Optimization of Biodiesel Production from Waste Cooking Oil by Box Behnken Design Using Response Surface Methodology

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Abstract- Interest in Biodiesel production has grown over the years due to concerns related to the environment, and the solutions include deriving energy from waste as the replacement for diesel, a petroleum-derived fuel. Biodiesel has been accepted as a "green fuel" as it is a renewable, non-toxic, safe and biodegradable energy material. The utilisation of waste cooking oil (WCO) by converting it into biodiesel is one of the promising alternatives to diesel. An attempt to optimise the biodiesel production from WCO (a waste material) has been made via this study. The process adopted was Trans-esterification of pretreated WCO, and the optimization of biodiesel production was carried out by Box-Behnken method using a response surface methodology. The variations between the analytical and experimental results were within acceptable limits. The response surface methodology resulted in an optimum yield of 96.88% (analytical), which was validated through an experiment within an acceptable error of 0.58%.

Keywords Waste cooking oil (WCO), Transesterification, Box-Behnken method, Response Surface Methodology.

1. Introduction

Around 88% of the energy supply throughout the world depends on fuels derived from petroleum (coal, natural gas and oil). These fossil fuels have a significant role in the power generation and transportation sector. Furthermore, these fuels are an economic burden to the underdeveloped countries in which the natural resources are very scarce. The production of oil is predicted to be the highest during the period between 2015 and 2030. Alternate sources of fuel to petroleum-derived fuel is more pressing than ever before due to global political uncertainty, depletion of resources, and ever-increasing price. Stringent emission norms are being implemented worldwide due to the severe environmental pollution being caused by the emission of greenhouse and toxic gases as a result of burning petroleum-based fuels. The consequences of these factors demand the development of low cost and less polluting alternatives to petroleum-derived fuels [1-4].

At the end of 2016, the population of the world was accounted for 7.4 billion, and by the end of the century, was predicted to increase to 12 billion. The rapid growth of population results in a consistently expanding energy demand. Regardless of the escalating energy demands, renewable energy has a sustainable future ahead, taking into account that the worldwide expenditures have grown by 5% [5-7]. This indicates there is an expanding interest for investment on renewable energy sources in contrast to petroleum-based resources. Furthermore, the newer policy on contract costs has quickened the utilization of renewable energy sources in the nations that are developing [8].

One of the alternative sources of energy that has the potential for the much-needed development as the above is bio-fuel [9]–[12]. Biofuels derived from waste or by-products as feedstock's through biological and chemical conversion techniques appeal to the researchers because they not only offer a solution to finding alternatives to conventional fuels but they mitigate both emission and cost issues as well [13]. Among various biofuels, biodiesel has been and will continue to be more promising both as a neat fuel and as a fuel suitable for blending with diesel [14]–[17]. This is due to the favourable chemical and other characteristics of biodiesel [18]. The use of biodiesel does not require modifications in the engine when used as its fuel

in contrast to the conventional diesel made from petroleum products; the biodiesel is non-hazardous, safe and clean because of its attributes of being carbon-neutral, renewable and biodegradable[19-20].

Biodiesel also termed as free fatty methyl esters (FAME), is the product obtained from synthesis of biomass and alcohol with a suitable catalyst [21]. The main deterrent in the commercializing biodiesel is the expense incurred in its mass production. Exploiting the waste materials for generating biodiesel will help to decrease the feedstock cost, and meanwhile make the procedure economical. In this study, waste cooking oil (WCO) was chosen as an alternative energy resource [22]–[27]. However, the problem was the nature of the fuel that resulted in presence of moisture and solid particles that were most originally present in the WCO[28].The WCO is normally disposed off to the surroundings as it cannot be reused for cooking. The university campuses can collect such waste oil from campus messes, cafeteria and even from surrounding hotels in large quantity. The technology involved in converting WCO into biodiesel needs to be optimised.The contribution of the energy added to the existing grid from biodiesel from WCO is also significant [29]. The property of biodiesel that is unfavorable when compared with the mineral diesel is its higher viscosity. [30]. The viscosity of the fuel influences fuel combustion with regards to atomization and spray characteristics - the higher viscosity of waste cooking oil results in larger droplets. Furthermore, this results in a smaller angle of spray injection which in turn results in poor vapourization of fuel and mixing of fuel with air. This will result in incomplete combustion emitting objectionable and toxic constituents in the exhaust. [31].

The problem of high viscosity of WCO that restricts its use as an alternative fuel in diesel engines can be overcome by the transesterification process which results in its conversion into biodiesel. Trans-esterification is an established and most popular technique adopted in biodiesel formation because of its higher yield.

