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Optimizing Biodiesel Production Using Response Surface Methodology and Characterizing the Biodiesel

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Abstract
The growing need for sustainable and eco-friendly energy sources has intensified research into alternative fuels such as biodiesel. This study focuses on optimizing the production of biodiesel through transesterification using Response Surface Methodology (RSM), a powerful statistical and mathematical tool for modeling and analyzing problems in which multiple variables influence a response. Key process parameters including reaction temperature, methanol-to-oil ratio, catalyst concentration, and reaction time were systematically varied and optimized using a central composite design (CCD). The optimized conditions yielded a high biodiesel conversion efficiency, demonstrating the effectiveness of RSM in reducing experimental trials while maximizing output. Following production, the biodiesel was thoroughly characterized in terms of its physicochemical properties, including density, viscosity, flash point, pour point, and calorific value. These properties were compared against ASTM D6751 and EN 14214 standards to assess fuel quality. The results confirmed that the produced biodiesel meets the required specifications, making it a viable alternative to conventional diesel. This work highlights the dual importance of process optimization and product quality assessment in biodiesel production, providing a comprehensive approach toward sustainable biofuel development.

Keywords: Biodiesel, Groundnut Oil, Response Surface Method, Central Composite Design, Optimization, Transesterification, Yield

1. Introduction

The depletion of fossil fuel reserves and the growing environmental concerns associated with greenhouse gas emissions have led to an increasing interest in renewable and sustainable energy sources. Biodiesel, a biodegradable and non-toxic fuel derived from renewable biological sources such as vegetable oils or animal fats, has emerged as a promising alternative to conventional diesel fuel. It offers several advantages, including lower emissions of carbon monoxide, unburned hydrocarbons, and particulate matter, along with a higher cetane number and better lubricity (Demirbas, 2009) [4]. The transesterification process, in which triglycerides react with an alcohol (typically methanol) in the presence of a catalyst to form fatty acid methyl esters (FAME) and glycerol, is the most common method for biodiesel production. However, the efficiency and yield of this process are highly dependent on various operational parameters such as reaction temperature, alcohol-to-oil ratio, catalyst concentration, and reaction time (Meher, Vidya Sagar, & Naik, 2006) [8]. Traditional methods of optimization often require extensive experimentation and resources, which can be both time-consuming and costly. To address these challenges, Response Surface Methodology (RSM) has been widely adopted in biodiesel research. RSM is a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes with multiple variables (Myers, Montgomery, & Anderson-Cook, 2009) [9]. It enables researchers to evaluate the interaction effects of different parameters efficiently and determine the optimal conditions for maximum biodiesel yield with fewer experimental runs. In addition to optimizing the production process, it is crucial to characterize the biodiesel to ensure that it meets international standards such as ASTM D6751

and EN 14214. The characterization includes the assessment of key physicochemical properties like density, viscosity, flash point, pour point, and calorific value, which directly influence engine performance and environmental impact (Knothe, Gerpen, & Krahl, 2005) [6]. This study aims to optimize the biodiesel production process using RSM and to characterize the produced biodiesel to evaluate its suitability as a diesel alternative. By integrating process optimization with fuel quality assessment, the study contributes to the advancement of sustainable biofuel technologies.

Response Surface Methodology (RSM) is an important optimization tool for biodiesel production, (Canakci *et al*., 2001) [3]. RSM, based on the combination of statistical and mathematical tools, is considered to be a valuable technique for the development, modification and optimization of various production processes (Montgomery, 2005; Raymond, *et al*., 2002) [10]. When understudy treatments are based on continuous array of values, then RSM can be used for the improvement, development and optimization of response variables, statistical analysis, on a second order polynomial with the equation below:

$$y = \beta o + \sum_{i=1}^{4} \beta_i X_i + \sum_{i=1}^{4} \beta_{ii} x^2 + \sum_{i=1}^{4} \beta_{ij} X_i X_j \qquad (1)$$

Where; X_i and X_j are uncoded independent variables, β_O is intercept, β_i, β_{ii} and β_{ij} represent the linear, quadratic and interaction constant coefficients respectively, while Y is the response variable. Response surface methodology (RSM) is a useful statistical technique, which has been applied in the research of complex variable processes (Myers and Montgomery, 2002). Multiple regression and correlation analysis are used as tools to assess the effects of two or more independent factors on the dependent variables. Furthermore, the central composite design (CCD) of RSM has been applied in the optimization of several biotechnological and chemical processes. Its main advantage is the reduction in the number of experimental runs required to generate sufficient information for a statistically acceptable result.

