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TAGUCHI'S METHOD FOR OPTIMIZATION OF PARAMETERS INVOLVED IN BIODIESEL PRODUCTION USING BENNE SEED OIL

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Abstract:

Biodiesel is the eco friendly best alternative fuel owing to its renewable nature and pollution free combustion characteristics. Production of Biodiesel promotes and develops rural economy. In India, advanced research is going on and hence a need has arrived to adopt the ways for commercialization of its production, utilization of by-products and the evaluation in engine with respect to emissions as well as additive response. To bring biodiesel efficient, concerted Research and development is required for production of good quality feed stock material and to develop an efficient and affordable biodiesel production system. Research has been done on various feed stock to improve commercial and efficient biodiesel production system. Advancements are made to find the optimum resources such as edible and non edible oils to be converted as a biodiesel. An attempt has been made to find the suitability of biodiesel production using Benne seed oil and parameters that effect its production analyzed. Various methods such as linear and non linear optimization methods were adopted to find the optimum parameters, tested for experimental results. Taguchi method of optimization is applied for the present experimental research on production of biodiesel using Benne seed oil. Transesterification, also called alcoholysis, is the process widely used in reducing the viscosity of triglycerides. The most prominent variables that influence the transesterification process are oil temperature, reaction temperature, ratio of alcohol to oil, type of catalyst and concentration, intensity of mixing, purity of reactants. From among the above parameters, reaction temperature (^{0}C), Catalyst amount (wt %), reaction time (min), Methanol/oil molar ratio were considered as variables and the interaction effects were evaluated. Quadratic regression analysis equation has been developed by using general ANOVA model. By this method, the contribution of each variable in biodiesel production was determined. The optimal variables for biodiesel production were determined. Thus, the biodiesel produced from Benne seed (Sesame Oil Ethyl Ester) was considered one of the best alternatives for fossil fuel.

Key Words: Transesterification, Biodiesel Production, Taguchi Method, Parametric Optimization & Benne Seed Oil

1. Introduction:

The fossil energy sources in the world are depleting while the energy demand is increasing manifold and there exists a gap between the demand and supply of the same. The promising renewable substitute source of fuel generated from natural tree born oils, fats of animals and even waste cooking oil has been identified as a solution for the alarming global twin problems of fossil fuel depletion and environmental degradation[1-3].In the beginning of diesel engines, vegetable oils were tried (their original compositions unaltered) as a conceivable engine fuel yet the thought never grabbed hold attributable to incongruence issues, for example, deterioration of the oil with time, high viscosity, and fouling of the engine.

Starting late the biodiesel route has been reactivated for different reasons like (a) it has been found that vegetable oil can be changed by methods for esterification into a product which is considerably more agreeable as a diesel fuel than the actual oil itself (b) a wide arrangement of vegetable oils can be used as crude material for transesterification; this has incited the likelihood that biodiesel production could be an approach to widen the part of agriculture (more businesses made and lessened fiscal weight for oil imports in creating countries).

Biodiesel is a type of sustainable power source that can be used specifically in any current, unmodified diesel engine. It has accomplished more prominent consideration attributable to its favorable circumstances, for example, (I) Energy Independence (ii) Smaller Trade Deficit (iii) Economic Growth (iv) Cleaner Air (v) Less Global Warming.

The vegetable oil is conceivably ready to supplant mineral oil in future. Biodiesel is produced through transesterification process, a technique in which organically derived oils are combined with alcohol (ethanol or methanol) in the presence of a catalyst to make ethyl or methyl ester (Zhang et al., 2003). Biodiesel can be blended with diesel fuel or used 100% particularly in an engine. Biodiesel can be obtained from rural products or sources, for instance, palm oil, coconut, soybean, shelled nut, castor, sesame, assault seed oils, squander vegetable oils, or microalgae oils. Biodiesel is physically similar to petroleum diesel yet has the benefit of being gotten from characteristic, inexhaustible sources. A blend of 20% biodiesel with 80% oil (B20) can be used as a part of all diesel-consuming equipment, including compression-ignition engines and oil heat boilers, without modifications.

