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Optimization of Biodiesel Parameters Using Response Surface Methodology and Production of Biodiesel

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ABSTRACT

The requirement for a renewable and environmentally gracious alternative resource of energy has grown in recent years as a result of increased knowledge of the negative impacts of petroleum-based fuels on the environment and the regular rise in crude oil prices. Biodiesel has been proven to be the ideal replacement for diesel because of its unique qualities, such as a huge decrease in greenhouse gas emissions, nonparticulate matter pollutants, non-sulfur emissions, less toxicity, and degradability. This article examines the pre-treatment stage, the physiological and chemical features of WCO, transesterification, esterification, and the manufacturing of biofuel from waste-cooked oil using several techniques and catalyst types. The elements that influence the stated process parameters are investigated, with a particular focus on the methanol to oil ratio (molar ratio), time of reaction, the temperature of the reaction, catalyst percentage, and yield of biodiesel. After the production of biodiesel, we can optimize the process parameters, for example, methanol to oil ratio, the temperature of the reaction, duration of reaction, and catalyst percentage, and also optimize the yield of biofuel generation with the CCD design of the Response surface methodology (RSM) algorithm using Design Expert software.

INTRODUCTION

Waste cooking oil refers to the production of oil from different frying activities, such as oil used in restaurants for frying purposes. Two categories of second-hand cooking are formed and used: primary and secondary-hand cooking oils. Primarily used cooking oil prefers to squander oil from clean vegetable oils and is usually generated by restaurants and shops. While second- or secondary-used cooking oil is waste oil derived from first- or primary-used cooking oil, it is typically generated by street vendors. These days, the oil is generally just thrown away, lacking any treatment. Then it will infect the whole environment when we just pay no attention to it. One single alternative to treating this second or secondary-used cooking oil is by conversion into biodiesel. That substitute will not only have environmental advantages but also be economical (Kawentar & Budiman 2013, Uddin et al. 2013). In today's world, power/energy is a crucial dynamic component for socioeconomic advancement. It has an impact on all aspects of human endeavors, for example, crop production, education, and transportation, amongst others. Petro-linked fuels are the most common type of fuel used in the transportation industry in practically all developed countries. Though climate change and rising pumping costs have shifted research focus to sustainable energy resources (Samuel et al. 2013, Phan & Phan 2008). The search for green energy sources is a topical subject that is gaining widespread communal and political attention owing to its abridged greenhouse gas emissions, biodegradability, sustainability, and spirited nature in comparison to fossil fuels and food supplies. Transesterification produces biodiesel from vegetable oil (waste cooking oil). According to the American Society for Testing and Materials (ASTM), biodiesel is distinct as a single alkyl ester of a lengthy chain of fatty acids resulting from sustainable feedstocks. The main disadvantage is the cost, which is significantly greater than that of oil-derivative diesel. The increased price of virgin or fresh oils, which might account for up to 75% of the overall built-up price, has resulted in biodiesel manufacturing prices being around 1.5 times more than petro-diesel. Waste cooking oils are 2 to 3 times less expensive than new virgin oils.

As a result, the total built-up price of biodiesel can be considerably reduced (Samuel et al. 2013). Though there are several successful reports on biodiesel generation from used cooking oil, it is not highly explored owing to

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the difficulty in transesterification as a result of high free fatty acid constituents. In recent work, we report the direct-scale manufacture of biofuel from waste cooking oil with a free fatty acid (FFA) content in the range of 4 to 5%. The generation is achieved in a single stage without any preceding acid treatment. That's why the utilization of used oil for fatty acid methyl ester (FAME) production or formation is highly suggested (Unni et al. 2013).