This procedure is appropriate for oils that contain low free fatty acid (FFA) content (< 4%). Oils having > 4% FFA is transformed by the acid-catalyzed process of transesterification. Transesterification is affected by a few procedures and parameters like the temperature of the reaction, type of catalyst, the concentration of the catalyst, alcohol type, and molar ratio of the oil, speed and time of reaction [32]. Optimizing these parameters will bring about higher yields and enhance biodiesel quality.

The presence of high free fatty acids (FFA) in waste cooking oil is a severe drawback for the production process (transesterification) of biofuel, which is sorted out with the help of the study was aimed at the optimization process of the transesterification of WCO by Box-Behnken design [37]–[39] using Response Surface Method [4], [40] to improve the efficiency of biodiesel production by analysis of variance (ANOVA). The biodiesel thus synthesized was characterized by using Gas Chromatography-Mass Spectrometry (GCMS) -and the chemical composition was analyzed. Finally, the feasibility of the obtained biodiesel as fuel to compression ignition engines was compared with the physicochemical properties of diesel as stated in Bureau of Indian Standard (BIS)[41][42].

2. Materials and Methods:

2.1. Materials

Waste cooking oil was collected from the university campus and neighbouring areas for three days and the average collection was assessed to see the trend of availability. The oil was collected from the campus canteens, hostel messes, local food joints etc. and the details of collection before and after use (available as waste) by the canteens/stalls are shown in table 1. The collected waste cooking oil was filtered to get rid of solid impurities, and moisture was removed by heating to 100°C. Subsequently, the contaminant and moisture-free oil were subjected to trans-esterification, and some of the parameters that influence the properties and must be optimized are methanol concentration, catalyst concentration, reaction time and reaction temperature [43].

Table 1. Data on cooking oil used and wasted

Canteen / Stall	Type of oil used	Day	Oil Used (litres)		
			Total oil used by canteen/ stall on each day	oil Remaining after use by canteen/stall	Oil available for this research work (average/3 days)
Canteen 1	Palm Olien	1	25	7	7
		2	25	5.5	
		3	25	8	
Canteen 2	Sunflower	1	25	6	6
		2	25	7.3	
		3	25	6	
Stall 1	Sunflower	1	8	1	1
		2	8	1	
		3	8	1	
Stall 2	Sunflower	1	2	0.5	0.4
		2	2	0.4	
		3	2	0.4	
Stall 3	Sunflower	1	4	1.7	2
		2	4	2	
		3	4	1.9	

2.2 Transesterification (alkaline catalyzed) of Pretreated Waste Cooking Oil

The optimization of transesterification process parameters is obtained by adopting the Box-Behnken design. The regression coefficients affecting the biodiesel yield were determined by regression analysis of the experimental data. The various fundamental, advantages and limitations of the Box-Behnken design were described by multiple researchers in their experiments for the analytical optimization [44]–[50].

The Box–Behnken Design is most feasible for evaluation of process parameters on the biodiesel yield in comparison to central composite design (CCD) with three or four reaction variables [43]. The design of experiments involving reaction parameters such as methanol concentration, reaction temperature, reaction time and catalyst concentration, coded as A, B, C and D, respectively, is shown in table 2. The coded reaction parameters were optimised using response surface methodology, and the response surfaces and counterplots were analysed. The input parameters were entered in Design-Expert® software v 11, which resulted in 29 runs, and the final results are included in Table 2.

Table 2: Design of Input Variable Range

Factor	Name	Units	Type	Minimum Coded Low	Uncoded	Maximum Coded High
A	Methanol	ml	Factor	-1 ↔ 150.00	200	+1 ↔ 250.00
B	Temperature	℃	Factor	-1 ↔ 60.00	65	+1 ↔ 70.00
C	Reaction time	min	Factor	-1 ↔ 60.00	90	+1 ↔ 120.00
D	Catalyst conc.	g	Factor	-1 ↔ 2.5	5	+1 ↔ 7.5
	Yield	%	Response			

Table 3: Design of experiments-based Box-Behnken experimental design.