As of late, Ahmad et al (2010) has prepared biodiesel from sesame oil by its transesterification with methanol utilizing NaOH as a catalyst and most extreme yield of 92% was attained at 60°C. The fuel properties of sesame biodiesel (100%, for example, specific gravity @ 60/60°F was 0.887, flash point 110°C, pour point - 18°C, kinematic viscosity @ 40°C 5.77, cetane number 53, and sulfur substance 0.0083.Engine energizing with sesame biodiesel and its blends (B20%, B10%, and B5%) regarding fuel consumption, efficiency, and power outputs seemed to have rise to execution contrasted with mineral diesel. There is no undeniable change in motor power yield even at 100% biodiesel. It was observed that the natural execution of sesame biodiesel was better than that of mineral diesel. This study supports the production of biodiesel from sesame seed oil as a reasonable other option to the diesel fuel. Sesame and other oil crops are a promising new energy supply sources. The potential of some plant oils that can be utilized to produce biodiesel has been displayed in Table 1.

Table 1: Yields of biodiesel from common crops

Source	Biodiesel yield (barrels per year per square mile)
Cotton	382
Soybean	542
Sesame	807
Safflower	905
Tung oil tree	1091
Sunflower	1113
Peanuts	1233
Rapseed	1385
Rapseed	1407
Jojoba	2116
Jatropha	2204
Coconut	3131
Oil palm (Oil palm)	6927

India is a notable for producing of a few oilseed crops like groundnut, mustard, rapeseed, sesame seed, and so on. By and large, Indians consume large quantity of edible oils especially as a cooking medium. Among the oilseed crops, sesame has been cultivated and improved for an impressive time span, especially in Asia and Africa, for its high content of edible oil and protein. It is also known as til (Hindi), hu mama (Chinese), sesame (French), goma (Japanese), gergelim (Portuguese) and ajonjoli (Spanish).

Sesame (Sesamum indicum L.) or Benne seed is considered as one of the significant oil crops worldwide. Its real outputs which are marketable are seed oil, whole seeds and meal. Benne seeds are developed in tropical regions all around the globe since old days, historical myths even uncover their beginning backpedal significantly further. As per Assyrian legend, when Gods for the making of the world, they used wine produced using Benne seeds. These seeds were acknowledged to have the essentially started in India and were specified in early Hindu legends. In these legends, a couple of stories were educated that Sesame seeds were the symbols of immortality. From India, Sesame seeds were spread to the Middle East, Africa and Asia. Sesame seeds were one of the main crops took care of for oil and also one of the earliest condiments (de Carvalho et al., 2001). These seeds were spread to the United States from Africa in the midst of the late seventeenth century. Starting at now, the greatest business creators of sesame seeds fuse India, China and Mexico.

2. Materials and Methods:

2.1 Materials: The Benne seed oil was acquired from Technochem Engineers Pvt. oil supplier at Hyderabad. Analytical grade chemicals, such as methanol 99% and KOH catalyst were purchased from the scientific chemist shop from Hyderabad. The experimental facilities have been provided by Gurunanak Institutions Technical Campus, Ibrahimpatnam.

2.2 Transesterification Process: Sesamum indicum, typically called beniseed in Africa however all around known as sesame, is a fast-growing crop whose oilseed can be utilized for biodiesel generation through transesterification process. It is an indispensable oilseed crop developed in numerous parts of the world. Its seed is comprises of 50% to 52% oil, 17% to 19% protein, and 16% to 18% carbohydrate [8]. Fatty acid compositions of the oil are mostly oleic (32.7% to 53.9%), linoleic (39.3% to 59%), palmitic (8.3% to 10.9%), and stearic (3.4% to 6.0%) acids [9].

Nevertheless, the fatty acid composition of this oil varies essentially among the different arrangements general [9,10]. Sesame oil has been created as a potential feedstock for biodiesel generation. Regardless of the way that the transesterification of this seed oil from Turkey and Pakistan cultivars to biodiesel has been represented [7,11,12], the procedure has not yet been optimized utilizing a statistical approach, such as response surface methodology, and the maximum yield reported was 92% [11].

The ideal vegetable oil utilized for biodiesel production must be promptly accessible, its plant should be easily cultivatable, and its composition must incorporate a high level of monounsaturated unsaturated fats (C16:1, C18:1), a low extent of polyunsaturated acids (C18:2, C18:3) and a controlled measure of saturated fatty acids (C16:0, C18:0) [1]. Transesterification of oil or fat to deliver a high yield of biodiesel is ordinarily explored by optimizing the following reaction variables: alcohol/oil molar ratio, catalyst concentration, reaction temperature, and reaction time involved in the process. Both the effects of the variables and their reciprocal interactions have been evaluated using Taguchi technique.

