CCD design and results of biodiesel yield for neem is shown in Tables 3. All 30 designed experiments for each seed oil sample were done and results analyzed using

multiple regressions with six replicates at the center of each design. The predicted values were obtained from the

model fitting technique and are seen to be sufficiently correlated to the observed values.

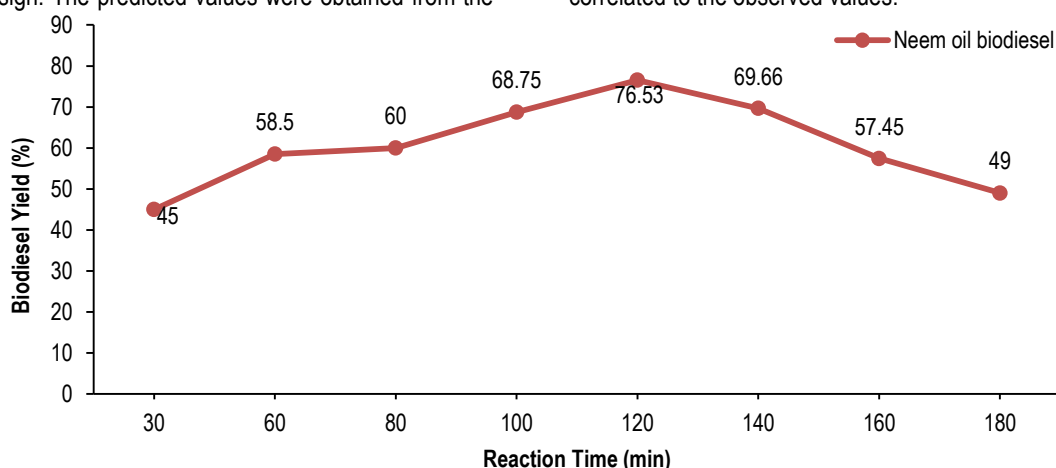


Figure 4: Effect of reaction time on biodiesel conversion

Table 3: Experimental design matrix and results for neem biodiesel production

Run		A: Catalyst	B: Molar ratio g	C: Temperature °C	D: Time Minutes	Yield %
151	Block 1	11.4	9.75	46.3	150.	77.0
20	2	Block 1	11.4	9.75	46.3	90.0
30	3	Block 1	7.88	12.0	52.5	85.6
10	4	Block 1	4.31	5.25	46.3	69.0
6	5	Block 1	1.00	7.50	52.5	85.0
29	6	Block 1	7.88	7.50	52.5	89.9
1	7	Block 1	4.31	9.75	46.3	87.0
19	8	Block 1	4.31	9.75	58.8	86.9
25	9	Block 1	11.4	5.25	46.3	89.0
5	10	Block 1	7.88	7.50	52.5	87.8
21	11	Block 1	11.4	9.75	58.8	60.0
23	12	Block 1	11.4	9.75	58.8	87.6
14	13	Block 1	4.31	5.25	58.8	81.2
26	14	Block 1	11.4	5.25	58.3	89.0
18	15	Block 1	7.88	7.50	52.5	87.0
2	16	Block 1	7.88	7.50	52.5	87.0
3	17	Block 1	7.88	7.50	65.0	70.0
17	18	Block 1	11.4	5.25	58.3	87.7
7	19	Block 1	4.31	5.25	46.3	95.0
12	20	Block 1	4.31	9.75	46.3	84.0
13	21	Block 1	7.88	7.50	52.5	83.0
4	22	Block 1	7.88	7.50	52.5	81.1
16	23	Block 1	11.4	5.25	46.3	89.0
9	24	Block 1	15.0	7.50	52.5	86.5
11	25	Block 1	7.88	7.50	40.0	85.7
22	26	Block 1	4.31	9.75	58.8	85.0
24	27	Block 1	7.88	7.50	52.5	86.0
27	28	Block 1	7.88	3.00	52.5	85.0
8	29	Block 1	4.31	5.25	58.8	93.0
28	30	Block 1	7.50	7.50	52.5	81.0

Equation 3 is the quadratic model equations (in coded factors) that correlate the yield of biodiesel to various process parameters. The evaluated coefficients of the response surface models are provided by this equation 3. The significance of each of the coefficients are checked from p-values (probability of error value), which also indicate the interaction strength of each parameter. Final Equation in Terms of Coded Factors is

$$Yield = -327 + 13.1A + 16.3 + B + 7.78C + 1.78D - 0.341AB - 0.0933AC - 0.0494AD - 0.116BC -$$

$$0.0666B - 0.0106CD + 0.00820A^2 - 0.00785B^2 - 0.0494C^2 - 0.00139D^2 \quad (3)$$

Where

- A = Catalyst amount (g)
- B = Methanol- Oil molar ratio
- C = Temperature (°C)
- D = Time (minutes)

The ANOVA in Tables 4 show the results of the lack of fit tests for the models. The lack of fit test describes the

variation in the data around any fitted model [14]. If the model does not fit the data well, the lack of fit will be significant.