REACTIONS OF WASTE OIL AND BIODIESEL

Transesterification

As indicated in Fig. 1, the triglyceride constituent of oil combines with the methanol in the presence of sodium hydroxide or another catalyst to produce esters and glycerol. In common, when using vegetable oil and animal fat as an initial material, there are three types of transesterification systems: homogeneous, heterogeneous, and enzymatic, depending on the catalyst used. Because methanol is more efficient, UVO is usually reacted with alcohol. Ethyl alcohol is used for animal fats, but ethyl alcohol and isopropyl alcohol can be used as well. Transesterification is supposed to be influenced by a variety of factors, such as temperature for reaction, pressure, time of reaction, agitation rate, type of alcohol (whether ethanol or methanol is used) and molar ratio, kind and concentrations of catalysts used, and dampness and FFA concentration in the feedstock oil (Sarno & Iuliano 2019, Rizwanul Fattah et al. 2020). The physical and chemical qualities of the feedstock oil determine the best values for these parameters to achieve higher conversion. Today, the majority of biodiesel is made from edible vegetable oils that have been transesterified using a homogenous alkali catalyst. Homogeneous catalysts, which might be liquid or gaseous, are soluble during the process. Acidic and alkaline are the two types of them. For esterification, acidic catalysts such as H_2SO_4 are commonly employed, while transesterification uses alkaline catalysts, for example, NaOH and KOH (Sarno & Iuliano 2019). Homogeneous catalysts have the following advantages: (i) the ability to catalyze reactions at lower reaction temperatures and air pressures; (ii) the ability to achieve a higher level of conversion in a shorter period of time; and (iii) availability and cost. This method produces a high-quality artifact with a quick turnaround time. Only refined vegetable oil with a low level of 0.5 wt. percent or less is permitted. Free fatty acid or an acid value of not greater than 1 mg $KOH.g^{-1}$ can be used effectively with an alkaline homogeneous catalyst. Furthermore, after the reaction is completed, the separation of these catalysts necessitates washing biodiesel through water, which may result in the slaughter of fatty acid alkyl (methyl or ethyl) esters, energy utilization, and the generation of huge amounts of dissipated water. As a catalyst is not easy to recover and catalyst can induce reactor deterioration, this raises the overall cost of biodiesel production. To avoid soap generation (due to alkaline catalyst use) and low product yields, the triglyceride and alcohol (methanol or ethanol) must be anhydrous, and the raw material must have a low free fatty acid (FFA) concentration (Sarno & Iuliano 2019, Rizwanul Fattah et al. 2020).

Esterification

Because FFAs can cause deposits and engine damage, most biodiesel requirements have a maximum FFA level. As illustrated in Fig. 2, esterification can be utilized to switch free fatty acids to biodiesel while also reducing FFAs. Fatty acids interact using alcohol in the absence of a catalyst to form fatty acid alkyl (methyl or ethyl) ester in this reaction (Biodiesel). The goal of the esterification process is to

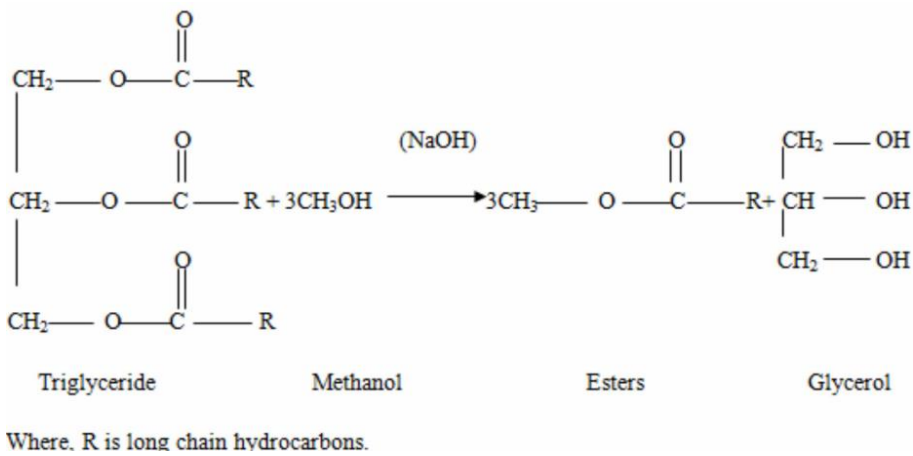

Fig. 1: A schematic illustration of the transesterification reaction (Sarno & Iuliano 2019).

reduce WCO's acidity. As conventional acid catalysts in the esterification process, sulphuric acid (H_2SO_4), hydrochloric acid (HCl), butyl-methyl imidazolium hydrogen sulfate ($BMIMHSO_4$), and sulfonic acid are commonly used (Sarno & Iuliano 2019, Ghiaci et al. 2011). Titration of oil through ethanol and diethyl ether (1:1) alongside potassium hydroxide (KOH) via phenolphthalein as a marker determines the acid values of the oil. The acid value is equal to $56.1*CV.m^{-1}$, where V represents the quantity of KOH (mL), C represents the concentration of potassium hydroxide (KOH) in M, and m represents the heaviness of the oil sample in g. For official techniques, AOCS Cd 3d-63 and ASTMD-664 were followed in this titration. The catalyst is chosen based on acidity. The feedstock can be transesterified without any pretreatment if the FFA content is less than 1%. According to research findings, maximum conversion is achieved at 2% v/v H_2SO_4. Because the reaction is reversible, equilibrium is the greatest stumbling block to its completion. The FFA can be reduced by reducing water by preheating in an oven. The Alcohol to Methanol Ratio, the catalyst and its amount used, and the process temperature are the primary factors determining the esterification reaction (Sarno & Iuliano 2019, Ghiaci et al. 2011).