Run Order	Variables				Biodiesel yield		Residual
	A Methanol Ml	B Temperature ℃	C Reaction Time Minutes	D Concentration of Catalyst gram	Actual Value	Predicted Value	
01	200	60	60	5	86.00	84.33	1.67
02	200	65	60	7.5	95.00	94.92	0.0833
03	200	65	90	5	94.00	90.80	3.20
04	200	65	120	2.5	92.00	90.58	1.42
05	150	65	90	7.5	97.00	99.00	-2.00
06	150	70	90	5	83.00	82.92	0.0833
07	150	65	60	5	89.00	88.25	0.7500
08	200	70	90	2.5	84.00	82.92	1.08
09	200	65	60	2.5	74.00	73.75	0.2500
10	200	65	120	7.5	92.00	90.75	1.25
11	250	65	90	2.5	90.00	89.00	1.0000
12	200	65	90	5	91.00	90.80	0.2000
13	200	65	90	5	89.00	90.80	-1.80
14	200	70	60	5	75.00	75.33	-0.3333
15	200	60	90	7.5	95.00	96.58	-1.58
16	150	60	90	5	86.00	84.92	1.08
17	150	65	120	5	84.00	82.08	1.92
18	200	70	0	7.5	88.00	86.58	1.42
19	200	65	90	5	92.00	9080	1.20
20	250	65	90	7.5	90.00	89.17	0.8333
21	150	65	90	2.5	76.00	77.83	-1.83
22	250	60	90	5	88.00	86.58	1.42
23	250	65	120	5	94.00	95.80	-1.25
24	200	65	90	5	88.00	90.80	-2.80

Run Order	Variables				Biodiesel yield		Residual
	A Methanol Ml	B Temperature ºC	C Reaction Time Minutes	D Concentration of Catalyst gram	Actual Value	Predicted Value	
25	200	70	120	5	85.00	87.67	-2.67
26	250	65	60	5	74.00	76.42	-2.42
27	200	60	120	5	84.00	84.67	-0.6667
28	200	60	90	2.5	77.00	78.92	-1.92
29	250	70	90	5	83.00	82.58	0.4167

Table 4: ANOVA (Analysis of variance) results based on Quadratic regression response used to predict biodiesel yield.

Source	Coefficient Estimate	Sum of Squares	Degrees of freedom	Mean Square	F-value	p-value
Model	90.80	1141.49	14	81.54	16.24	< 0.0001
A-Methanol Volume	0.333	1.33	1	1.33	0.2655	0.6144
B-Methanol Volume	-1.50	27.00	1	27.00	5.38	0.0360
C-Reaction Time	3.17	120.33	1	120.33	23.96	0.0002
D- Na OH Concentration of Catalyst	5.33	341.33	1	341.33	67.98	< 0.0001
AB	-0.5000	1.0000	1	1.0000	0.1991	0.6622
AC	6.25	156.25	1	156.25	31.12	< 0.0001
AD	-5.25	110.25	1	110.25	21.96	0.0004
BC	3.00	36.00	1	36.00	7.17	0.0180
BD	-3.50	49.00	1	49.00	9.76	0.0075
CD	-5.25	110.25	1	110.25	21.96	0.0004
A^2	-2.02	26.60	1	26.60	5.30	0.0372
B^2	-4.52	132.81	1	132.81	26.45	0.0001
C^2	-3.28	69.57	1	69.57	13.85	0.0023
D^2	-0.0250	0.0041	1	0.0041	0.0008	0.9777
Residual		70.30	14	5.02		
Lack of Fit		47.50	10	4.75	0.8333	0.6308
Pure Error		22.80	4	5.70		
The correlated total sum of squares		1211.79	28			
Standard Deviation		2.24				
Mean		86.72				
Coefficient of Variation %		2.58				
R^2		0.9420				
Adjusted R^2		0.8840				
Predicted R^2		0.7448				
Adequate Precision		15.6676				

The experimental procedure for biodiesel production through transesterification was carried out by taking one litre of waste cooking oil in a three-neck flat bottom round flask reactor and heated to a temperature of 65°C within a range of 800 to 900 rpm. Meanwhile, the methoxide was being prepared by mixing 200 ml of methanol with 5g of sodium hydroxide. The prepared mixture was added to the preheated oil and stirred continuously for 90 minutes. The reactor is

equipped with reflux condenser which is maintained at room temperature to avoid evaporation of methanol. Upon completion of the prefixed reaction time, the reaction mixture was transferred to a separating funnel and allowed to settle for at least 8 hours [51] resulting in two layers-biodiesel (top layer) and mixture (bottom layer) of glycerin, methanol and other impurities. The obtained biodiesel was separated from glycerin and other impurities and washed with hot distilled water until the washed water was clear from glycerin, methanol and other impurities (transesterification byproducts). The washed biodiesel was then heated to 100°C for an hour to remove the moisture content. The experimental procedure was repeated for the predicted values from the response surface regression model, as shown in Table 3.