The lack of fit value of 3.13 for neem biodiesel implies that the lack of fit is not significant. The large p values of 0.110 for the lack of fit for the neem biodiesel production model also illustrate that the lack of fit is not significant; implying the model adequately described the

data. The model F- value of 7.56 also implies that the model is significant. From the ANOVA Table 4 also, the p-value of the model for neem biodiesel of 0.000182 and demonstrates very high significance in predicting the response values and the suitability of the models. The very low probability values indicate the high significance of the fitted models. Table 4 also present the significance of all coefficients established by p-values.

Table 4: ANOVA for response surface quadratic model for neem biodiesel optimization (Analysis of variance table [Partial sum of squares - Type III])

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1.32E+003	14	94.5	7.56	0.000182	significant
A-Catalyst	315.	1	315.	25.2	0.000152	
B-Molar Ratio	180.	1	180.	14.4	0.00177	
C-Temperature	191.	1	191.	15.3	0.00139	
D-Time	359.	1	359.	28.7	< 0.0001	
AB	120.	1	120.	9.61	0.00733	
AC	67.7	1	67.7	5.42	0.0343	
AD	447.	1	447.	35.8	< 0.0001	
BC	41.9	1	41.9	3.35	0.0871	
BD	323.	1	323.	25.9	0.000134	
CD	61.9	1	61.9	4.96	0.0417	
A ²	0.280	1	0.280	0.0224	0.883	
B ²	0.0433	1	0.0433	0.00347	0.954	
C ²	102.	1	102.	8.13	0.0121	
D ²	42.9	1	42.9	3.44	0.0835	
Residual	187.	15	12.5			
Lack of Fit	162.	10	16.2	3.13	0.110	not significant
Pure Error	25.8	5	5.16			
Cor Total	1.51E+003	29				
Std. Dev.	3.53		R-Squared	0.876		
Mean	84.4		Adj R-Squared	0.760		
C.V. %	4.19		Pred R-Squared	0.358		
PRESS	969.		Adeq Precision	12.3		

The low values of the coefficients of variation (CV) 4.19 % indicate that the results of the fitted model are reliable. The quality of the model fit was evaluated by the coefficient of determination (R²) which was calculated to be 0.876, indicating that the developed model equation successfully captured the correlation between the process parameters and the yield of biodiesel. The coefficient of determination R² is a measure of the total variation of the observed values of the extracted oil about the mean explained by the fitted model [14]. The value of the adjusted coefficient of determination (R² Adj.) is 0.760, also very high, supporting the significance of the model. As the fitted model Equation 2 provides good approximation to the experimental conditions, the model is used to find the values of the process parameters for optimum yield of biodiesel.

The terms AB, AC, AD, BC, BD and CD in equations 3 are interaction terms. Interaction terms show the effect of two factors on biodiesel yield. It can be observed that the variable with the largest effect on biodiesel yield is the linear term of processing time (D) (p- value of less than 0.0001) and the interaction terms of amount of KOH catalyst and processing time (AD) (p – value of less than 0.0001), followed by the interaction terms of methanol- oil molar ratio and processing time (BD) (p – value =

0.000134) then the ,linear term of amount of processing temperature (C) (p – value = 0.000139), linear term of amount of catalyst (A) (p – value = 0.000152), interaction terms of KOH catalyst and methanol- oil molar ratio (AB) (p – value = 0.001733), then the linear term of methanol- oil molar ratio (B) (p- value = 0.00177 followed by the quadratic terms of processing temperature (C²) (p – value = 0.0121), the interaction terms of catalyst amount and processing temperature (AC) (p- value = 0.01343), the interaction terms of processing temperature and processing time (CD) (p- value = 0.0417) (Table 4). However, the effects of the interaction terms (BC) (0.0871) and the quadratic terms (A², B² and D²) (0.883, 0.954 and 0.0835) are found to be insignificant (p>0.05).