Benne seed oil of 150 gm was taken in a heat resistant glass container of 250 ml and the temperature of the oil was increased to the set temperature by utilizing a heater. Certain measure of Methanol was was calculated in accordance to the molar ratio(mol/mol). Fixed quantity of catalyst i.e. KOH was dissolved in preheated alcohol using a mixer. After the catalyst totally dissolved in alcohol solution, the mixture was poured into preheated Sesame oil. To stop the leakage, Para film-sealed beaker was used. The final solution was kept in water bath shaker machine and set the reaction temperature and RPM of shaking. The glass beaker was removed from the water bath shaker when the reaction was completed (i.e. 60 min in the experiment).The products of the reaction were kept in a separating funnel in which the separation of the biodiesel and Glycerol takes place. The separated top layer was biodiesel and bottom layer glycerol. After accumulation of biodiesel separately, biodiesel was washed two-three times with hot (approximately 45°C) deionized water to expel the pollutions from biodiesel as an unreacted catalyst.

2.3 Taguchi's Approach to Parameter Design: Taguchi's way to deal with parameter design furnishes the plan build with an orderly and proficient strategy for deciding close optimum design parameters for execution and cost (Kackar, 1985; Phadke, 1989;

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Taguchi 1986). The objective is to choose the best mix of control parameters so the item or process is most robust concerning the noise factors.

The Taguchi technique utilizes orthogonal arrays from design of experiments theory to analyze about a large number of variables with a small number of experiments. Utilizing orthogonal arrays altogether decreases the number of experimental configurations to be studied. Moreover, the results drawn from small number of tests are valid over the entire experimental region spanned by the control factors and their settings (Phadke, 1989).

Orthogonal arrays are not special to Taguchi. They were discovered significantly before (Bendell, 1988). Nonetheless, Taguchi has disentangled their utilization by giving classified arrangements of standard orthogonal arrays and corresponding linear graphs to fit specific projects (ASI, 1989; Taguchi and Konishi, 1987). A typical tabulation is appeared in Table 2.

Table 2: $L_9\ (3^4)$ Orthogonal Array

	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

The Taguchi technique can decrease innovative work costs by enhancing the effectiveness of producing data expected to plan frameworks that are uncaring to utilization conditions, yield of a process, manufacturing variation, and deterioration of parts. Subsequently, advancement time can be abbreviated fundamentally; and major design parameters influencing operation, performance, and cost can be recognized. Besides, the ideal selection of parameters can bring about wider tolerances with the goal that low cost components and production processes can be used. In this manner, manufacturing and operations costs can likewise be extraordinarily lessened. Thus, Taguchi's approach for parameter design is utilized for the present research process.

2.4 Overview of the Taguchi Method: Figure 1 provides a brief overview of the process followed by Taguchi's approach to parameter design (Phadke, 1989; Wille, 1990). The details of these steps are briefly described in the following sections.

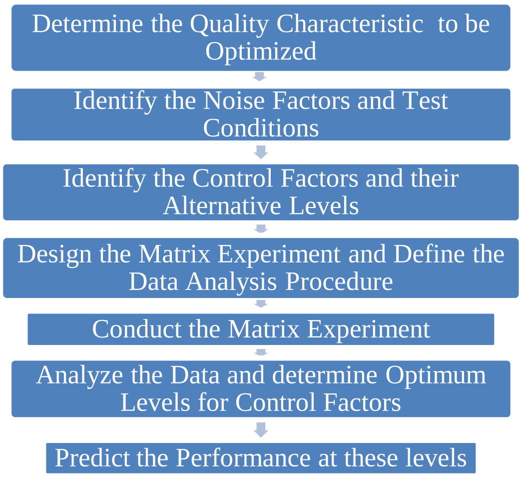

Figure 1: Flowchart of the Taguchi Method

Loss Function for Nominal-is-best: Generally, there are three types of loss functions: higher is better, nominal is best, and lower is better. Taguchi imposes the following quadratic loss function for a nominal-is-best situation

$$\text{Loss} = k[S^2 + (\bar{y} - n)^2]$$

Where k is a constant. $\bar{y}$ and S^2 are the mean and variance of the measurements of quality characteristic respectively, and n is the nominal value (target) of the a product (or process). The quadratic loss function consists of two parts: the variance and the squared distance between the mean and the nominal value. In order to minimize the loss to consumer or society, there are three approaches: (1) reduce the variance, (2) move the mean closer to the nominal value, and (3) a combination of both (1) and (2).