2.3. Selection of Model for Biodiesel Yield.

Response surface methodology was used to build a relationship with biodiesel and reaction variables by building the regression model using mathematical and statistical techniques. The quadratic regression model was chosen to predict the biodiesel yield as a response from reaction variables by analysing the experimental data.

3. Results and Discussion

3.1. Optimization of Transesterification Variables (A, B, C & D):

3.1.1. Selection of model for biodiesel yield.

The different biodiesel yields obtained from Box-Behnken method based on the quadratic regression model are tabulated in Table 3.

The multiple quadratic regression analysis of coefficients of Box-Behnken model variables resulted in the following model to predict the biodiesel yield.

$$\text{Yield Biodiesel} = +90.80 + 0.3333A - 1.50 + 3.17C + 5.33D - 0.5000AB + 6.25AC - 5.25AD + 3.00BC - 3.50BD - 5.25CD - 2.02A^2 - 4.52B^2 - 3.28C^2 - 0.0250D^2 \quad (a)$$

The equation (a) in terms of coded factors can be used for predicting the response for given levels of each factor. To justify the model, the F-value should be higher than critical F-value and P-value should be less than 0.005. Hence the selected model is significant based ANOVA results as in table 4.The relative impact of each variable cannot be decided by the equation (a) however, the P-value from ANOVA results as in table 4 decides the significance of each term. The P-values with a value of less than 0.0500 shows that model terms are significant. In this case, B, C, D, AC, AD, BC, BD, CD, A^2, B^2, C^2 are significant model terms. The values which are higher than 0.1000 (A, AB & D2) indicates that the model terms are non-significant.

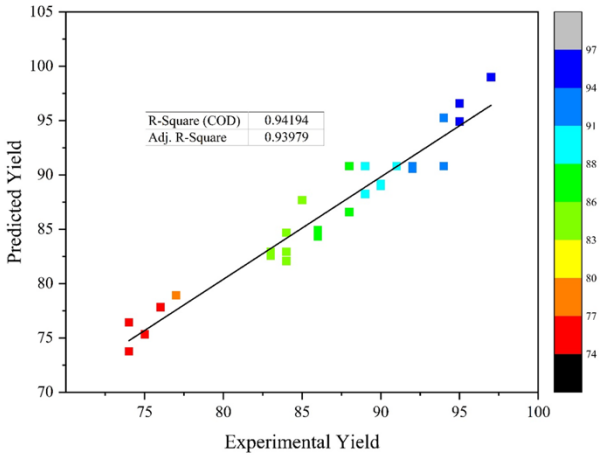

Fig.1. Coefficient of determination-R2 (COD) between predicted yield (%) and experimental yield (%)

The effect of transesterification variables on biodiesel yield was determined by the Coefficient of determination- R2 (COD) between predicted yield (%) and experimental yield (%) as shown in Figure-1. In this study, the regression model resulted in an R2 value of 0.942, which signifies a 94.2% influence of process parameters on biodiesel yield. The variation between experimental and predicted yield is acceptable as the points are scattered around the regression line, as seen in Figure-1. Furthermore, the variance in

Predicted R^2 (0.7448) and Adjusted R^2 (0.8840) is less than 0.2; thus, no modifications are required in the regression model. However, it is essential to verify the accuracy of the model via experimental results (Figure-2). Therefore the process variables predicted by the regression model to produce maximum biodiesel yield is to be compared with the experimental value. The optimum values of variables to produce biodiesel: methanol was found to be 150ml, reaction time of 63 min, reaction temperature 62°C, and NaOH catalyst concentration of 7.5g which helped to achieve the maximum predicted biodiesel yield of 96.88%. The average of experimental biodiesel yield was 96.3% with a marginal difference of 0.58% from the predicted value. This validates the accuracy of the selected regression model by anticipating the influence of transesterification variables on biodiesel yield. Further, the significance of model terms AC, AD, BC, BD, CD were analyzed on three-dimensional (3-D) surface plots, as shown in Figure-3 to Figure-8. The 3-D plots are the result of an interaction between any two transesterification process variables and biodiesel yield. The resultant counterplots are the projections of specific biodiesel yield in response to particular variables on a two-dimensional plane.