Therefore in terms of parameters that have significant effects on biodiesel yield equation [1] becomes

$$\text{Yield}(\%) = -327 + 1.78D - 0.0494AD - 0.0666BD + 7.78C + 13.1A - 0.341AB + 16.3B - 0.0494C^2 - 0.0933AC - 0.0106CD \quad (4)$$

3.4 Optimization of Process Parameters Conditions

The graphical representation of the regression equation 1 and the effects of two independent variables within the experimental ranges are depicted in 3D- surface

plots and contour plots in Figures 5 to 10. The response surface and contour plots are the graphical representation of the regression equation used to visualize the relationship between the response and experimental levels of each factor. The shapes of the surface plots indicate different interactions between the variables. The contour curves describe the trends in the yields of biodiesels when process parameters are decreased or increased.

3.4.1 Interactive effects of process parameters on biodiesel yield

As shown in Figure 5 increased biodiesel yield was observed with increasing catalyst amount and methanol- oil molar ratio. However, an increase in both factors beyond the optimum region resulted in a decrease in biodiesel production efficiency. At catalyst amount higher than 9.66 g, the biodiesel yield began to decrease at all of methanol-

oil molar ratios. Similarly, at methanol- oil molar ratio higher than 8.70: 1, biodiesel yield begins to decrease. The contour plots in Figures 5b shows that midpoints of catalyst amount and methanol-oil molar ratio result in optimum biodiesel yield (7.88g of catalyst and 7.50:1 molar ratio respectively).

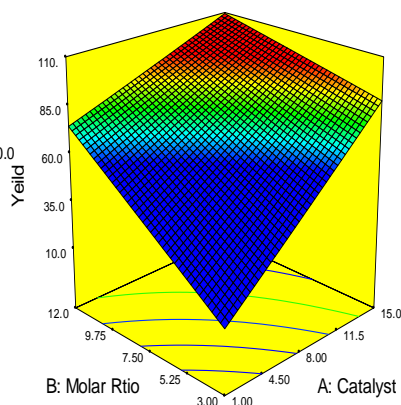
In the interaction between catalyst amount and reaction temperature, the contour plot in Figures 6b illustrates that increasing reaction temperatures result in increased biodiesel yields. Also increase in catalyst amount increased yield of biodiesel till a midpoint after which the yields decreased. As seen from the contour curve, reaction temperatures must be kept high enough for the reaction rate to be rapid but low enough to avoid the evaporation of methanol. A temperature of 52.50°C can be deduced as the optimum from the plots.

Design-Expert® Software

Yield
95
60

X1 = A: Catalyst
X2 = B: Molar Ratio

Actual Factors
C: Temperature = 40.0
D: Time = 60.0



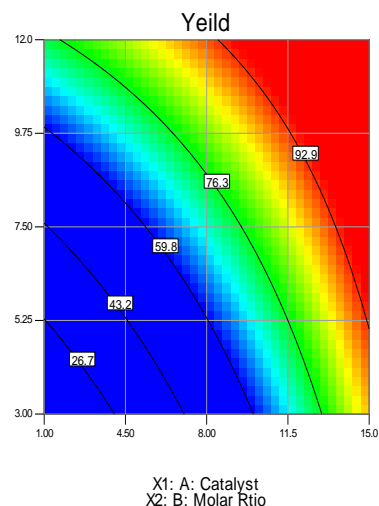
(a)

Design-Expert® Software

Yield
95
60

X1 = A: Catalyst
X2 = B: Molar Ratio

Actual Factors
C: Temperature = 40.0
D: Time = 60.0



(b)

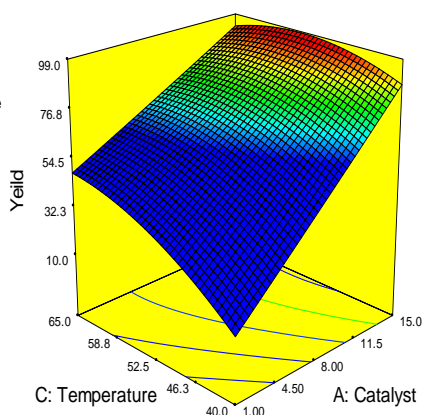
Figure 5: Effect of catalyst amount and methanol- oil molar ratio on neem seed biodiesel yield: (a) 3- Dimensional surface plot (b) Contour plot