2. Materials and Methods

2.1 Materials

Groundnut oil was procured from a local vendor in Akure, Sodium hydroxide (NaOH), Hydrochloric acid (HCl), Methanol (99.8% purity) and Anhydrous Sodium Sulphate (Na_2SO_4) of analytical grade were purchased from National Research Institute for Chemical Technology, Kaduna (NARICT**).**

2.2 Methods

2.2.1 Procedure for Oil Pre-Treatment

The vegetable oil was put for free fatty acid test (FFA), the FFA result was below 1, which makes it suitable for biodiesel production without additive. The oil was pre-heated at a temperature of 100°C to remove water and other volatile impurities (Bello *et al*., 2015) [2].

2.3 Production of Biodiesel

2.3.1 Transesterification Procedure

The groundnut oil was converted to biodiesel, using 99.8% pure methanol and hydrochloric acid as catalyst. Methanol was the choice of alcohol because it is cheap and it is a short chain alcohol that reacts faster. In order to optimize the yield, the catalyst employed was prepared at different concentration, ranging from 1.0 - 1.65 wt%, methanol in excess molar ratio, ranging from 4 -7:1 to oil was used. The pre-heated oil was thereafter transferred to the reactor alongside with methanol, the mixture was stirred at 450 rpm at temperature ranges from 45 – 65 °C for 2 hours. The mixture was thoroughly stirred in the mixing tank to form methoxide. The product was discharged into the separating funnel for 24 hours, in order to make it settle down. After the settling, the product was observed to have been separated into two distinct layers. The lighter biodiesel was at the top while the heavier glycerol was at the bottom. The biodiesel yield was determined using the equation; Biodiesel yield

$$(\text{wt. \%}) = \frac{weight\ of\ biodiesel\ produced}{weight\ of\ oil\ used} \text{ x } 100\% \qquad (2)$$

The methyl ester (biodiesel) was then washed with distilled water at a volume ratio of 3:1 by stirring gently at room temperature. Thereafter it was dried by passing it through anhydrous Sodium Sulphate (Na_2SO_4). The dried biodiesel was stored in a refrigerator to prevent oxidation (Bello *et al.*, 2015) [2]. The Table1 below shows the yields of biodiesel produced, i.e, the experimental values obtained.

Table 1: Results (% yield) from the screening experiment

S/N	Molar Ratio (A)	Catalyst Conc. (B)	Temperature (°C) (C)	Yield (%) (Y)
1	5	1.00	45	74.65
2	5	1.00	65	77.92
3	5	1.50	45	74.86
4	5	1.50	65	76.64
5	7	1.00	45	74.98
6	7	1.00	65	79.76
7	7	1.50	45	72.87
8	7	1.50	65	78.87
9	6	1.50	45	73.80
10	6	1.25	60	76.00
11	6	1.00	55	78.02
12	6	1.65	55	76.76
13	4	1.25	55	75.76
14	7	1.25	55	80.86
15	6	1.25	55	77.08
16	6	1.25	55	79.05
17	6	1.25	55	79.46
18	6	1.25	55	78.61
19	6	1.25	55	78.92
20	6	1.25	55	78.98

Characterization of Oil and Biodiesel

The Physiochemical properties of the fuel were determined with respect to ASTM D6751 and EN 14214 methods. Undertaken in Reservoir/PVT Laboratory, Petroleum Department College of Engineering, Afe Babalola University Ado-Ekiti, (ABUAD) Ekiti State, Nigeria. The analyses carried out were: cloud point test, pour point test, iodine value, saponification value, cetane index, acid value, density measurement and peroxide value.

2.4.1 Cloud Point Test

Cloud point is the temperature at which wax first becomes visible when the fuel is cooled to a temperature of below 25^0 C. The biodiesel was poured into test jar up to the level marked. Then adjusted the position of the cork carrying the test thermometer so that the cork fits tightly (AOAC, 1999).

