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Factor Interactions and the Modelling Of Biodiesel Production Reaction from Waste Vegetable Oil

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Abstracts

Chemically transesterified biodiesel is a mixture of mono – alkyl esters of triglycerides synthesized from a variety of lipids sources. The yield of biodiesel is influenced by several variable factors. This paper presents factor interactions in biodiesel production from waste vegetable oil (WVO) via base – catalyzed transesterification reaction with methanol. The factors studied are catalyst concentration, reactant ratio, contact time and reaction temperature. Optimization was carried out using these variables and sodium hydroxide as catalyst. Multiple linear regression (MLR) and analysis of variance (ANOVA) were carried out and biodiesel production yield model was established. Results indicate that the catalyst concentration is the most important factor that influence yield. Furthermore, there is no significant factor interaction involving reactant ratio, contact time and reaction temperature in biodiesel production. The MLR and ANOVA model fitted to the analytical data obtained is of the form: $Y_i = – 36.555 + 2199X_{i1} – 2299X_{i2} + 5.469X_{i3}$ where Y_i, X_{i1}, X_{i2} and X_{i3} are the biodiesel production yield, catalyst concentration, contact time and reaction temperature respectively.

Keywords: *Factor Interaction; Modelling; Biodiesel; Transesterification; Waste Vegetable Oil.*

Introduction

Biodiesel is a diesel – grade fuel and heating oil that is made from a variety of animal fats, vegetable oils, waste cooking oils and algal oil. Transesterification reaction is the most common method of preparing biodiesel. The reaction is often base - , acid- or enzyme – catalyzed [1-4] and is affected by several variable factors. These factors include catalyst type and concentration, reactant ratio, contact time, reaction temperature, water and free fatty acids (FFAs) in the feedstock, reaction kinetics and mechanism [5- 8]. Factor interaction occurs when the effect of two or more factors are not additive [9]. Statistical analysis is used to evaluate the effects of factors in experimental results. Furthermore, analysis of variance (ANOVA) and curvilinear regression methods are generally employed to fit polynomials to data. The multiple linear regression (MLR) model relates the value of the response variable, Y_i to two or more predictor variables, $X_{i1}, X_{i2} \dots X_{in}$. The first order form of the MLR model [10, 11] is

$Y_i = \beta_0 + \beta_{i1} + \beta_{i2} + \dots + \beta_{in} + \varepsilon_i$

where $\beta_0, \beta_1 \dots \beta_n$ are regression coefficients and ε_i is the random error term. The least square estimates of the regression coefficients are $b_0, b_1 \dots b_n$ and they are the important statistical parameters for the model.

Harri et al [12] used MLR method to study the correction of spectral interference of calcium in sulphur determination. In the study a suitable MLR calibration method was developed that proved to be fast and easy to use in practice. Studies on optimization and modelling of biodiesel reaction have been reported [13, 14].

This paper presents factor interactions and the modelling of base – catalyzed transesterification reaction used for biodiesel production from waste vegetable oil (WVO). WVO is a potential raw material for biodiesel production in Nigeria.

Materials and methods

Materials

Waste vegetable oil was obtained from Fast Food Companies in Abakaliki and Owerri townships. Analytical grade methanol (99.7%, BDH) was used. Sodium hydroxide (NaOH) was purchased from Avondale Laboratory, Oxon.

Experimental design

Catalyst is a factor. Experiments were conduced to investigate the effect of catalyst concentration on yield. The NaOH catalyst concentration runs were chosen as

0.5, 1.0, 1.5, 2.0 and 2.5%. Each run is replicated four times giving a total of 5x4 or 20 experimental units for catalysis.

A 2^3 factorial experimental design was used to determine the optimum conditions. Three variables namely methanol: oil volume ratio (factor A), contact time (factor B) and reaction temperature (factor C) were studied at both high and low levels. The response variable is biodiesel yield. Table I gives two – way factorial levels for factors A, B and C.

Table I: Two – way factorial levels for factors A, B and C

Factor	Level	
	High	Low
(A) Methanol: Oil volume ratio	6:1	1:1
(B) Contact time / h	2	0.5
(C) Reaction temperature / ºC	60	30

Method

A preliminary titration was carried out to determine the FFAs in the WVO and to establish how much catalyst was needed for complete transesterification reaction. Transesterification reaction was done in a 250 – cm^3 conical flask reactor. The WVO was put in the reactor that was kept in a water bath. Next the catalyst was dissolved in methanol and added to the WVO in the reactor. The mixture was heated to selected temperature and time for proper mixing to produce fatty acid methyl esters (FAMEs), i.e., biodiesel and glycerol. At the end of reaction the mixture was cooled to room temperature and transferred to a separating funnel. Biodiesel and glycerol were the upper lower layers respectively. The two layers were separated by gravity and centrifugation. The biodiesel phase was washed with hot distilled water at 50ºC four times in order to purify it. It was eventually dried over anhydrous sodium carbonate and its volume measured. The biodiesel product was analyzed for its purity using Gas Chromatography (GC).

Results and discussion

Effect of catalyst concentration

The amount of catalyst used in the transesterification process affects the yield of methyl esters. Sodium hydroxide was chosen as catalyst in this study because of its economic reasons [8]. The catalyst concentration varied in the range of 0.5 to 2.5%. Table II gives the yield for the NaOH – catalyzed process.