Design-Expert® Software

Yield
95
60

X1 = A: Catalyst
X2 = C: Temperature

Actual Factors
B: Molar Ratio = 3.00
D: Time = 60.0



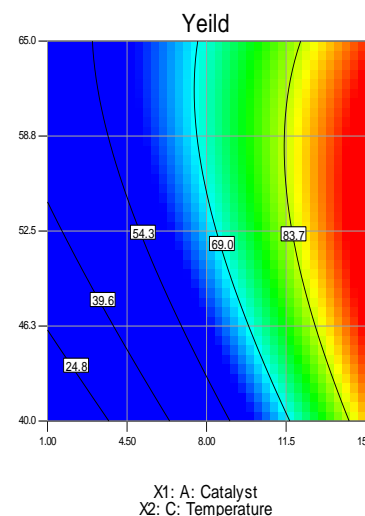
(a)

Design-Expert® Software

Yield
95
60

X1 = A: Catalyst
X2 = C: Temperature

Actual Factors
B: Molar Ratio = 3.00
D: Time = 60.0



(b)

Figure 6: Effect of catalyst amount and processing temperature on neem seed biodiesel yield: (a) 3- Dimensional surface plot (b) Contour plot

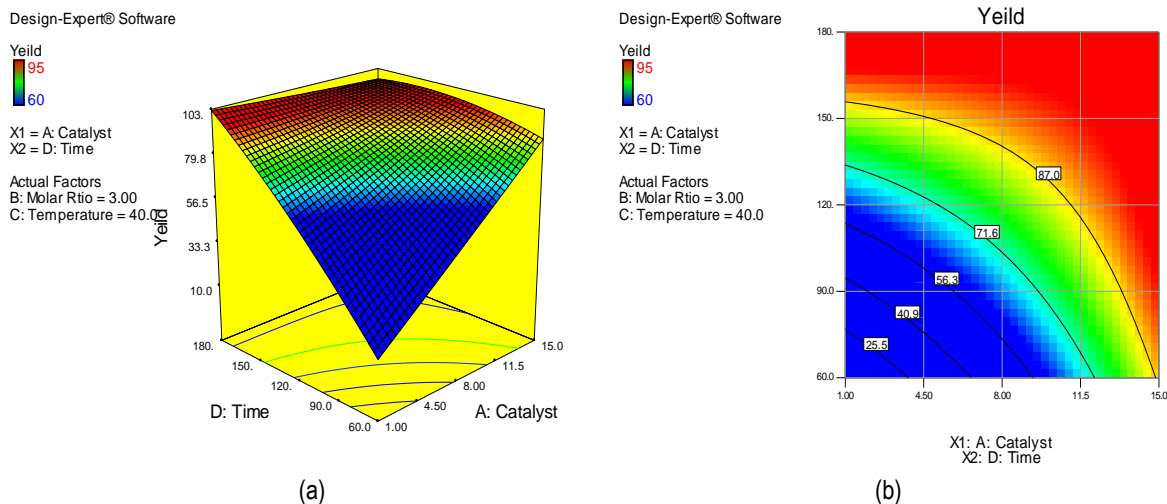


Figure 7: Effect of catalyst amount and processing time on neem seed biodiesel yield: (a) 3- Dimensional surface plot (b) Contour plot