2.4.2 Pour point test

Pour Point is the temperature at which the amount of wax out of solution is sufficient to gel the fuel, thus it is the lowest temperature at which the fuel can flow. The cold point characteristics of biodiesel products depend on chain length and degrees of unsaturation, with long chain saturated fatty acid esters displaying particularly unfavorable cold temperature behavior (Ramadhas *et al*., 2005) [11].

2.4.3 Iodine Value (Wiji's method)

The iodine value of oil or fat is the weight of iodine absorbed by 100 parts by weight of the sample. A solution of about 0.63g of iodine and 10g of potassium iodine was prepared in a 25cm using distilled water and this solution was kept in a cool place (AOAC, 1999).

Calculation

$$\text{Iodine value} = \frac{\text{(b - a) X 1.269 X M}}{\text{Weight in gram of sample used}} \quad (3)$$

Where b, is the titre value of blank, a, is the titre value of sample and M, is molarity of Na_2SO_3

2.4.4 Saponification Value

To 2g of the groundnut oil, 25ml of 0.5m ethanolic KOH was added and heated under reflux for 30 minutes with the final mixture being titrated with 0.5m hydrochloric acid using phenolphthalein indicator. From the values obtained the saponification of the biodiesel was calculated (AOAC, 1990).

Calculation

$$\text{Saponification value} = \frac{(b-a)X\ 28.05}{Weight\ of\ sample\ used} \quad (4)$$

Where
b = volume of HCl used for blank
a = volume of HCl used for sample
28.05 value of ½ of molar mass of KOH.

Cetane index (CI)

Cetane index (CI was determined from the correlation given by (Krisnangkura, 1986):

$$CI = 46.3 + (5458/SV) - 0.25\ IV \quad (5)$$

Where; SV is Saponification value,
IV, is Iodine value

2.4.5 Kinematic viscosity

The kinematic viscosity was determined with a Herzog GmbH MP-480 that involves measuring the time for a fixed volume of the fuel to flow under gravity through a capillary at a known and constant temperature of 15^0 C (Bello and Age, 2012) [2].

Kinematic viscosity = Calibration constant (mm^2/s^2) x mean time of flow (s).

2.2.6 Density Measurement

The volume of the biodiesel was measured with the help of a density bottle. The weight and volumes of the oil were recorded and the density calculated. Volume of the biodiesel used for density calculation = 200ml

2.2.7 Acid Value

The acid value of oil or fat is the number of mg of potassium hydroxide required to neutralize the free fatty acid in 1.0g of the sample. 25 ml diethyl ether with 25ml ethanol was mixed and warmed on hot plate for few minutes to remove the dissolved gases in the mixture. About 1.10g of the oil was dissolved in the neutralized solvent mixture and also warmed on hot plate for few minutes and removed. Two drops of phenolphthalein indicator was added to the solution and the solution was titrated against standardized 0.1M potassium hydroxide. The yellow colour of the oil solution became milky immediately the indicator was added and this later turned pink at the end-point. The process was repeated for two consecutive titre values (AOAC, 1990).

Calculation

$$\text{Acid value} = \frac{56.1\ X\ titre\ value\ (ml) X\ Molarity\ of\ base}{weight\ of\ sample\ used} \quad (6)$$

Free Fatty Acid

General procedure

1. Pipette exactly 10ml of sample into a conical flask
2. Dissolve in 100ml methanol
3. Add 2-3 drops of phenolphthalein
4. Add considerable amount of sodium hydroxide solution (0.1M) into the burette and titrated until the colour changes from colourless to pink.

$$\text{Mole of NaOH} = \frac{Molarity * Volume}{1000} \quad (7)$$

2.5 Optimization Process

A total number of 20 experiments were performed to obtain the actual values for the optimization. The percentage yields for the optimization of biodiesel production by RSM based on Central Composite Rotatable Design (CCRD) were obtained. Central composite design of experiments was applied with three design parameters, namely the methanol-to-oil molar ratio (A), catalyst concentration (B) and reaction temperature (C). Based on the preliminary experiments and literature review, Sheih, *et al*, 2003), the high and low values of temperature are 65^0 C and 45^0 C, respectively. The catalyst concentration is designated "high" at 1.65 wt.% and "low" at 1 wt.%. Similarly the methanol-to-oil molar ratio is taken as "high" at 7:1 and "low" at 4:1. The central points are 55^0C, 1.25 %, and 6:1 for temperature, catalyst concentration and molar ratio respectively.