Control Factors: Control factors are those factors that can be controlled amid production and experiment. For instance, the types and colors of raw material are control factors in a production process. A design related to the control factors is called the inner array.

Noise Factors: Noise factors are those factors that influence product or process performance however are troublesome, costly, or difficult to control. For instance, air temperature or vibration may influence automobile carburetor performance, however them two are difficult to control. A design related to the noise factors is called the outer array.

Signal-to-Noise Ratio: Dr. Taguchi proposed a class of statistics called signal-to-noise ratios (S/N) which can be used to measure the effect of noise factors on the process performance. By maximizing the S/N ratios, the loss functions are minimized. These SIN

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ratios take into account both the amount of variability and closeness to the average response. In this paper, we will only consider three of them: smaller-is-better, larger-is-better and target-value-is-best.

Smaller-is-Better (Variance of Response): This S/N ratio assumes that the target for the response is zero and is appropriate when specifications indicate an upper tolerance limit only.

$$S/N_s = -10 \log \left(\frac{1}{n}\sum y_i^2\right)$$

The goal of an experiment for smaller-is-better situations is to minimize y_i^2 and y. That is we aim to maximize -10 log $\left(\frac{1}{n}\sum y_i^2\right)$

Larger-is-Better (Mean of Response): This S/N ratio asswnes that the goal is to maximize the response and is appropriate when specifications indicate a lower tolerance limit only.

$$S/N_s = -10 \log \left(\frac{1}{n}\sum(1/y_i^2)\right)$$

Again, the goal of an experiment for larger-is-better situations is to maximize the response (e.g., yield of a process). But maximizing y is the same as minimizing 1/y. This means that we aim to maximize -10 log $\left(\frac{1}{n}\sum(1/y_i^2)\right)$

Target-Value-is-Best (Ratio of Mean to Variance of Response): This S/N ratio assumes that the given target is best and is appropriate when there is a target value with both upper and lower tolerance limits.

$$\frac{S}{N_N} = -10 \log \left(\frac{1}{n}\sum(1/y_i^2)\right)$$

The goal of an experiment for target-value-is-best situations is to reduce Variability around a specific target. When the variability of the response is reduced, relative to the average response, $\frac{S}{N_N}$ will increase.

3. Results and Discussion:

Considering the experimental factors A-Molar ratio (mol/mol), B-Catalyst amount (w %), C-Reaction time (min) and D-Reaction temperature (°C), the following are the results of biodiesel yield using Benniseed oil and the calculated value of S/N ratio is shown for each experiment considering the loss function Larger-is-better since the yield of Biodiesel is to be maximum.

Table 3: The results of experiments and SNR values

Expt No	Process Control Factors				Biodiesel Yield (%)	S/N ratio
	A	B	C	D		
1	4	0.5	60	50	56.68	35.0686
2	4	1.0	75	55	89.65	39.0510
3	4	1.5	90	60	88.78	38.9663
4	6	0.5	75	60	75.42	37.5497
5	6	1.0	90	50	85.76	38.6657
6	6	1.5	60	55	91.32	39.2113
7	8	0.5	90	55	72.35	37.1888
8	8	1.0	60	60	78.38	37.8841
9	8	1.5	75	50	70.03	36.9057