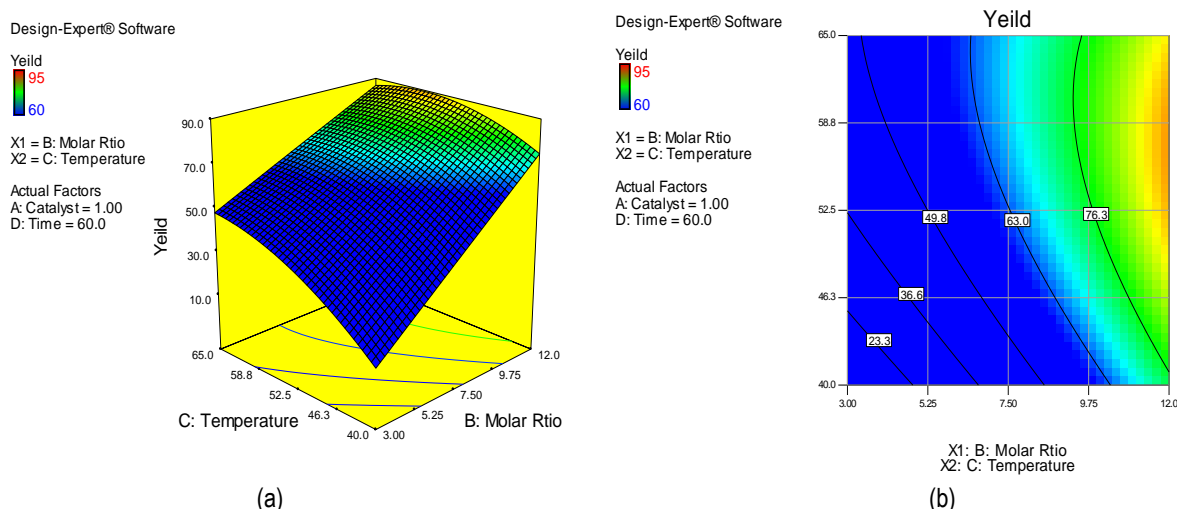


Figure 8: Effect of processing temperature and methanol- oil molar ratio on neem seed biodiesel yield: (a) 3- Dimensional surface plot (b) Contour plot

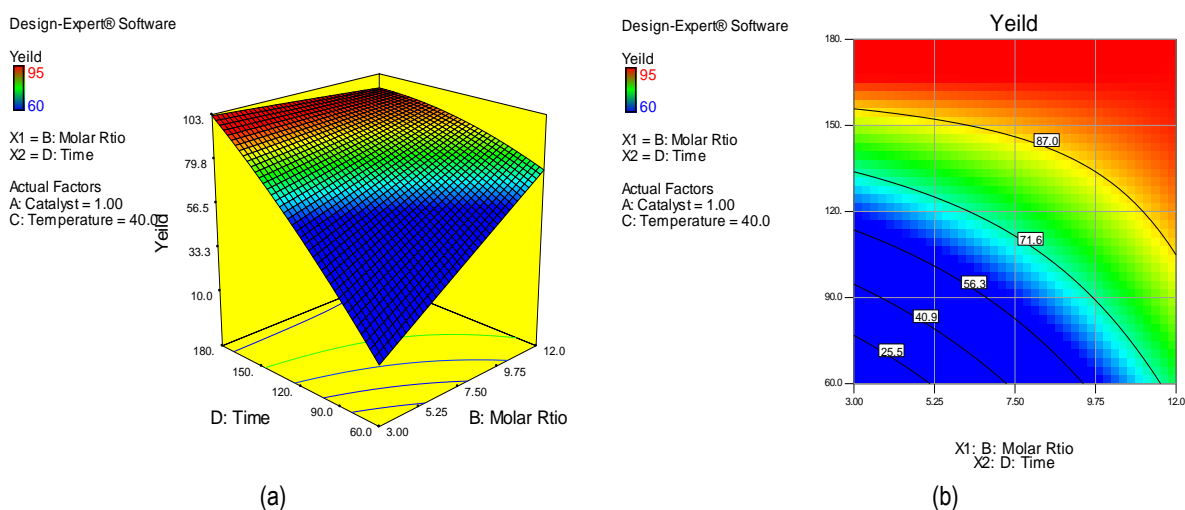


Figure 9: Effect of methanol- oil molar ratio and processing time on neem seed biodiesel yield: (a) 3- Dimensional surface plot (b) Contour plot