A full quadratic model was fitted to the experimental data by conducting regression analysis. This involves reducing the mean square error (MSE) between the output given by the

equation and the desired output over multiple iterations. The lower the mean squared error, the better the fit of the curve. The synthesis of biodiesel from vegetable oil transesterification using groundnut oil was developed and optimized using the Central Composite Design (CCD) and Response Surface Methodology (RSM). The design was performed using a Design of Experiment software "Design of Expert 8.0.7.1 academics version.'' The results obtained were used to determine the values of the three parameters that gave maximum biodiesel yield.

2.5.1 The Steps Involved in Optimization are as follows

(a) Establish the design matrix: Depending on the number of variables, the number of the experiments was performed to establish the model varies. The minimum number of coefficients in the general three-dimensional quadratic model is 12. Our model was fitted to data obtained using 20 sampling points. These sampling points were arrayed on a 3-dimensional hypercube, each dimension of the hypercube representing the range to be tested for one variable. The suspected optimum was chosen as the center of the hypercube. Two experiments were performed at the center of the hypercube the rest of experimental conditions scattered essentially randomly near the borders of the hypercube so as to minimize the prediction variance of the resulting quadratic model. This aspect of the design matrix was carried out by the computer program (Yuhui *et al.*, 1996) [16].

(b) Determine physically reasonable mean, maximum, and minimum levels for each variable to be tested. The three significant variables selected are: the molar ratio, catalyst concentration and temperature. The variables and their levels used are shown in Table 2.

Table 2: Variable range assignments for response-surface experiments

Process Variable	Center	Range
A: Molar Ratio (MeOH:oil)	6:1	4:1 – 7:1
B: Catalyst Concentration (wt %)	1.25	1.0 – 1.65
C: Temperature (°C)	55	45 – 65

(c) Perform the experiments**:** The conditions of the 20 experiments that were performed, was determined from the mean and the range for each variable and the design matrix. The yield from each of the experiment was measured as described in Table 4 (Yuhui *et al.*, 1996) [16].

(d) Develop a mathematical model: A quadratic model with the form of equation was obtained using SYSTAT 5.2 (MGLH module) starting with all the terms in equation 1 and using the same stepwise regression algorithm and criteria outlined above (Yuhui *et al.*,1996) [16].

(e) Locate and characterize the stationary points of the response surface**:** Having found an appropriate model, the optimum for the yield was determined analytically by partial differentiation against each variable and equating the gradient to zero. Coordinates of the resulting stationary point provide estimates for the variable concentrations giving the optimum results. The stationary point was then verified by carrying out the experiment at those values (Yuhui *et al.*,1996) [16].

3. Results and Discussion

3.1 Results

Table 3, shows the Physiochemical properties of groundnut oil and its biodiesel. The acid value, iodine value, peroxide value, saponification value, density, kinematic viscosity, pour point, cloud point and cetane index were characterized in line with the specifications of ASTM D6751 and EN 14214 standard.

Table 3: Physiochemical properties of groundnut oil and biodiesel

Property	Units	Groundnut oil	Biodiesel	ASTM D6741	EN 14214
Acid Value	(mgKOH/g)	15.37	3.37	0.80max	0.5max
Iodine Value	(mgI_2/g)	114.0	92.20	_	120max
Peroxide Value	(meq.g)	18.0	8.40	_	_
Saponification Value	(mgKOH/g)	187.84	154.50	_	_
Density	(g/cm^3)	956	922	_	860 – 900
Kinematic viscosity	(mm^2/s)	22.7	6.60	1.9 - 6.0	3.5 - 5.0
Pour Point	(^0C)	-3.00	-6.0	_	_
Cloud Point	(^0C)	8.0	10	_	D2500
Cetane Index	_	26	51	47min	51min
Free Fatty Acid	%	0.75	_	_	_