MATERIALS AND METHODS

If the free fatty acid content in oil exceeds 5% of the feedstock, then a pretreatment process is required before reacting with the alkaline base catalyst (Ribeiro et al. 2011).

Materials

The WCO used in the making of biodiesel was collected from the local street shops and FFA was measured with two different oil samples collected from different shops (0.7% and 0.2%). For example, methanol with 99% purity, potassium hydroxide (KOH) with 90% purity, and for some quality checks for oil and biodiesel, phenol red indicator LR grade, isopropyl alcohol with 99% purity, bromophenol blue, hydrochloric acid 0.01N LR grade for soap content, and 1% phenolphthalein indicator were used for excess catalyst in the process. Alcohol (methanol) is used for the transesterification process, and the KOH base catalyst is used as the base catalyst (Table 1).

Synthesis of Methyl Esters

The synthesis or production of biodiesel initially requires pretreatment if the FFA content is high. First, the oil is heated

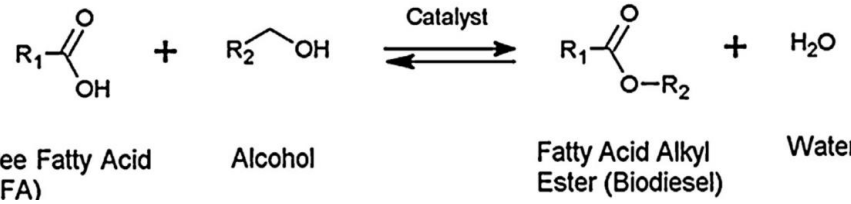

Fig. 2: Schematic illustration of the esterification reaction (Sarno & Iuliano 2019).

Fig. 3a: Shows two layers of upper layer of biodiesel and the bottom layer of glycerol.

Fig. 3b: Shows biodiesel after washing.

Table 1: Quality analysis of oil and biodiesel.

Quality parameters	Analysis result
Acid value of oil	9mg.KOH^{-1}.g^{-1}
Free fatty acid content in oil	4.5%
Soap content(ppm)	285ppm

to a temperature of 100°C to eliminate any moisture content available in the oil, then the heated oil is cooled down. Again, heat the oil to a different temperature range, from 40 to 75°C, the process temperatures are given in the process Table 4. After heated oil reaches the desired temperature, KOH (normally 0.3 to 1 percent of oil according to FFA content of oil, the catalyst % is taken) with methanol is mixed (ratio of methanol to oil is calculated as per desired data given in Table 4) and added to the process for transesterification reaction with continuous stirring of the process mixture at a desired temperature. The stirring was also continuous for about 45 min to 120 min (all data in Table 4 show the minimum range and maximum range of different parameters). Thereafter, two layers were produced; the upper layer is of biodiesel, and the lower layer is of glycerol, as shown in Fig. 3a and 3b. Then, the mixture was allowed 24 h to properly settle so that all the biodiesel was properly separated from the glycerol. After 24 h, the glycerol was separated from the biodiesel and further processing was done (washing and testing). Washing of biodiesel is done through hot water with 3 to 5 washes with water and then drying of the biodiesel with heating at a temperature of above 100°C for 1 h.

Analysis of Process (Biodiesel)

After the synthesis of biodiesel and before washing, the quality check for biodiesel is done. By using the 3/27 methanol test (Heisner 2020), you can check whether the oil is properly reacted or not. In this test, 3mL of prepared biodiesel was taken and added to 27 mL of methanol, then mixed vigorously in the vial for 5 to 10 seconds. If there is any oil or unreacted oil or fall seen at the bottom of the vial, it means the oil is not properly reacted. If there is no fall seen at the bottom, it means the oil is properly reacted. The 3/27 methanol test was performed both before and after washing the biodiesel (see Fig. 4a and 4b).

Excess Catalyst in Biodiesel

The high level of catalyst content in biodiesel leads to the problem of soap formation and increases the soap ppm level in biodiesel. By eliminating or removing excess catalyst (KOH) in prepared biodiesel, take 100 mL of isopropyl alcohol into a 250 mL beaker and then add about 12 mL of biodiesel. Mix properly. Add 5 drops of 1% phenolpthalein indicator to the beaker. If the solution in the beaker stays clear, it means there is no extra catalyst in the biodiesel. If the solution turns magenta after the addition of the indicator, it means there is some extra catalyst present in the biodiesel. The biodiesel requires some treatment to neutralize it, so take 0.01 N HCL and put the HCL drop-wise in the beaker slowly until the solution color changes from magenta to clear solution. After the excess catalyst removal process, the next step is the soap content test for the biodiesel.

