



MULTI-OBJECTIVE OPTIMIZATION OF KUSUM OIL BIODIESEL PRODUCTION USING GREY RELATIONAL ANALYSIS IN TAGUCHI METHOD

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Abstract: Biodiesel (mono alkyl esters) is a cleaner-burning diesel fuel produced using natural, renewable sources, for example, vegetable oils. The utilization of biodiesel in ordinary diesel engine outcomes in a large reduction of unburned hydrocarbons, carbon monoxide, and other matter harmful to nature. Biodiesel works well with new technologies and catalysts, which reduces the soluble fraction of diesel particulate but not the solid carbon fraction, particulate traps, and exhaust gas recirculation leading to longer engine life. As the fossil fuels are depleting constantly, a need has arrived to produce biodiesel from various feedstock. An attempt has been made to produce biodiesel from Kusum (*Carthamus tinctorius* L.) oil and the process parameters namely the methanol-to-oil molar ratio, catalyst concentration, reaction time and reaction temperature for biodiesel production were optimized. Taguchi robust design process was used by taking L9 orthogonal array and analyzed the performance parameters that influence the production process. The results showed that the optimum yield of biodiesel was 93.8% with viscosity 5.60 cSt, with a methanol-to-oil molar ratio of 4:1, catalyst concentration of 1.5 wt%, reaction time of 90 min and reaction temperature of 60°C. From the response table of the average grey relational grade, it is found that the largest value of grey relational grade Methanol-to-oil molar ratio, Catalyst concentration, (wt%), Reaction time, (min), Reaction temperature are 4:1, 1.5 wt%, 90 min and 55°C respectively. These are the recommended levels of controllable process factors when better Yield, lesser viscosity are simultaneously obtained. The ANOVA of grey relational grade for multi-performance characteristics reveals that the catalyst concentration is the most significant parameter. The multi parameter output such as Yield and viscosity at 40°C were optimized using grey relational analysis.

Keywords: Biodeisel, process parameters, Taguchi grey relational analysis method, Kusum oil.

I. Introduction

Kusum (*Carthamus tinctorius* L.) is a very spread, herbaceous, thorn like yearly plant. It is monetarily developed for vegetable oil separated from the seeds. Plants are 30 to 150 cm (12 to 59 in) tall with globular bloom heads having yellow, orange, or red blossoms. Each branch will for the most part have from one to five blossom heads containing 15 to 20 seeds for each head. Kusum is local to parched conditions having regular rain. It grows a profound taproot which empowers it to flourish in such conditions.

Carthamus tinctorius L. is a plant. The flower and oil from the seeds are utilized as prescription. Kusum seed oil is utilized for forestalling coronary illness, including "hardening of the arteries" (atherosclerosis) and stroke. It is additionally used to treat fever, tumors, hacks, breathing issues, coagulating conditions, torment, coronary illness, chest torment, and horrendous wounds. A few people utilize it for instigating sweating; and as a diuretic, stimulant, antiperspirant, and expectorant to help extricate mucus. Ladies now and again utilize Kusum oil for missing or agonizing menstrual periods; they utilize Kusum blossom to cause a fetus removal. In nourishments, Kusum seed oil is utilized as a cooking oil. In manufacturing, *Carthamus tinctorius* L. flower is utilized to shading beautifying agents and color textures. *Carthamus tinctorius* L. seed oil is utilized as a paint solvent.

The seed oil substance of *Carthamus tinctorius* L. ranges from 30-45 % percent. Its oil is utilized by both food producers and by industry. High linoleic Kusum oil is utilized as a part of human nourishment, however in later a long time advertise request has definitely moved from the conventional high linoleic oils to high oleic oil. High linoleic oil is esteemed as a drying specialist in paints and varnishes on account of its non yellowing trademark. High oleic *Carthamus tinctorius* L. oil is bring down in soaks and higher in monounsaturated than olive oil (Berglung et al. 2007).

The transesterification procedure is a vital procedure in the creation of biodiesel in light of the fact that it diminishes the viscosity of vegetable oils and conveys it closer to that of conventional diesel oil, in this manner maintaining a strategic distance from the engine related issues and increasing the engine life. Alkali catalyzed transesterification reaction is the most embracing techniques for generation of biodiesel in light of the fact that it is easy to remove the particular esters. This procedure is material for oils that have low free fatty acid level (<4) and acid catalyst transesterification process is pertinent just for high free fatty acid level (>4) oils.