Final Equation in terms of Actual Factors

Design-Expert 8.0.7.0 software (mini tab software) was used for regression and graphical analyses of the data obtained. *Table 4,* shows the Second Order Central Composite Rotatable Design, aimed at maximizing the yield. The predicted model for percentage of FAME content (Y) in terms of the coded factors is shown in Equation 8:

$$Y = 72.62543 - 0.75149*A + 2.97626*B + 5.06121*E - 004*C - 0.78448*A*B + 0.039125*A*C - 0.030253*B*C \quad (8)$$

Where A, is the Molar ratio, B is the Catalyst concentration, C is the reaction Temperature and E means Exponential function. The predicted model produces the optimal conditions for each of the variable parameters investigated to have a maximum biodiesel yield, where the optimum condition for molar ratio is 7:1, catalyst concentration to be 1.0 wt.%, and the reaction temperature is 65 ^oC, while the optimum biodiesel yield was 80.72%.

Table 4: Results (% yield) from the predicted model

S/N	Molar Ratio (A)	Catalyst Conc. (B)	Temperature (°C) (C)	Yield (Model) % (Y)
1	5	1.00	45	75.30
2	5	1.00	65	78.70
3	5	1.50	45	74.23
4	5	1.50	65	77.25
5	7	1.00	45	75.84
6	7	1.00	65	80.72
7	7	1.50	45	73.89
8	7	1.50	65	78.48
9	6	1.50	45	74.06
10	6	1.25	60	77.79
11	6	1.00	55	76.81
12	6	1.65	55	77.66
13	4	1.25	55	75.24
14	7	1.25	55	78.28
15	6	1.25	55	76.81
16	6	1.25	55	76.81
17	6	1.25	55	76.81
18	6	1.25	55	76.81
19	6	1.25	55	76.81
20	6	1.25	55	76.81

3.1.1 Effect of Methanol-to-oil Molar Ratio

The contour plot shows that, methanol-to-oil ratio is one of the important factors that affect the conversion of triglyceride to FAME. Stoichiometrically, three moles of methanol are required for each mole of triglyceride, but in practice, a higher molar ratio is required in order to drive the reaction towards completion and produce more FAME as products. The results obtained in this study are in agreement with Figure 1 below.

The methanol-to-oil ratio showed positive influence to the yield of methyl ester, the yield increases with the increase in molar ratio. The increase is due to the positive sign in the experimental model. Higher ratio of methanol used at 7:1, could maximize triglyceride molecules on the catalyst's active sites which could increase the catalyst activity.

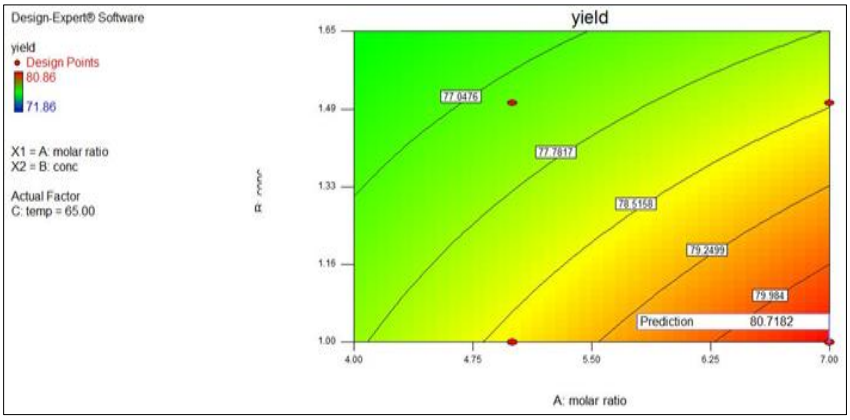

Fig 1: Effect of catalyst concentration and molar ratio versus yield (contour plot)

3.1.2 Effect of Temperature

The effect of temperature on biodiesel conversion is shown in *Figure 2.* Increase in reaction temperature, clearly influences the reaction rate and biodiesel yield in a positive manner. The temperature increase affected the biodiesel yield in a positive way till a temperature of 65°C and thereafter the yield decreases. The increase in the yield of FAME at higher reaction temperature is due to higher rate of reaction.

