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Biodiesel Production Optimization using Heterogeneous Catalyst (Al_2O_3) in Karanja oil by Taguchi Method

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Abstract*: Biodiesel is renewable and environmental friendly fuel which has the potential to obtain considerable performance of engine. The aim of this work is to optimize the transesterification process for production of biodiesel using Taguchi method. In this experimental work, the Karanja oil transesterification is done to produce biodiesel using Al_2O_3 as a heterogeneous catalyst, using five parameters and five levels. Orthogonal array obtained by Minitab to analyze the interaction effect by using Taguchi method for the transesterification reaction. The parameters such as molar ratio of methanol to oil, catalyst concentration, reaction temperature, reaction time and stirring speed are effect on biodiesel yield. Effect of these parameters is investigated on small scale. Experimental yield obtained at optimal conditions i.e. are 20:1 molar ratio of methanol to oil, addition of 3% Al_2O_3 catalyst, reaction temperature 65ºC, reaction time 60 min and 600 rpm stirring speed is 80%.

***Keywords:* Biodiesel, Transesterification, Heterogeneous catalyst, Optimization**

I. INTRODUCTION

Today the world's needs are growing day by day about everything. Nature has a fixed stock of natural resources but the population is increasing at a tremendous rate. Diesel fuels are used in various fields and have significance for the economy of nations. Rise in environmental consciousness and limited petroleum reserves, it is necessary to find out alternative fuels [3]. Biodiesel have the properties like no toxicity, high degradability, low emission of carbon monoxide, particulate matter and unburned hydrocarbons. It has an international attention as an alternative to diesel fuel [3]. Biodiesel does not require any modification in conventional compression engine.

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The Karanja oil methyl ester yields, obtained by transesterification process. As per array developed by Taguchi method, there were 25 sets of experiments of transesterification process for production of biodiesel. Ratio of methanol to oil, catalyst concentration, reaction temperature, reaction time and stirring speed [2] were taken as per array obtained by Taguchi method.

A Operating conditions

Different Parameters affecting the Transesterification process

Effect of different parameters studied as follows.[2]

1) Variation of Molar Ratio in reaction.
2) Effect of amount of catalyst.
3) Effect of temperature on reaction.
4) Effect of reaction time of reaction
5) Effect of stirring speed on reaction.

The operating conditions for each parameter and levels are listed below:

For catalyst Al_2O_3

Table I. Optimizing parameter conditions

A:Molar Ratio %	B: Catalyst %	C: Reation Temp. ºC	D:Reaction Time min	E: Reaction Speed rpm
A1 = 5	B1 = 1.0	C1 = 55 ºC	D1 = 60 min.	E1 = 300 rpm
A2 = 10	B2 = 1.5	C2 = 60 ºC	D2 = 90 min.	E2 = 400 rpm
A3 = 15	B3 = 2.0	C3 = 65 ºC	D3 = 120 min.	E3 = 500 rpm
A4 = 20	B4 = 2.5	C4 = 67ºC	D4 = 150 min.	E4 = 600 rpm
A5 = 25	B5 = 3.0	C5 = 70 ºC	D5 = 180 min.	E5 = 700 rpm

II. EXPERIMENTAL ARRAY DEVELOPED BY TAGUCHI METHOD AND YIELD OBTAINED WITH SN RATIOS

Taguchi Design
Design Summary
Taguchi Array L25 (5^5)
Factors: 5
Runs: 25
Columns of L25 (5^6) array: 1 2 3 4 5

Table II. Taguchi array for optimization of parameters (Sample readings)

MOLAR RATIO	CATA-LYST %	REACT TEMP.	REACT TIME	REACT SPEED	% YIELD	SNRA1	SRES
5	1	55	60	300	60	35.5630	0.231455
5	1.5	60	90	400	62	35.8478	-0.1543
10	3	55	90	500	70	36.9020	-1.31158
15	1	65	180	400	65	36.2583	0.231455
15	3	60	150	300	74	37.3846	-0.54006
20	2.5	60	180	500	72	37.1466	-0.54006
20	3	65	60	600	80	38.0618	2.160247
25	1	70	150	500	70	36.9020	0.617213
25	1.5	55	180	600	72	37.1466	0.231455

The highlighted row of above table gives the optimum values of input parameters for maximum yield, because of higher values of SN ratio.

III. ANALYSIS BY TAGUCHI METHOD

Taguchi Analysis: %YIELD versus Molar Ratio %, Catalyst ... tion Speed
Larger is better

Table III. Response Table for Signal to Noise Ratios

Level	Molar Ratio %	Catalyst %	React Temp. °C	React Time	React Speed
1	36.37	36.33	36.68	36.96	36.94
2	36.77	36.64	36.83	36.83	36.77
3	36.84	36.84	37.01	36.93	36.75
4	37.11	37.24	36.99	36.90	37.05
5	37.47	37.51	37.05	36.94	37.04
Delta	1.10	1.19	0.37	0.13	0.31
Rank	2	1	3	5	4

Main Effects Plot for SN ratios

Main effect plot is used to examine differences between level means for one or more factors. It graphs the response mean for each factor level. [1]

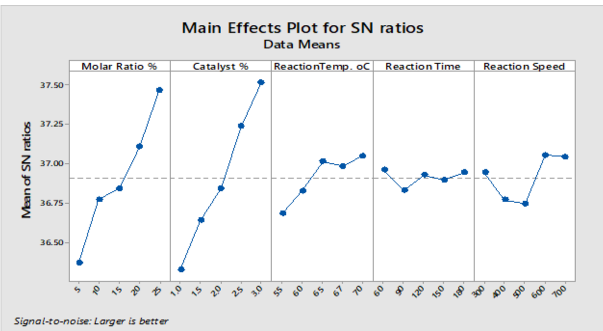

Fig.1. Main Effects Plot for SN ratios

From above graphs it is observed that graphs of mean of S/N ratios vs molar ratio and mean of S/N ratios vs catalyst% are steeper than others, so it is concluded that these two parameters i.e. molar ratio and catalyst % affects the yield mainly and effects of other three parameters can be neglected.