The effect of catalyst on yield is shown in Fig.1. The data indicate that the production yield increases with increase in catalyst concentration up to an optimum value of 2.0% giving a yield of

96.7%. Thereafter the yield decreased with increase in concentration of catalyst.

It was observed that excess amount of the catalyst forms soap and emulsion that tended to increase the viscosity and gelling of the system and also lowers the biodiesel yield [1, 14].

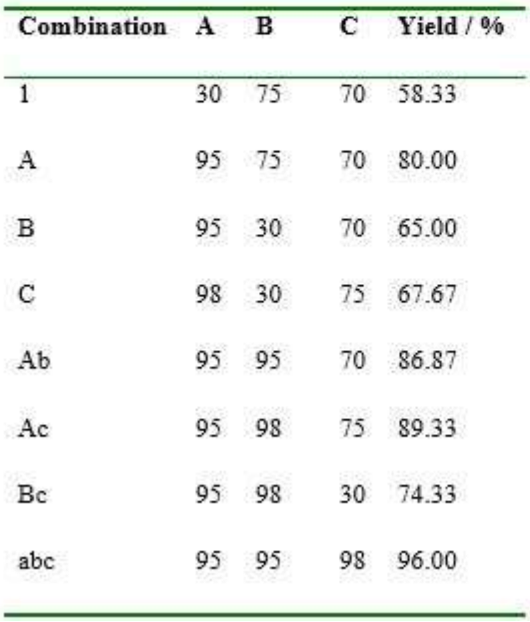
Table II Biodiesel yield and catalyst concentration

Concentration of catalyst / %	Biodiesel yield / %
0.5	76.7
1.0	80.0
1.5	86.7
2.0	96.7
2.5	83.3

Factor interactions

The dependence of biodiesel yield on methanol: oil volume ratio (factor A), contact time (factor B) and reaction temperature (factor C) were studied. These factors were chosen because they are among the principal factors that influence the transesterification process. Table III gives the possible combinations of factor levels for factors A, B and C. The data in Table IV summarizes the results of factor interactions in biodiesel production [9]. The results suggested that no significant interactions occur between the factors investigated.

Table III: Possible combinations of factor levels and yields



Combination	A	B	C	Yield / %
1	30	75	70	58.33
A	95	75	70	80.00
B	95	30	70	65.00
C	98	30	75	67.67
Ab	95	95	70	86.87
Ac	95	98	75	89.33
Bc	95	98	30	74.33
abc	95	95	98	96.00

The number 1 is used to indicate that all factors are at the low level. A, B and C are at two factor levels- high and low.

Table IV: Factor interactions in biodiesel production

All are not significant at the 5% probability level

Factor interaction	**Effect**	**Sum of square**	**F - ratio**
Three-factor interactions			
ABC	-0.048	0.00932	$7.9\text{x}10^{-8}$
Two-factor interactions			
AB	0.053	0.0112	$9.5\text{x}10^{-8}$
BC	-0.053	0.0112	$9.5\text{x}10^{-8}$
AC	-0.053	0.0112	$9.5\text{x}10^{-8}$
Single factor (Main effect)			
C	9.238	344.70	$2.94\text{x}10^{-3}$
B	6.718	180.53	$1.54\text{x}10^{-3}$
A	21.718	1886.69	$1.61\text{x}10^{-2}$

Table V: Data for yield MLR model fitting

Legends:

23wsxxY_i / %	**X_{i1} / %**	**X_{i2} / h**	**X_{i3} / °C**
72.9	0.5	0.5	30
84.3	1.0	1.0	40
88.9	1.5	1.5	50
96.6	2.0	2.0	60
91.4	2.5	2.5	70

Y_i = biodiesel yield in %,
X_{i1} = catalyst concentration in %,
X_{i2} = contact time in h and
X_{i3} = reaction temperature in °C.

Table VI: Important statistical parameters of the fitted MLR model

Coefficient	**Value**
b_0	-36.555
b_1	2199
b_2	-2299
b_3	5.469
R	0.510
R^2	0.260
R^2 (adj.)	0.014

Model fitting

The analytical data for the (MLR) model fitting is presented in Table V. The reactant ratio was maintained at 6:1 methanol: oil volume ratio in all the experimental runs. This data was analyzed the using the MATH CAD 7.0 statistical software. The fitted MLR model is of the form: $Y_i = -36.555 + 2199X_{i1} - 2299X_{i2} + 5.469X_{i3}$ where Y_i, X_{i1}, X_{i2} and X_{i3} are the biodiesel production yield, sodium hydroxide catalyst concentration, contact time and reaction temperature respectively. Table VI gives the important statistical parameters of the fitted model. The constant term and regression coefficients give significant values of t suggesting that all three predictor variables should be included in the fitted model. Using this regression equation, the yield of an unknown WVO sample could be solved by interpolation.

Conclusion

The study showed that optimum sodium hydroxide concentration for the production of biodiesel from WVO was 2.0% which gave 96.7% yield. No interactions occurred between the factors namely, reactant ratio, contact time and reaction temperature during transesterification process. An optimized MLR model for biodiesel production from WVO has been established.

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