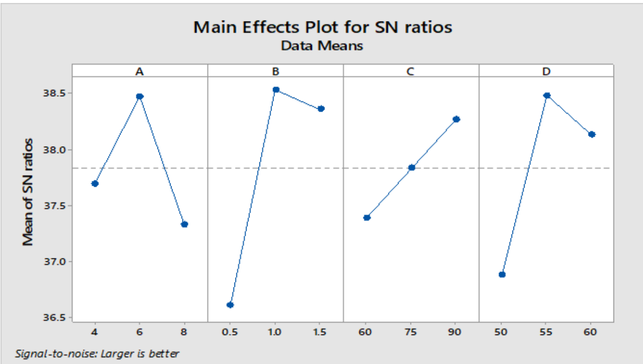

Figure 2: Main effects plot for SN ratios for Yield vs all input factors

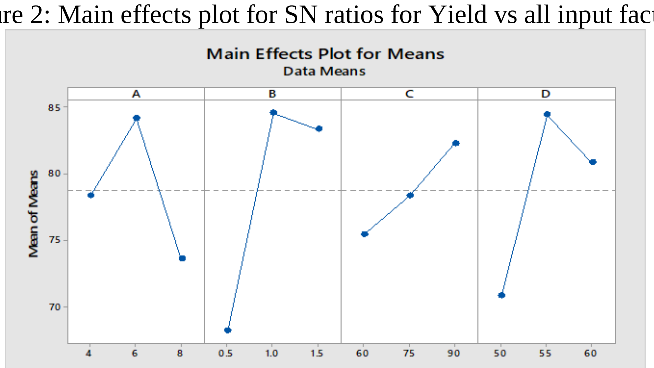

Figure 3: Main effects plot for Means for Yield vs all input factors

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Main effects plot of mean at each level of a factor are prepared and shown in Fig 2 and Fig 3. These plots are used to compare the magnitudes of main effects and compare the relative strength of the effects across factors. Apart from the plots, the significance is to be evaluated by considering the effects in the analysis of variance table.

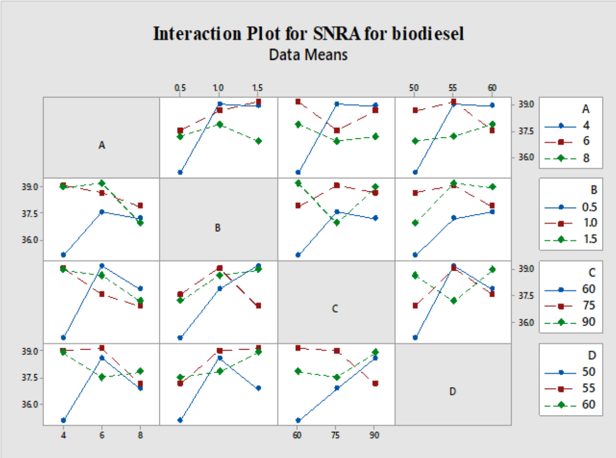

Figure 4: Interaction Plot for SNRA for biodiesel

Figure 4 represents the interaction plot of Yield. As the yield of biodiesel production is to be maximized, larger is better option is selected. From the graph, it can be observed that the highest yield is achieved at Methanol/Oil molar ratio 6, Catalyst amount (wt % 1.0), Reaction time 90 min, and Reaction temperature 55^{0}C.

Taguchi Analysis: Yield versus Methanol/Oil Molar ratio, Catalyst amount, Reaction Time, Reaction Temperature

Table 4: Response Table for Signal to Noise Ratios Larger is better

Level	Methanol/Oil Molar Ratio	Catalyst Amount (% Wt)	Reaction Time	Reaction Temperature
1	37.70	36.60	37.39	36.88
2	38.48	38.53	37.84	38.48
3	37.33	38.36	38.27	38.13
Delta	1.15	1.93	0.89	1.60
Rank	3	1	4	2

From the table 4, it can be observed that the rank of each process parameter was given along with the range. The range of each process parameter was calculated as the difference between the largest and smallest S/N ratio. The higher value of the range was given as 1. As per the rank of the process parameter, the parameter B (Catalyst concentration) has been recognized as the most effective parameter for the performance parameter Yield.

Table 4 shows response table for signal to noise ratio for Yield of biodiesel. This response table shows the effects of the input factors on Yield. Higher the slope in the main effects plot corresponding values of delta is higher in the response table. The rank represents directly the level of effect of input based on the values of delta. According to ranks, the effects of input factors on Benne seed biodiesel yield in sequence of effects are catalyst amount (% wt), reaction temperature, Methanol/oil molar ratio and reaction time. The results indicate that amount of catalyst (% wt) affects the yield of biodiesel at the highest level and reaction time at the lowest level. However, the effect of reaction temperature is to be seen since the value of delta is nearer to the corresponding value of catalyst amount.