Soap Content Test for Biodiesel

The high level of soap content in biodiesel results in the clogging of filters and engines of automobiles. The soap

Fig. 4a: Conversion complete (no fall seen).

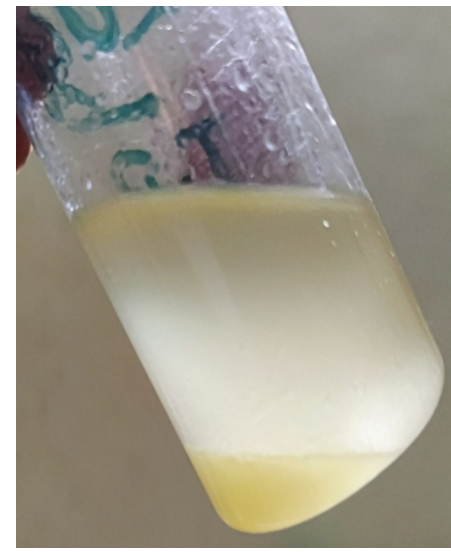

Fig. 4b: Incomplete conversion (fall seen).

Table 2: Analyzing the quality of biodiesel based on the soap content chart.

Soap Content	Fuel Quality
at or below 41 ppm (NaOH) or 66 ppm (KOH)	Within ASTM standards
Above ASTM Standards but Below 200 ppm	Should not pose any threat to a fuel filter or engine
200-300 ppm	maximum soap content which should be allowed in fuel
300-400 ppm	May clog fuel filters, not recommended, wash more
400-500 ppm	High soap content, not recommended, wash more
Above 500 ppm	Can possibly leave ash in your engine and cause long-term damage, not recommended, wash more

content of fuels should be according to the ASTM standard as shown in Table 2. The testing of soap content for biodiesel requires 0.01 N HCL, bromophenol blue, and isopropyl alcohol. Take 100 mL of isopropyl alcohol into a 250 mL beaker, then add about 12 mL of biodiesel into the beaker and mix them. Add 15 to 20 drops of bromophenol blue into the beaker until the solution turns a dark blue color. After that, titrate the solution with 0.01 N HCL. Note that the mL of HCL is required to change the color of the solution from a dark blue color to a yellowish color. Soap content should be checked before and after washing and drying. In the case of the KOH catalyst, the 320 value factor is taken, and in the case of the NaOH catalyst, the 304 value factor is used. The ppm is calculated by multiplying the catalyst factor by the amount of HCL required to get the PPM of the biodiesel sample.

RESULTS AND DISCUSSION

Experimental Design and Parameters Optimization

Box-Behnken design (BBD) and central composite design are the two major experimental designs utilized for response surface optimization (CCD). In this study, we used design expert software to apply the CCD design of the response surface methodology. In the response surface approach, two essential models are typically used, namely the first-degree and second-degree models (Kumar Ghosh & Mittal 2021). When the response can be well explained by a linear function of independent variables, a first-degree model is used. However, when the system has curvature, a second-degree model is used, and a high-degree polynomial is used. In all of these models, there is a correlation between independent variables like time of reaction, temperature, molar ratio, catalyst weight percent, and the resulting variable (yield percent). Table 3 shows the practical amounts and ranges of several independent variables used in the production of biodiesel. In this work, 30 experimental runs were done and consisted of 16 factorial, 8 axial, and 6 center points. The 2nd-degree model is applied in this article, which suggests 30 runs. We already discussed how this system shows curvature.

Experimental design for the production of biodiesel: the coded values of different independent variables are specified in Table 4. The methanol to oil (molar ratio) and catalyst percent are represented by the coded variables x_1 and x_2. The x_3 and x_4 denote the temperature of the reaction and time, respectively (Kumar Ghosh & Mittal 2021).

Quadratic equation Eq. (1) states the performance of the system. For multiple regression data analysis, a statistical program was utilized. Calculating the regression equation and studying the response of 3D surface plots and contour plots provides the optimum value of selected variables.

$$Y = \beta_0 + \sum_{j}^{k}{}_{=1} \beta_j x_j + \sum_{i=1}^{k} \beta_{jj} x_j^2 + \sum\sum_{i<j}^{k} \beta_{ij} x_i x_j + \varepsilon \quad \ldots(1)$$

Whereas Y denotes the biodiesel yield percentage, and *xi*, and *xj* represent actual independent variables in the appearance of encoding; β_0, β_j, β_{jj}, *and* β_{ij} expressed as intercept,linear,quadratic, and interaction constant coefficients also ε denotes a random error.