Enzymatic catalyzed transesterification can likewise be utilized for the generation of biodiesel from poor quality feedstock like utilized cooking oil, animal fat, and so forth. This procedure is done within the sight of enzyme, for example, lipase. This procedure has many points of interest over the ordinary transesterification process like age of zero byproduct, no difficulty in separation, and requiring moderate reaction conditions. However, yield, reaction times, and costs are still critical compared to alkaline catalyzed transesterification reaction [1, 2].

Non catalyzed Biox transesterification process is another strategy accessible for the production of biodiesel. In transesterification reaction biodiesel yield is moderate in view of the low solvency of alcohol in oil. This problem is solved by using a cosolvent, tetrahydrofuran, to stabilize methanol [3, 4]. Non catalyzed supercritical methanol technique is the latest strategy accessible for producing biodiesel. This technique requires just 4 minutes to finish the reaction yet requires high alcohol oil ratio, high capital cost, and high pressure (80 bar) and temperature (350°C– 400°C) [5– 7].

E. Mayer et al. [8] in his Research Paper found out a Method to determine globally optimal schedules for cyclically operated plants. O. J. Alamu et al.[9] in his Comparative Analysis found that PKO as an alternative source of diesel fuel amongst others for renewable energy. J. E. N. McLeod and S. S. Rivera [10] in their Research Paper derived a Model to optimize the risk in biofuel plants with respect to human error.

S. Sayyar et al. [11] in their Research Paper Optimized extraction of Jatropha oil from seeds using organic solvent based for achieving maximum oil yield for various operating parameters. R. D. Elms and M. M. El-Halwagi [12] in his Research Paper derived an Optimization formulation for scheduling and operation of flexible Biodiesel plants accommodating a variety of feedstock to produce Biodiesel. A. H. West et al. [13] in his Research Paper found Simulation of a process for the economic assessment of Biodiesel production.

A. A. Refaat et al. [14] in his Research Paper derived Optimization of production procedure. P. K. Sahoo and L. M. Das [15] In their Research Paper found Methods of preparation of Biodiesel from non-edible oils. P. D. Patil and S. Deng [16] in their Comparative Analysis discussed Comparison of fuel properties of Biodiesel produced from different edible and non-edible vegetable oils. L. F. Bautista et al. [17] in their Research Paper discussed Fatty acid methyl esters production from waste cooking oil using a factorial design of experiments and a central composite design. S. Sri Rahayu and A. Mindaryani[18] in their Research Paper found Optimum conditions of the washing and to find a correlation of the extraction variables. Waste Management and Research Center (WMRC), Illinois, 2005 in its Feasibility Report [19] gave Feasibility analysis of biodiesel.

II. Materials and methods

2.1 Materials

Carthamus tinctorius L. seed oil was purchased from Terra Firma Projects Private Limited, Begumpet, Hyderabad, India. All reagents such as methanol (GR grade, moisture <0.02%) and analytical-grade catalyst potassium hydroxide (KOH) were obtained from a local chemical store.

The *Carthamus tinctorius* L. oil was sifted utilizing filter paper and was used for biodiesel production by the transesterification process (Fig. 1).

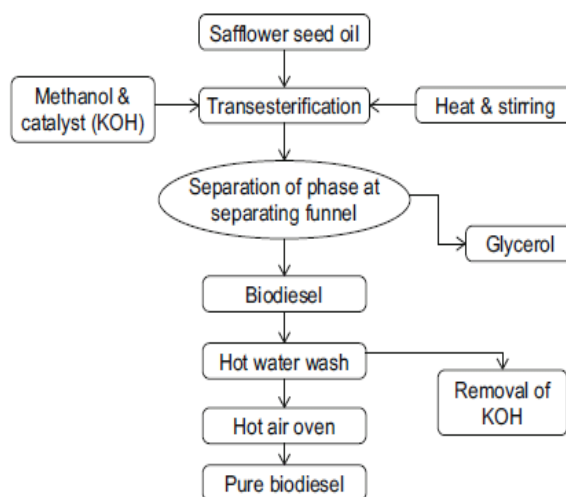


Fig: 1 Biodiesel preparation stages of *Carthamus tinctorius* L. oil

2.2 Methods

(1) 150 g of Kusum oil was taken in a 250-mL glass vessel and preheated up to 105– 110°C to expel the moisture from the oil and afterward permitted to cool to 45– 50°C.

(2) Now methyl Alcohol (CH₃OH) for methanol-to-oil molar proportions of 4:1, 6:1 and 8:1 and catalyst potassium hydroxide (KOH) at 0.5 wt% (weight percent), 1.0 and 1.5 w% of the oil were blended together.

(3) This homogeneous blend of methyl liquor and catalyst KOH was blended with 150g *Carthamus tinctorius* L. seed oil.