Table 5: Response Table for Means

Level	Methanol/Oil Molar Ratio	Catalyst Amount (% Wt)	Reaction Time	Reaction Temperature
1	78.37	68.15	75.46	70.82
2	84.17	84.60	78.37	84.44
3	73.59	83.38	82.30	80.86
Delta	10.58	16.45	6.84	13.62
Rank	3	1	4	2

Table 6: S/N ratio and Predicted S/N ratio for yield of biodiesel of benne seed

Methanol/Oil Molar Ratio	Catalyst Amount (% Wt)	Reaction Time	Reaction Temperature	SNRA	PSNRA
4	0.5	60	50	35.0686	35.0686
4	1.0	75	55	39.0510	39.0510
4	1.5	90	60	38.9663	38.9663
6	0.5	75	60	37.5497	37.5497
6	1.0	90	50	38.6657	38.6657
6	1.5	60	55	39.2113	39.2113
8	0.5	90	55	37.1888	37.1888

8	1.0	60	60	37.8841	37.8841
8	1.5	75	50	36.9057	36.9057

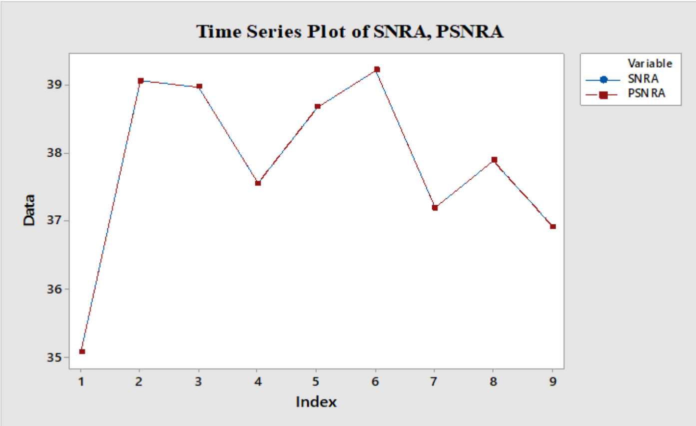

Figure 5: Time scale plot of signal to noise ratio and predicted signal to noise ratio

Table 6 shows the values of signal to noise ratio (SNRA) and Predicted signal to noise ratio (PSNRA) for yield of biodiesel of benne seed. The values of predicted signal to noise is very much close to the calculated signal to noise values hence the analysis of Taguchi for signal to noise ratio is correct. The representation of effects of various parameters on yield and optimize condition is very much nearby. Figure 5 represents time scale plot of signal to noise ratio and predicted signal to noise ratio. This plot is shown for graphical representation of various values in sequence.

Table 7: Analysis of Variance for yield of biodiesel

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	603.31	150.83	1.38	0.382
Methanol/Oil Molar ratio	1	34.32	34.32	0.31	0.606
Catalyst amount (% Wt)	1	347.78	347.78	3.17	0.150
Reaction Time	1	70.11	70.11	0.64	0.469
Reaction Temperature	1	151.10	151.10	1.38	0.306
Error	4	438.54	109.63		
Total	8	1041.85			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
10.4707	57.91%	15.82%	0.00%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-1.6	54.0	-0.03	0.977	
Methanol/Oil Molar ratio	-1.20	2.14	-0.56	0.606	1.00
Catalyst amount(% Wt)	15.23	8.55	1.78	0.150	1.00
Reaction Time	0.228	0.285	0.80	0.469	1.00
Reaction Temperature	1.004	0.855	1.17	0.306	1.00

Regression Equation

$$\text{Yield} = -1.6 - 1.20\,A + 15.23\,B + 0.228\,C + 1.004\,D$$

Table 7 represents the analysis of variance for yield of biodiesel for 95% confidence level. The value of F i. e. variance value to be compared with Fcr which can be found out from the F table as follows: Fcr = Fc.l.,n1,n2 = F0.05,1, 8 = 5.3177

Where Fcr is the critical value of variance, c.l = Confidence level, n1 = degree of freedom for input factor, n2 = total degree of freedom

From ANOVA it can be concluded that catalyst amount and reaction temperature are significant factor affecting the yield of biodiesel since respective F values are higher than Fcr. This analysis is correct since corresponding p values are small.

4. Conclusion:

Hence, the highest yield was achieved with the process parameters at Methanol/Oil molar ratio 6, Catalyst amount (wt % 1.0), Reaction time 90 min, and Reaction temperature 55^{0}C was observed and are depicted in the graphs.

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