Regression Equation for Yield of Biodiesel

The essential parameters that affect the resultant (biodiesel yield) are; the molar ratio (methanol to oil ratio (*x1*)), catalyst percentage (*x2*), the temperature of reaction (*x3*), time of reaction (*x4*) (Kumar Ghosh & Mittal 2021). Experimental

Table 3: Levels of independent variables for the experimental design.

Factor	Name	Units	Minimum	Maximum	Mean
A	Methanol/oil ratio (x_1)	$Mol.mol^{-1}$	1.0000	13.00	7.00
B	KOH catalyst (x_2)	%	-0.0500	1.75	0.8500
C	Temperature (x_3)	°C	42.50	72.50	57.50
D	Time (x_4)	Min	7.50	157.50	82.50

Table 4: CCD design for biodiesel production.

Runs	Independent variables				Points	Yield
	(x_1)	(x_2)	(x_3)	(x_4)		
1	7	0.85	72.5	82.5	Axial	98.4
2	4	0.4	65	120	Factorial	70.6
3	10	0.4	50	120	Factorial	96.8
4	7	0.85	57.5	82.5	Center	86.8
5	4	0.4	50	45	Factorial	32.6
6	7	0.85	57.5	82.5	Center	86.2
7	7	0.85	57.5	82.5	Center	98.7
8	7	0.85	57.5	82.5	Center	98.7
9	10	1.3	65	120	Factorial	80
10	4	1.3	65	45	Factorial	84.2
11	4	0.4	65	45	Factorial	38.7
12	4	1.3	50	45	Factorial	82.2
13	10	0.4	50	45	Factorial	82
14	4	1.3	65	120	Factorial	92.5
15	7	0.85	57.5	82.5	Center	98.7
16	7	0.85	57.5	157.5	Axial	98.5
17	10	0.4	65	120	Factorial	94.8
18	7	1.75	57.5	82.5	Axial	78
19	1	0.85	57.5	82.5	Axial	38.9
20	7	0.85	57.5	82.5	Center	98.7
21	4	0.4	50	120	Factorial	85.7
22	10	1.3	65	45	Factorial	92.3
23	4	1.3	50	120	Factorial	90.6
24	10	1.3	50	120	Factorial	86.5
25	7	0.05	57.5	82.5	Axial	41.3
26	7	0.85	42.5	82.5	Axial	95.2
27	10	1.3	50	45	Factorial	94.6
28	13	0.85	57.5	82.5	Axial	88.8
29	7	0.85	57.5	7.5	Axial	60.1
30	10	0.4	65	45	Factorial	92.3

runs are carried out to find the coordination between different parameters. The observed verdicts of the whole factorial central CCD were compared to the polynomial Eq. (1) using multiple regression analysis in Table 4. The equation of multiple regression for the yield of biodiesel formation as a function of many variables is shown in Eq. (2).

$$Y = -1.73211 + 1.47311x_1 + 10.17824x_2 - 0.145439x_3 + 0.107262x_4 - 0.045366x_1^2 - 2.26447x_2^2 + 0.001667x_3^2 - 0.000111x_4^2 - 0.391099x_1x_2 + 0.000304x_1x_3 - 0.003777x_1x_4 - 0.006894x_2x_3 - 0.025322x_2x_4 - 0.000504x_3x_4 \quad \ldots(2)$$

The sign attached to the coefficient predicts the impact of the regression coefficients on the result or response. A negative sign indicates a combative effect, while a positive sign indicates a coadjuvant result. x_1, x_2, x_3, x_4 are four linear factors, and the interaction of x_1x_4 The coadjuvant effect is represented by the remaining quadratic intercepts. x_1^2, x_2^2, x_3^2, x_4^2 and relations of x_1x_2, x_1x_3, x_1x_4, x_2x_3, x_2x_4, x_3x_4 predicts the combative effect. Confirmation of adequacy of the model is determined by the use of analysis of variance (ANOVA) (Kumar Ghosh & Mittal 2021) given in Table 5. Coefficient of determination R^2 is utilized to test whether the model is fit or not, the R^2 is calculated as 0.9363, suggesting that previously model states or explain 93.63% of the response variability, the transesterification experiment factors exhibited a total variation of 93.63(R^2) and adj.R^2