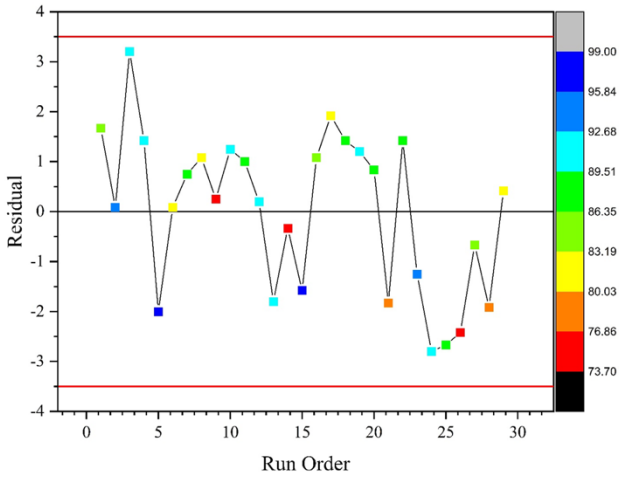

Fig. 2. Comparison of residual errors and run order

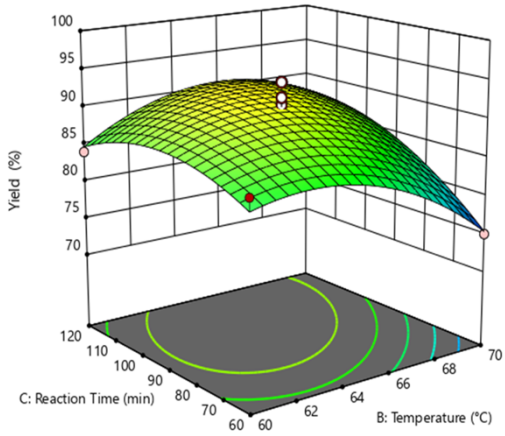

Fig. 5. 3-D surface plots showing variables effect on biodiesel yield: Reaction time and temperature.

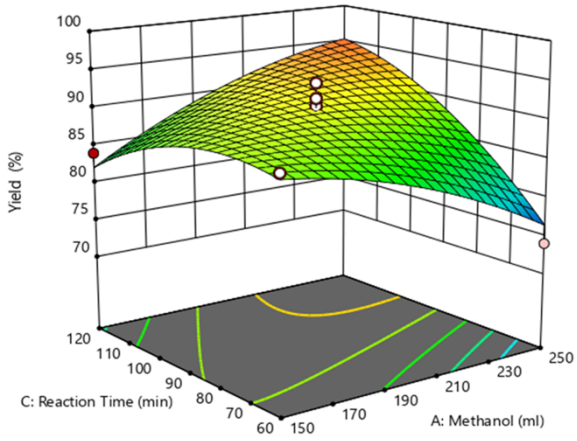

Fig. 3. 3-D surface plots showing variables effect on biodiesel yield: Reaction time and methanol

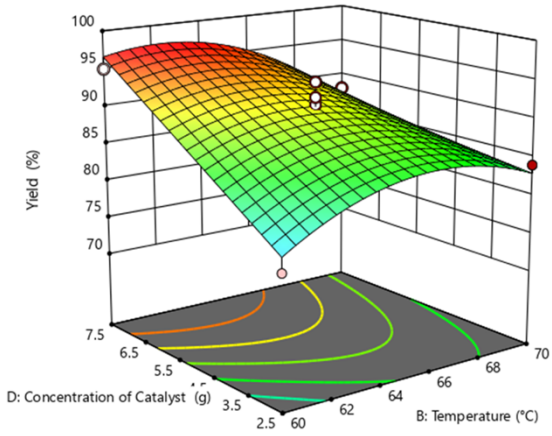

Fig. 6. 3-D surface plots showing variables effect on biodiesel yield: Concentration of catalyst and temperature.

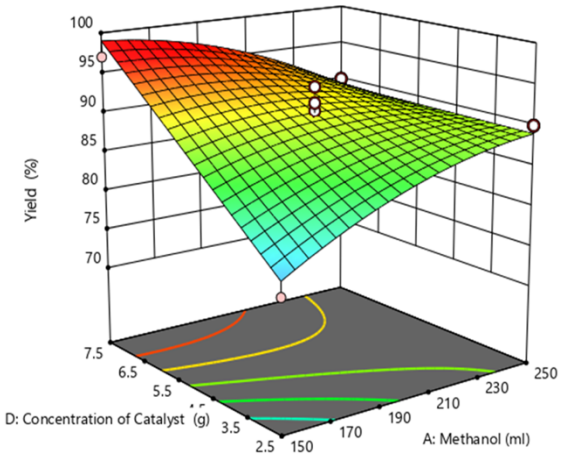

Fig. 4. 3-D surface plots showing variables effect on biodiesel yield: Concentration of Catalyst and Methanol.