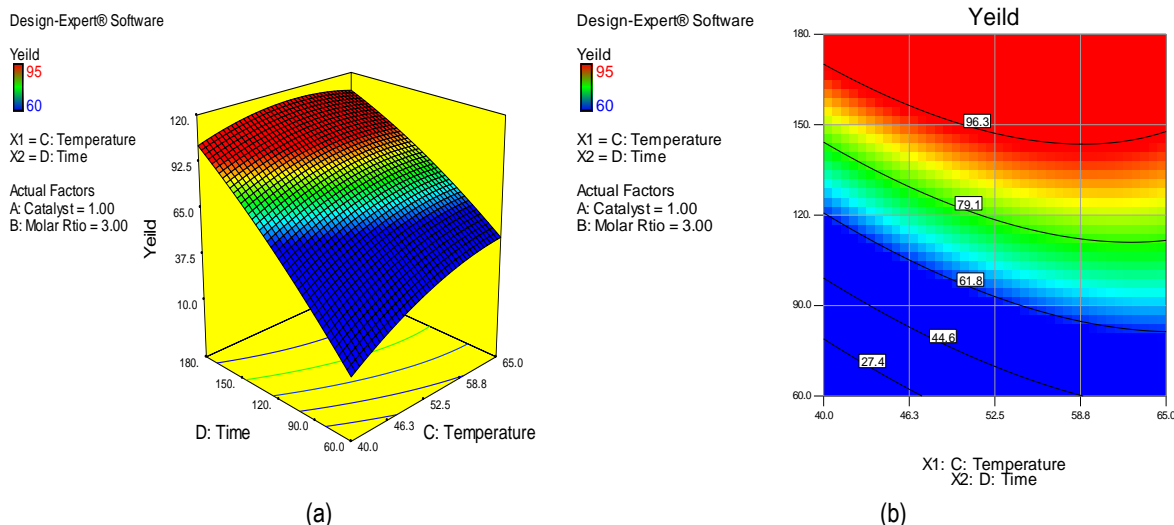


Figure 10: Effect of temperature and processing time on neem seed biodiesel yield: (a) 3- Dimensional surface plot (b) contour plot

3.5 Validation of the Model

The values of maximized parameters were used to validate experimentally the predicted values of the responses using the model equation. An 84.79 % biodiesel yield was obtained from the real experiment with as low as only 2.29 % error indicating that the model is adequate for the producing neem biodiesel. The optimal values obtained from the model equations for reactive production of neem biodiesels are: amount of catalyst, 5.34 g, methanol- oil

molar ratio, 6:1, reaction temperature 50.38°C and process time of 106.67 minutes. The maximum yield of biodiesel that can be obtained under these optimum conditions is 86.78%, while actual (experimental) yield is 84.79 %.

The design expert plot of predicted biodiesel yield against actual yield in Figure 11 clearly shows how close the experimental value of biodiesel yield is to the predicted values.

Table 5: Predicted and Actual Values of Yield under Maximum Parameter Conditions for Neem Biodiesel

Predicted Optimum Parameters			Biodiesel Yield(%) values		
Catalyst gram	Methanol-oil molar ratio	Temperature °C	Processing time(min)	Predicted	Experimental
5.34	6.10 :1	50.38	106.67	86.78	84.79

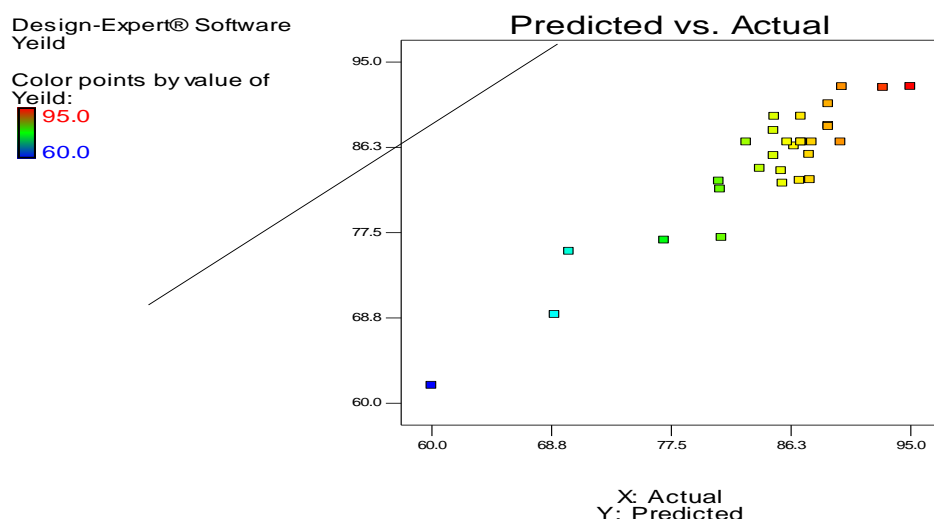


Figure 11: Design Expert Plot of Predicted Yield against Actual (Experimental) Yield for Neem Biodiesel

4. Conclusion

The application of CCD RSM in seeking optimal conditions for biodiesel production has been investigated.

From the results obtained the following conclusions are drawn;

- a. From the statistical analyses, the p-value of the model for neem biodiesel of 0.0002 shows very high significance in predicting the response values and the suitability of the model.
- b. It also be seen from the ANOVA table that the variables with the greatest influence on biodiesel yield are interaction terms of amount of KOH catalyst and processing time (AD)
- c. The results of the validation experiment is good agreement with the values predicted by the model which shows that RSM and CCD can be conveniently used for modeling and optimizing of biodiesel production parameters.

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