IV. INTERACTION PLOT FOR PARAMETER A AND B (FOR MOLAR RATIO AND CATALYST %) :

Taguchi Analysis: %YIELD versus Molar Ratio %, Catalyst %

Table IV. Response Table for Signal to Noise Ratios

Level	Molar Ratio %	Catalyst %
1	36.37	36.33
2	36.77	36.64
3	36.84	36.84
4	37.11	37.24
5	37.47	37.51
Delta	1.10	1.19
Rank	2	1

Interaction Plot for SN ratios:

Taguchi method generally focuses on main effects, but it is important to test suspected interactions. Interaction plot is used to measure whether the effect of one factor on response characteristic depends on the level of other.[1]

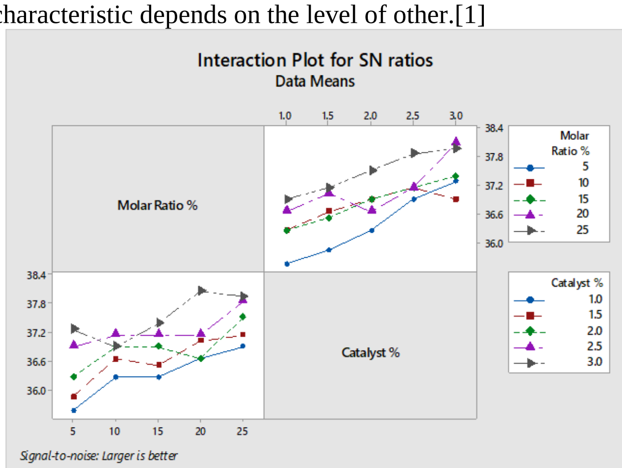

Fig.2.Interaction Plot for parameter A and B (For molar ratio and Catalyst %)

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The above interaction plot shows that the maximum value of SNR at catalyst 3% and molar ratio 20 i.e. the maximum yield at this combination.

V. REGRESSION ANALYSIS:

Regression Analysis: %YIELD versus Molar Ratio %, ... , Reaction Speed

Table V. Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	528.758	105.752	48.07	0.000
Molar Ratio %	1	208.080	208.080	94.58	0.000
Catalyst %	1	288.000	288.000	130.90	0.000
ReactionTemp. ^{o}C	1	26.818	26.818	12.19	0.002
Reaction Time	1	0.080	0.080	0.04	0.851
Reaction Speed	1	5.780	5.780	2.63	0.122
Error	19	41.802	2.200		

Model Summary

In model summary R square value provides a measure of how well the model is fitting the actual data. Here R square value is 92.67%, this shows that the model obtained is fitted to actual data.

Table VI. Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.48327	92.67%	90.75%	87.90%

Regression Equation

Regression equation is statistical model that determine the specific relationship between the input parameters and output parameters. It gives the outcome with a relatively small amount of error.

%YIELD = 40.62 + 0.4080 Molar Ratio % + 4.800 Catalyst % + 0.1949 Reaction Temp. - 0.00133 Reaction Time + 0.00340 Reaction Speed

Normal Probability plot of Residuals for %YIELD

The normal probability plot is a graphical tool for comparing a data set with the normal distribution. A straight line in this plot shows the data fit a normal probability distribution. There are very low residual values and all residuals obtained are almost along the line.

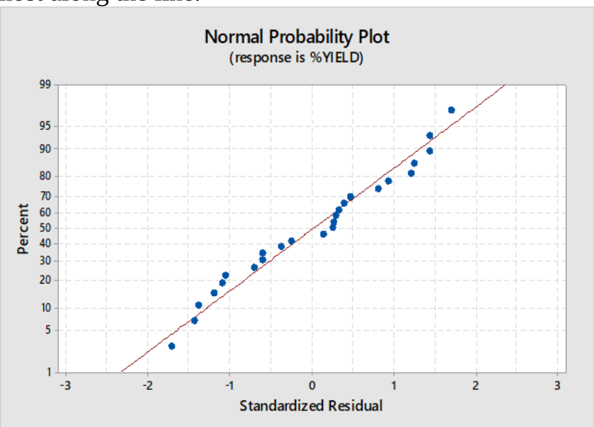

Fig.3. Normal Probability plot

VI. CONCLUSION

The analysis by Taguchi method has been carried out for optimizing the transesterification method for production of biodiesel from Karanja oil [1]. The various input parameters such as molar ratio, catalyst %, reaction temperature, reaction time and stirring speed have been optimized using SNR based on this study, it can be concluded that as follows;

1) Experimental yield obtained at optimal conditions i.e. are 20% molar ratio of methanol to oil, addition of 3% Al_2O_3 catalyst, reaction temperature 65°C, reaction time 60 min and 600 rpm stirring speed is 80%.
2) From main effective plots, it is observed that graphs of mean of S/N ratios vs molar ratio and mean of S/N ratios vs catalyst % are steeper than others, so it is concluded that these two parameters i.e. molar ratio and catalyst % affects mainly on the yield.
3) The interaction plot proves that the maximum value of SNR at catalyst 3% and molar ratio 20% i.e. the maximum yield at this combination.
4) Here R square value is 92.67%, this shows that the model obtained is fitted to actual data.
5) A straight line in the normal probability plot shows the data fit a normal probability distribution. There are very low residual values and all residuals obtained are almost along the line.

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