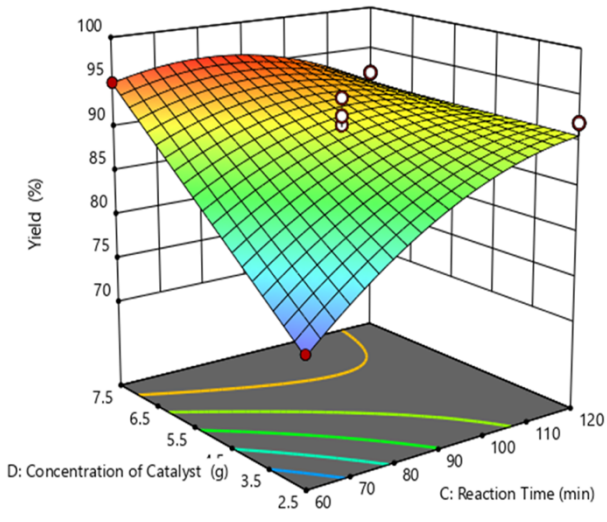

Fig. 7. 3-D surface plots showing variables effect on biodiesel yield: Concentration of catalyst and reaction time.

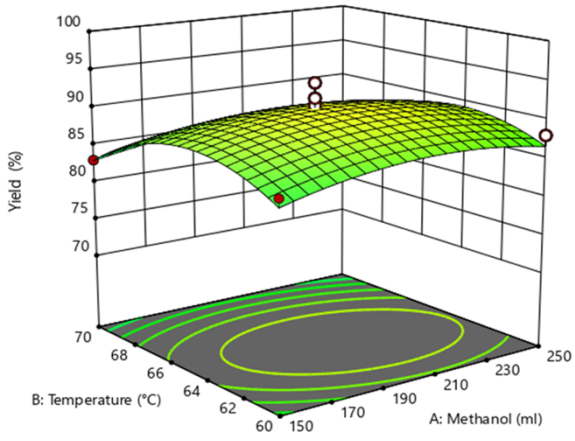

Fig. 8. 3-D surface plots showing variables effect on biodiesel yield: Temperature and methanol

3.1.1. The implication of methanol volume:

One of the goals of the 3-D plots was to analyze the effect of reaction time and methanol, the concentration of NaOH catalyst and methanol and temperature and methanol on biodiesel yield and the plots are shown in Fig-3, Fig-4 and Fig-8. The methanol, reaction temperature, reaction time and NaOH catalyst concentration respectively were varied from 150ml to 250 ml, 60℃ to 70℃, 60 min to 120 min and 2.5g to 7.5g respectively. To maximize the biodiesel yield in the transesterification process, a vital role is played by an optimum methanol volume. The increase in methanol volume, when studied in the range between 150ml and 250ml (Figure-8), resulted in an increased yield until 170ml of methanol addition was reached, and was followed by a steady a decrease in yield. This trend was observed even after an increase in methanol volume beyond 170ml, where although the solubility of glycerol increased, the purification process itself became most complicated and resulted in lesser yield. From Table 3 (using ANOVA regression analysis) evidently, the change in methanol volume does not efficiently affect the conversion of waste cooking oil into biodiesel as the factor A is not a significant model term. Therefore, an optimum methanol volume resulted from this study is 150 ml and increasing the value beyond 150 ml may decrease the yield of biodiesel as the solubility of glycerol increases. From Figure-3 it is evident that both methanol and reaction time is dominant at lower values, and low reaction time (60 min to 70 min) and low methanol (150 ml to 160 ml) concentration is useful for a high biodiesel yield. The higher concentration of catalyst (5g to 7.5g) and the lower concentration of methanol volume (150 ml to 160 ml) resulted in higher biodiesel yield (Figure-4).

3.1.2. The implication of reaction temperature

Yet another goal of the 3-D plots was to analyze the effects of reaction time, and temperature, the concentration of catalyst and temperature and temperature and methanol on biodiesel yield and the plots pertaining to these results are shown in Fig-5, Fig-6 and Fig-8 respectively. The methanol, reaction temperature, reaction time and NaOH catalyst concentration were varied between 150ml and 250 ml, 60℃ to 70℃, 60 min to 120 min and 2.5g to 7.5g respectively. The maximum biodiesel yield is seen at lower methanol volume and lower temperatures (figure 8). The methanol volume required is lesser at the temperature range of between 60 and 62ºC, as methanol boils beyond 65ºC. The evaporation of methanol is controlled beyond 65ºC by employing condenser to cool the vapours back to reaction unit. Increasing the reaction temperature beyond 65ºC, the conversion of biodiesel yield decreases as methanol starts to boil and a lesser amount of methanol is available for conversion of oil into biodiesel. Thus, in this study, the optimized reaction temperature to produce higher biodiesel yield was determined to be 62℃.