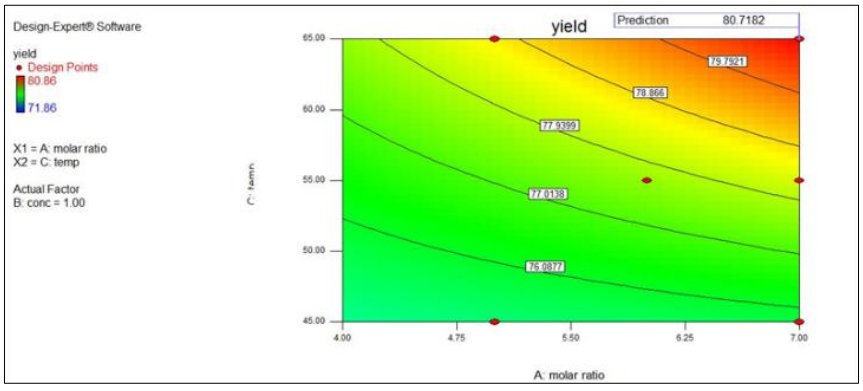

Fig 2: Effect of reaction temperature and molar to oil ratio versus yield (contour plot)

3.1.3 Effect of catalyst concentration

Figure 3, shows the contour surface plot of reaction temperature against catalyst concentration. Increase in catalyst concentration shows a negative effect on the process, which brought a reduction in the biodiesel yield, but with reduction in catalyst concentration, the biodiesel yields increases and the maximum yield was achieved at catalyst concentration of 1.0 wt.% at reaction temperature of 65°C. The increase in the yield of FAME at lower reaction concentration, was due to low catalyst concentration.

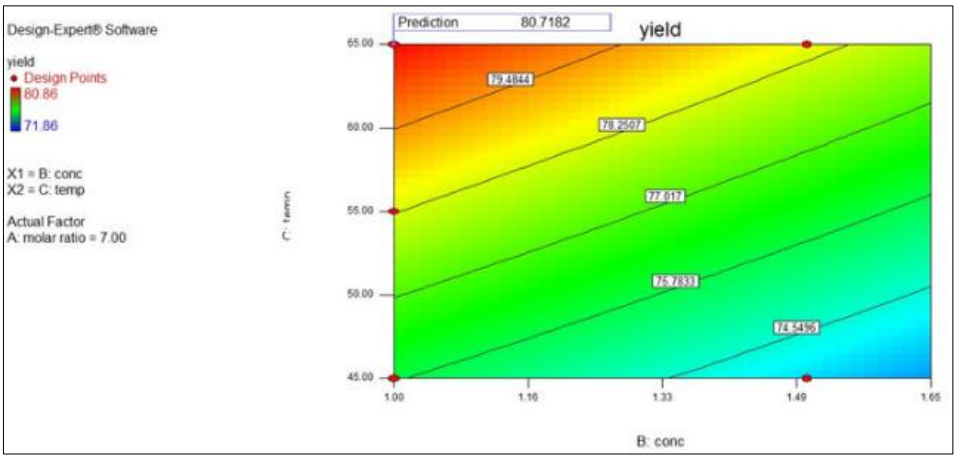

Fig 3: Effect of reaction temperature and catalyst concentration on yield of (contour plot)

3.1.4 3D Response surface plot of temperature and methanol-oil ratio

Figure 4, is a 3D response surface plot for the interaction of temperature effect and methanol-oil ratio on biodiesel yield at catalyst concentration of 1.0 wt.% for 2 hours at a constant stir speed of 450rpm. Biodiesel yield increases with increase in methanol to oil molar ratio up to 7:1, after which the yield decreases with excessive temperature beyond the optimal temperature of 65^0C, because methanol evaporates at temperature above 64 ^{o}C.