Table 5: ANOVA analysis of variance for a yield of biodiesel.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	41.41	14	2.96	15.75	< 0.0001	significant
A-Methanol/oil ratio	9.65	1	9.65	51.39	< 0.0001	
B-KOH catalyst	5.94	1	5.94	31.62	< 0.0001	
C-Temperature	0.0011	1	0.0011	0.0060	0.9391	
D-Time	4.85	1	4.85	25.83	0.0001	
AB	4.46	1	4.46	23.75	0.0002	
AC	0.0007	1	0.0007	0.0040	0.9505	
AD	2.89	1	2.89	15.38	0.0014	
BC	0.0087	1	0.0087	0.0461	0.8329	
BD	2.92	1	2.92	15.55	0.0013	
CD	0.3215	1	0.3215	1.71	0.2105	
A^2	4.57	1	4.57	24.34	0.0002	
B^2	5.77	1	5.77	30.71	< 0.0001	
C^2	0.2411	1	0.2411	1.28	0.2750	
D^2	0.6692	1	0.6692	3.56	0.0786	
Residual	2.82	15	0.1878			
Lack of Fit	2.28	10	0.2281	2.12	0.2099	not significant
Pure Error	0.5369	5	0.1074			
Cor Total	44.23	29				

"R^2 = 93.63% and adj.R^2 = 87.68%

of 87.68%. This states to facilitate the model has the best association and makes an accurate prediction. In an analysis of variance, (ANOVA) of Table 5 shows the probability of p-value is not greater than 0.0001 which means the model is significant (Anbessa & Karthikeyan 2019).

Analysis of the Impact of Transesterification Parameters

Graphically, contour and 3D surface plots show the effects of transesterification parameters on the result (biodiesel yield).

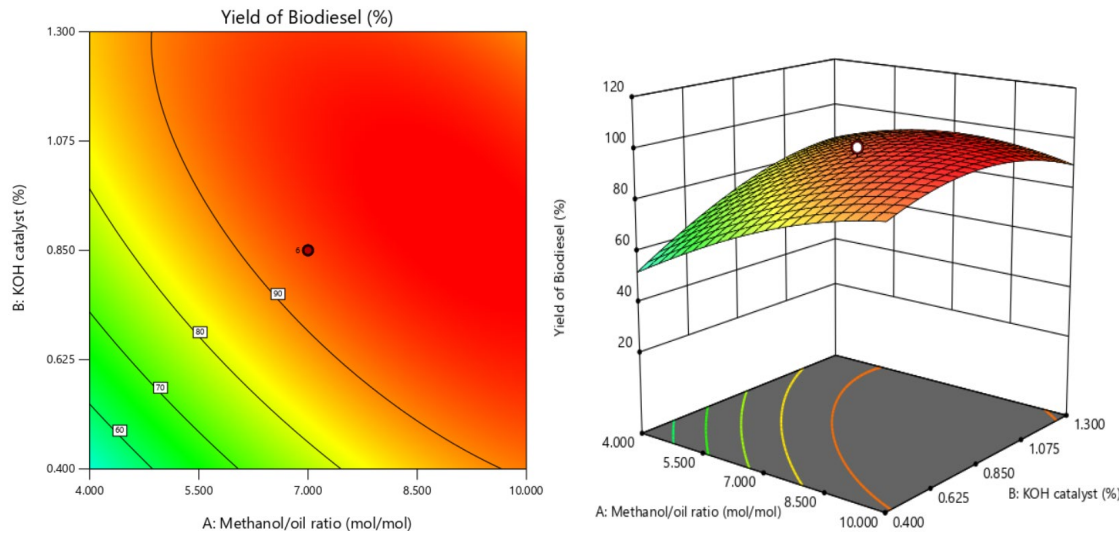

Fig. 5: (a) Represents a Contour plot and (b)shows a 3D surface plot showing the interaction of methanol/oil ratio and catalyst wt%.