3.1.3. The implication of reaction time

The 3-D plots used to analyze the effect of reaction time and methanol, reaction time and temperature and concentration of catalyst and reaction time, are shown in Fig-3, Fig-5 and Fig-7, respectively. The methanol, reaction temperature, reaction time and NaOH catalyst concentration were varied from 150ml to 250 ml, 60℃ to 70℃, 60 min to 120 min and 2.5g to 7.5g respectively. Overall, within the experimental framework, the maximum biodiesel yield was found at lower reaction times. From the patterns shown in Fig-3, Fig-5 and Fig-7, it is evident that increasing the reaction time even after the equilibrium state of the reaction mixture will not help in increasing the biodiesel yield: and yet, increasing the reaction time may cause reverse transesterification to reduce the biodiesel yield. Thus, from this study, the optimized reaction time required to produce higher biodiesel yield was determined to be 63 minutes.

3.1.4. The implication of NaOH catalyst concentration:

The 3-D plots shown in Fig-4, Fig-6 and Fig-7 were also to analyze the effect of NaOH, the concentration of catalyst and methanol, NaOH concentration of catalyst and temperature and NaOH concentration of catalyst and reaction time on biodiesel yield. The methanol, reaction temperature, reaction time and NaOH catalyst concentration were varied from 150ml to 250 ml, 60℃ to 70℃, 60 min to 120 min and 2.5g to 7.5g respectively. In general, the combination of the different variables with NaOH, higher biodiesel yields are obtained at higher concentrations of NaOH. The NaOH catalyst plays a significant role in the conversion of waste cooking oil (triglycerides) into biodiesel (methyl esters) through alcoholysis reaction. The optimized value of NaOH value was determined to be 7.5g, which was on the higher coded value. Further, experimentation was conducted to validate the optimized value; and it was found that by increasing the NaOH catalyst concentration beyond 7.5gm, the biodiesel yield decreased. This is due to the saponification process that occurs during transesterification resulting in the formation of emulsions during the washing process. Higher the concentration of NaOH resulted in the formation of salts and soaps by exchanging the ions and also leads to reverse transesterification.

3.2. Chemical Composition and Physicochemical Properties of Biodiesel Produced.

3.2.1. GCMS and composition analysis.

The Chemical composition and physicochemical properties of biodiesel produced in this work were determined by using Gas chromatography-mass spectrometry (GCMS). A Shimadzu GCMS-QP2010SE SH-Rxi™-5Sil MS-Low-polarity phase column was used at a column oven temperature of 50°C and split injection at a temperature of 280°C with a column flow rate of 1.0mL/min. The column temperature was initially set at 50°C for 2 minutes followed by ramping 6°C/sec to 220°C, held 2 minutes, and finally ramped at 20°C/sec to 280°C and keeping for 5 minutes.