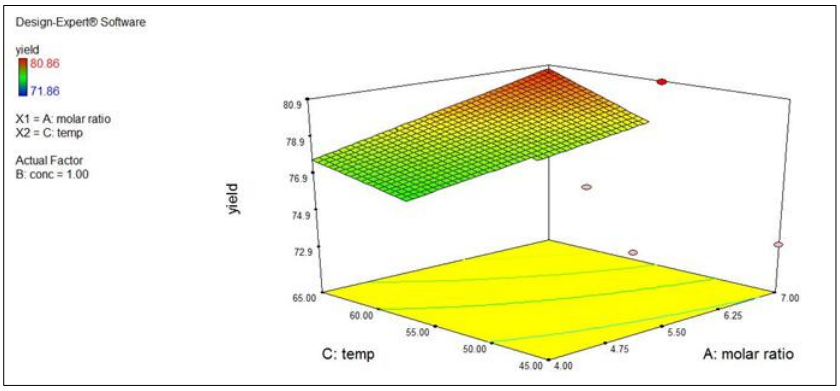

Fig 4: Effect of Interaction of Temperature and Methanol-oil ratio on Biodiesel Yield.

3.1.5 3D Response surface plot of interaction of molar ratio and catalyst concentration

Figure 5, is a 3D response surface plot of the interaction effect of molar ratio and catalyst concentration on biodiesel yield when methanol-oil molar ratio is 7:1, at a constant stir speed 450 rpm and at a temperature of 65°C. Biodiesel yield decreases with increase in catalyst concentration. Addition of excessive catalyst favors saponification reaction and reduces biodiesel yield (Goyal *et al*., 2012) [5].

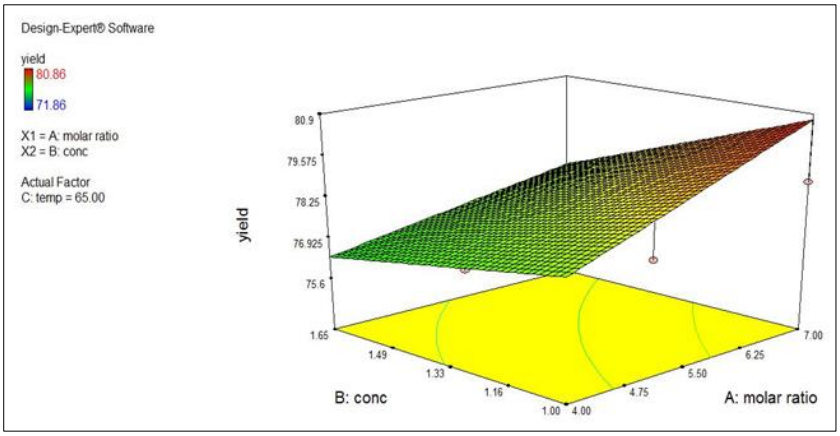

Fig 5: Effect of Interaction of molar ratio and Catalyst Concentration on Biodiesel Yield.

3.1.6 3D Response surface plot of the interaction of temperature and catalyst concentation

Figure 6, is a 3D response surface plot of the interaction effect of temperature and catalyst concentration on biodiesel yield when methanol-oil ratio is 7:1 for a constant period of 2 hours and at constant stir speed of 450 rpm. Temperature beyond 65^0C, decreases biodiesel yield as soap may be formed which prevents ester layer formation.

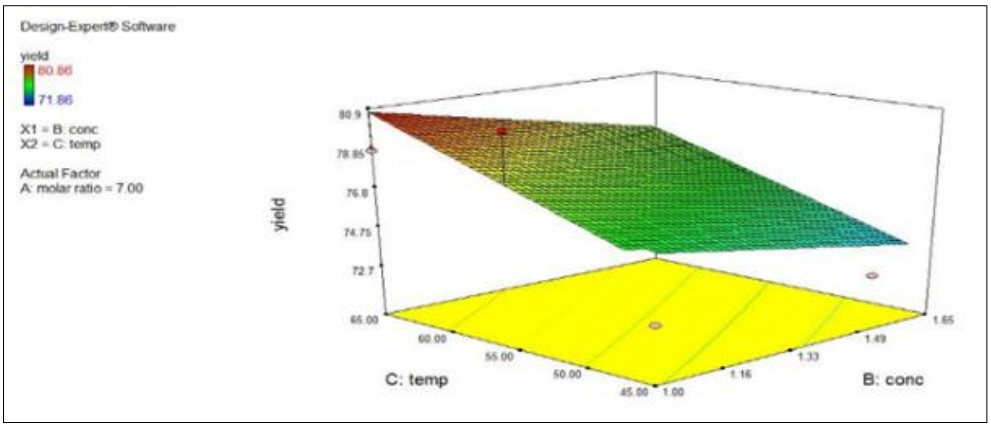

Fig 6: Effect of Interaction of reaction temperature and Catalyst Concentration on Biodiesel Yield.