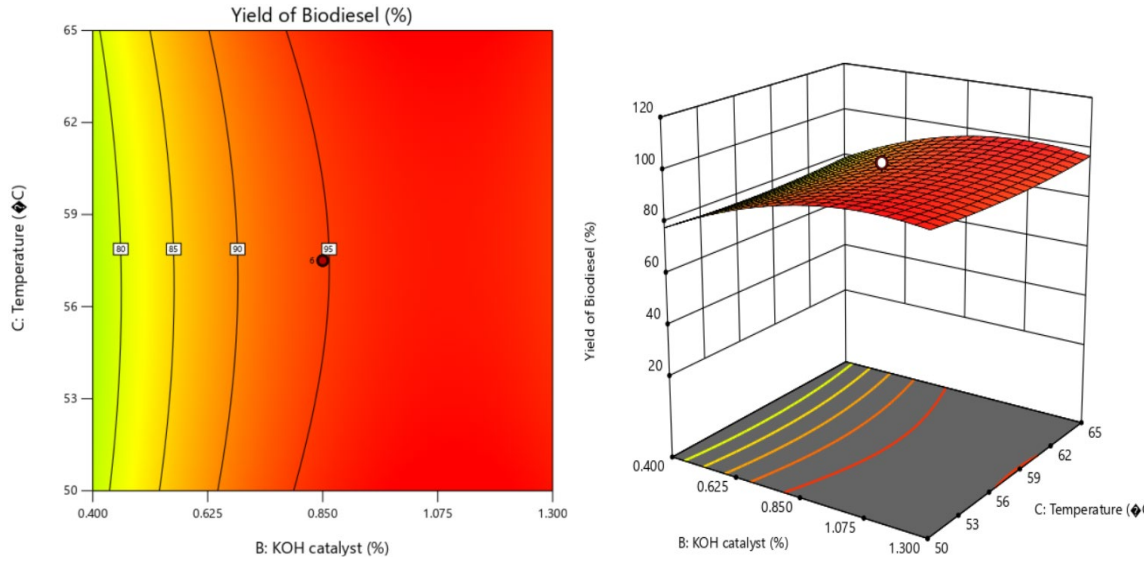

Fig. 6: (a) Represents contour plot (b) 3D surface plot shows the interaction of catalyst % and temperature.

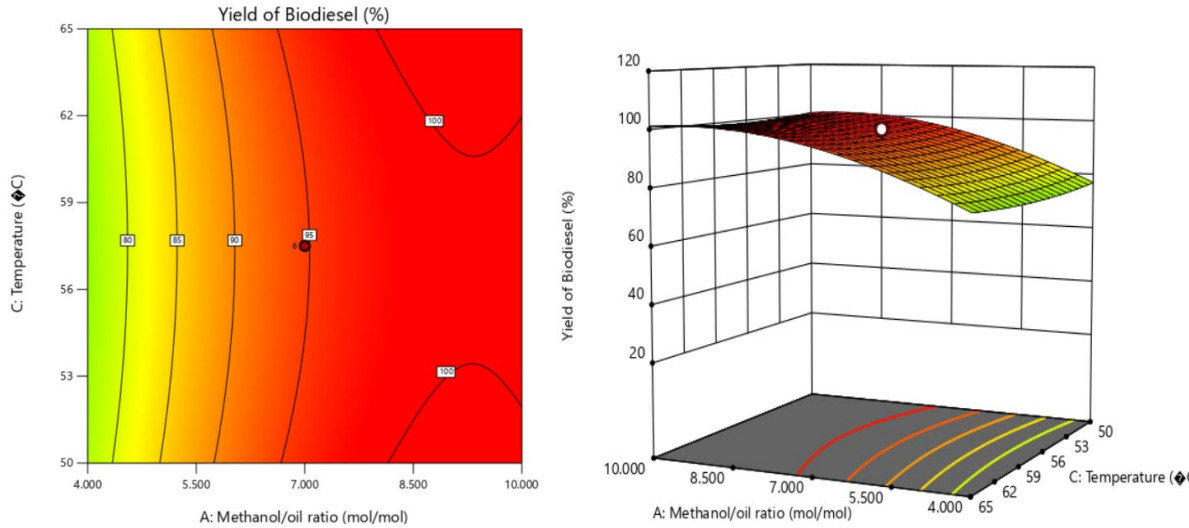

Fig. 7: (a) Represents contour plot (b) Shows 3D surface plot andrelations of methanol/oil ratio and temperature.

Fig. 5(a) depicts the relationship between the methanol/oil ratio and the catalyst percent, as well as the effect on yield. According to Fig. 5(b) of the 3D surface plot, as the molar ratio (methanol/oil ratio) increases, so does the yield of biodiesel, which ranges from 4:1 to 10:1. the optimal methanol/oil ratio is determined by optimization. The best optimum ratio that was achieved is a 10:1 methanol/oil ratio, and this gives a yield of 98.84% for biodiesel. By observing the data, it is found that increasing the methanol/oil ratio with catalyst gives an increment in biodiesel yield due to the higher number of active sites. However, too much catalyst percent results in excess emulsion (Hazmi et al. 2021). maximum yield is obtained at optimized conditions of methanol/oil ratio (10:1) and catalyst 1.3%, which gives 98.84 yields.