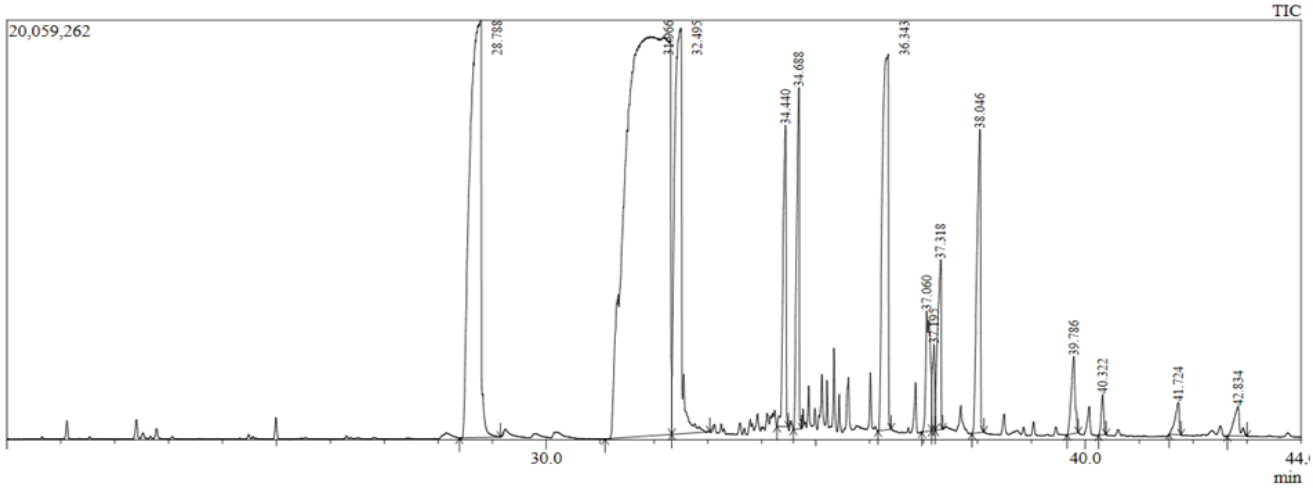

Fig. 9. GCMS of the waste cooking oil biodiesel

Table-5: Chemical composition of waste cooking oil biodiesel

Sl No.	Name	Formula	Concentration (Percentage)
1	Hexadecanoic acid, methyl ester	$C_{16}H_{32}O_2$	15.06
2	6-Octadecenoic acid, methyl ester, (Z)-	$C_{18}H_{34}O_2$	53.08
3	Methyl stearate	$C_{19}H_{38}O_2$	9.44
4	Cis-13-Eicosenoic acid, methyl ester	$C_{21}H_{40}O_2$	2.78
5	Eicosanoic acid, methyl ester	$C_{21}H_{42}O_2$	2.82
6	Docosanoic acid, methyl ester	$C_{23}H_{46}O_2$	7.05
7	Tricosanoic acid, methyl ester	$C_{24}H_{48}O_2$	1.69
8	2H-Isoindole-2-acetic acid, 1,3-dihydro-1,3-di	$C_{24}H_{24}N_4O_8$	0.62
9	2-[5-(2-Methyl-benzooxazol-7-yl)-1H-pyrazol	$C_7H_9N_3O_4$	1.86
10	Tetracosanoic acid, methyl ester	$C_{25}H_{50}O_2$	3.39
11	2,4,6-Tri-tert-butylphenol, trimethylsilyl ether	$C_{18}H_{30}O$	0.94
12	Hexacosanoic acid, methyl ester	$C_{27}H_{54}O_2$	0.31

Table-6: Comparison of Physicochemical properties of waste cooking oil biodiesel with diesel

Property	Unit	Diesel[52]	Biodiesel range[41]	Waste cooking oil biodiesel
Density at 15°C	g/m^3	815 to 845	860-900	925
Kinematic Viscosity at 40°C	cst	2 to 4.5	3.5-5.0	4.56
Flash Point	°C min	60	101	182
Carbon residue (Ramsbottom)	Percent by mass, Max	0.30	0.05	0.04
Water content	Mg/kg, max	200	500	50
Copper corrosion	3 h at 50°C Max	Not worse than 1	1	1

Hexane was used as a solvent for GCMS with a ratio 20:1 for reducing the concentration of fuel sample, and 4μL of the sample was then injected for analyzing the composition. The peaks were analyzed (Fig-9), and the compositions are tabulated in table 5. The presence of hydrocarbon chains in waste cooked oil biodiesel ranging from C16 to C27 behaves similar to diesel with a range of C10 to C18 confirms the suitability of using as fuel in diesel engines

3.2.2. Physicochemical properties of waste cooking oil biodiesel.

The physicochemical properties of waste cooking oil biodiesel were determined and compared with the range specified by the Bureau of Indian Standards (BIS) [41] and are shown in table-6. The properties of waste cooking oil biodiesel were compared with diesel fuel and found that all the properties are in acceptable range except density. The density value of waste cooking oil is slightly higher than in the acceptable range and won't need much attention during blending with diesel fuel. The general tendency of any biodiesel is to have a higher flash point than mineral diesel. The obtained waste cooked oil biodiesel has a higher flashpoint makes it safer for handling and storage. However, the effect higher flashpoint on performance and emission characteristics has to be analysed with experimental results.

4. Conclusion and Recommendation

The WCO is a kitchen waste that can be processed to be converted into biodiesel and thus its disposal into landfills may be avoided. WCO originating from biomass resulting from open-air frying process is a low-cost justifiable alternative for diesel fuel [53]-[57]. However, the process of transesterification warrants further intensive research for it to be used as a sustainable and feasible alternative to diesel. The regression model used for optimizing the variables of the transesterification process has shown negligible variation with the experimental results. The significance of optimized variables involved in the transesterification could make the whole process cost-effective by utilizing lower temperature values and shorter time. The response surface methodology resulted in an optimum yield of 96.88% (analytical), which was validated through an experiment within an acceptable error of 0.58%. The biodiesel yield resulted from the current research found to be increased from the previous study [58]–[63].

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