3.1.7 Use of Data Obtained

The results obtained were used to maximize the method of Surface Response Methodology. A response surface design is a set of advanced design of experiments (DOE) techniques that helps to better understand and optimize the response. Response surface design methodology is often used to refine models after determining the important factors using factorial designs; especially if there is curvature in the response surface.

Table 5, shows the relationship between the experimental and predicted yields for biodiesel, in which the maximum yields produced for both the experimental and predicted values were achieved with the variables parameters at optimum conditions.

Table 5: Experimental and predicted Yields

S/N	(A)	(B)	(C)	$Yield_{exp}$	$Yield_{model}$
1	5	1	45	74.65	75.3
2	5	1	65	77.92	78.70
3	5	1.5	45	74.86	74.23
4	5	1.5	65	76.64	77.25
5	7	1	45	74.98	75.84
6	7	1	65	79.76	80.72
7	7	1.5	45	72.87	73.89
8	7	1.5	65	78.87	78.48
9	6	1.5	45	73.80	74.06
10	6	1.25	60	76.00	77.79
11	6	1.25	55	78.02	76.81
12	6	1	55	76.76	77.66
13	4	1.65	55	75.76	75.24
14	7	1	55	80.86	78.28
15	6	1.25	55	77.08	76.81
16	6	1.25	55	77.05	76.81
17	6	1.25	55	78.16	76.81
18	6	1.25	55	78.61	76.81
19	6	1.25	55	78.02	76.81
20	6	1.25	55	78.22	76.81

3.2 Discussion

The decreased in methanol/oil molar ratio from 7:1 and 6:1 while keeping the other variable parameters at their respective optimal values, produces biodiesel yield of 76.81%, thus biodiesel yield decreased by 3.91% but at the cost of significantly increase in the molar ratio of methanol versus oil from 6 to 7:1 does not appear to be cost-effective. It is understood that using a methanol/oil molar ratio at 7:1 for production of biodiesel from groundnut oil will give optimal yield. Thus alkali catalysis was determined to be a suitable process for biodiesel production from groundnut oil.

4. Conclusion

The groundnut oil biodiesel is a potential renewable fuel. In this research, the biodiesel production from groundnut oil through transesterification route was studied. The biodiesel yield as a function of molar ratio of methanol to oil, catalyst concentration and reaction temperature was determined. Reaction temperature and molar ratio shows positive effect on biodiesel yield whereas increase in catalyst concentration shows a negative effect on biodiesel yield. The response surfaces demonstrate significant interaction effect between temperature and molar ratio. The optimization results from RSM and actual are comparable. The predicted yield for biodiesel at optimum conditions for the maximum biodiesel yield were found to be at methanol/oil molar ratio of 7:1, NaOH catalyst concentration of 1.0 wt% (by the weight of groundnut oil), reaction temperature 65^0C, rate of mixing 450 rpm and a reaction time of 2 hours is 80.72%. With the same optimal conditions, an experiment was conducted which produces actual biodiesel yield of 79.76%, which gives a difference of 0.96% when comparing the actual and predicted yield of biodiesel.

The response surface methodology proved to be a valuable tool for evaluating the effects of various factors in the production of biodiesel fuel from groundnut oil. A second-order model was successfully developed to describe the relationships between biodiesel and test variables, which are methanol/oil molar ratio, catalyst concentration, reaction temperature, when rate of the mixing and reaction time were fixed at 2 hours and 450 rpm respectively. The fuel properties, such as kinematic viscosity, density, cloud, pour point test, flash point, Iodine value, Saponification value, Cetane index, Acidic value and Peroxide value measured are within the ASTM D6751 and EN 14214 limits for biodiesel.

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