Likely, Fig. 6(a) and (b) indicate the effects of interactive factors such as KOH catalyst percentage and temperature of reaction on the resultant response. Fig. 7(a) and (b) show the response of correlated factors to the methanol/oil ratio and temperature of the reaction. A 3D surface plot represents the increase in yield of biodiesel as temperature increments from 50°C to 65°C. This increase in yield is because the speed of transesterification ranges increases as the temperature increments due to the enhancement of a

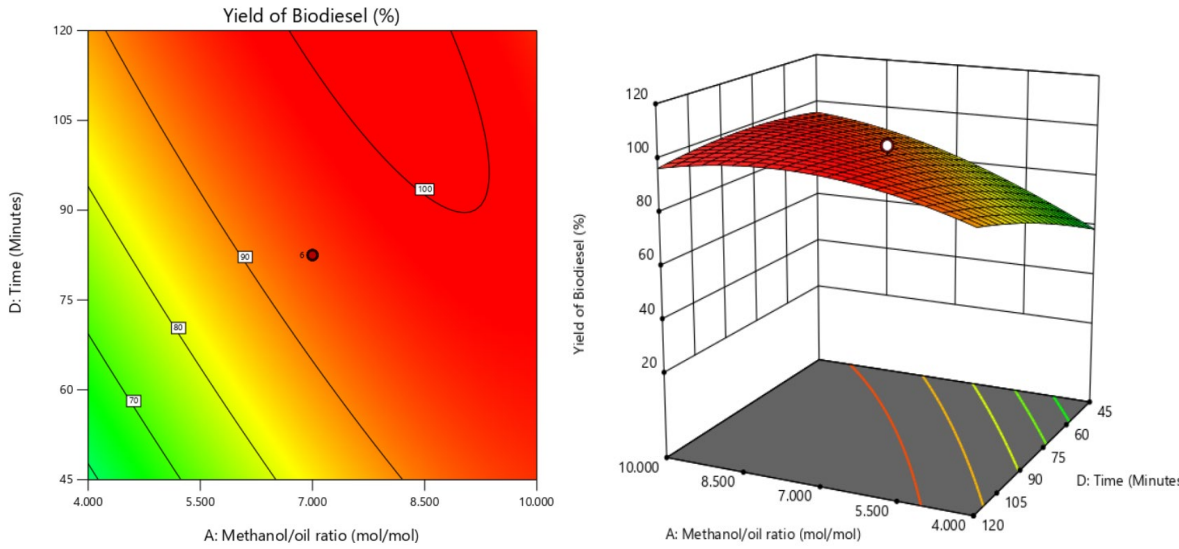

Fig. 8: (a) Represents contour plot (b) Shows 3D surface plot and relations of methanol/oil ratioand reaction time.

Table 6: Optimized result of the process.

Transesterification parameters	Optimum values
Yield of biodiesel	98.84%
Methanol/oil ratio	10:1
Catalyst%	1.3%
temperature	65°C
time	45 min

homogenous mixture (miscibility) when methanol and oil are mixed at high temperatures (Kumar Ghosh & Mittal 2021). The optimum temperature for the best yield is 65°C, which is optimized through RSM optimization with 1.3% catalyst loading for a higher yield.

Fig. 8(a) and (b) represent the interaction of molar ratio (methanol to oil ratio) and reaction time and its effect on the resultant (yield) of biodiesel. Higher ratios of methanol to oil lead to a more rapid conversion of biodiesel. Also, the time of reaction for the process depends on the nature of the catalyst (acid or base catalyst). Typically, the catalyst requires less significant time (1–2 h) for the conversion of biodiesel from oil. As the yield of biodiesel increases with reaction time, excess time of the reaction can lead to deteriorated yield and more glycerol production (Kumar Ghosh & Mittal 2021). After optimization, the optimum reaction time was 45 min for high conversion.

The optimized values are calculated from the regression equations. The different transesterification parameters are summarized. After studying the contour plot and 3D surface plots, we get optimum values for the highest yields of biodiesel production. The maximal yield of biodiesel is calculated to be 98.84% and was predicted using design expert software as the methanol/oil ratio =10:1 catalyst =1.3%, temperature =65°C, and time =45 min. We can conclude from the analysis of all contours and surfaced plots that the maximum yield of biodiesel obtained was 98.84%. The optimized results are given in Table 6.

CONCLUSION

The conversion of biodiesel from triglycerides is based on important parameters and the response surface methodology. The optimized results are obtained by solving the regression equation by using the CCD of the response surface methodology. The response surface methodology is a suitable method to optimize the best or highest level of yield. Thirty experimental runs were carried out for analysis using CCD-based RSM. Studying contours and 3D surface plots were utilized to find optimum results. Whereas we get 98.84% of the yield achieved at methanol/oil ratio (10:1), catalyst percentage (1.3%), temperature (65°C), and time (45 min). This study represents a better yield of biodiesel production and a long-term solution for environmental benefits.

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