(4) The conical flask containing the mixture of oil, alcohol and catalyst was heated at a consistent temperature of 50– 60°C [20–22] and mixed at the same time at the same time inside a water bath shaker at around 700 rev/min for 60 min, 75 min and 90 min, individually.



Fig: 2 a) *Carthamus tinctorius* L. seeds b) *Carthamus tinctorius* L. flower c) Biodiesel separation from glycerine

(5) After finishing of the reaction time, the products were poured into a separating funnel and kept 1– 2 h for separation of phases [11]. In the separating funnel, the products separated into two layers. Because of higher specific weight, glycerol settled at the bottom and the upper layer was biodiesel (Fig. 2c). The glycerol was disposed of.

(6) After separation, the biodiesel was washed with hot distilled water keeping in mind the end goal to expel remaining methyl alcohol, catalyst and impurities present.

(7) Finally, the biodiesel was set in a hot air oven furthermore, heated at 100°C to remove excess water content.

Nine experiments run using the Taguchi method was selected according to orthogonal array L9. The experimental design matrix and effect of factors on the performance parameters are shown in Table 2.

2.3 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 S/N 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 assumes that the goal is to maximize the response and is appropriate when specifications indicate a lower tolerance limit only.

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

2.4 Grey relational analysis

Data Pre-Processing

In GRA, data pre-processing is required since the range and unit in one data sequence may differ from the others. Data pre-processing is also necessary when the sequence scatter range is too large, or when the directions of the target in the sequence are different. Data pre-processing is a process of transferring the original sequence to a comparable sequence. For this purpose, the experimental results are normalized in the range between zero and one. Depending on the characteristics of data sequence, there are various methodologies of data pre-processing available for the GRA. The procedure is given below.

- ❖ Identify the performance characteristics and process parameters to be evaluated.
- ❖ Determine the number of levels for the process parameters.
- ❖ Select the appropriate OA and assign the process parameters to the OA.
- ❖ Conduct the experiments based on the arrangement of the OA.
- ❖ Normalize the experimental results of Yield of biodiesel and viscosity.
- ❖ Perform the grey relational generating and calculate the grey relational coefficient.

- ❖ Calculate the grey relational grade by averaging the grey relational coefficients.
- ❖ Analyze the experimental results using the grey relational grade and ANOVA.
- ❖ Select the optimal levels of process parameters.
- ❖ Verify the optimal process parameters through the confirmation tests.

III. RESULTS AND DISCUSSION

Table:1 Chosen parameters and their levels

Process parameters	Levels			
		-1	0	1
Methanol-to-oil molar ratio	A	4:1	6:1	8:1
Catalyst concentration, wt%	B	0.5	1.0	1.5
Reaction time, min	C	60	75	90
Reaction temperature	D	50	55	60

Table:2 Test data summary for the responses

Expt no.	Input parameters/levels				Responses	
	A	B	C	D	Yield (Y ₁) of biodiesel	Viscosity (Y ₂) at 40°C in cSt
1	4:1	0.5	60	50	76.07	10.31
2	4:1	1.0	75	55	94.21	8.79
3	4:1	1.5	90	60	93.81	5.60
4	6:1	0.5	75	60	86.12	12.01
5	6:1	1.0	90	50	90.34	11.99
6	6:1	1.5	60	55	95.54	7.14
7	8:1	0.5	90	55	84.14	11.39
8	8:1	1.0	60	60	88.66	8.98
9	8:1	1.5	75	50	83.80	10.23

Table 1 shows the experimental data of chosen parameters for the preparation of biodiesel from Kusum oil. Four parameters Methanol-to-oil molar ratio, Catalyst concentration wt %, Reaction time min and Reaction temperature °C were chosen as input parameters. The Yield (Y₁) of biodiesel and Viscosity (Y₂) at 40°C in cSt were taken as output parameters or responses in the experiments. The mean response refers to the average value of the performance characteristic for each parameter at different levels. The average value of Yield of biodiesel for each parameter at levels -1, 0 and 1 are calculated. The main effects of the various process parameters when they change from the lower to higher levels can be visualized from the Fig. 1 that shows the response graphs of Yield of biodiesel from Kusum Oil. It is clear from the Fig. 3 that the Yield of biodiesel from Kardi Oil is highest at A0 (6:1), B0 (1.0 % wt) , C1 (90 min), D0 (55°C).

The results indicated that the increase of Methanol to Oil molar ratio tends to increase the Yield of biodiesel up to 6:1 and further it was decreased as the Methanol to Oil molar ratio increased to 8:1. As the Catalyst concentration, wt% was increased from 0.5 to 1.0, the Yield was increased and a slight decrease as it increased to 1.0. As the reaction time in minutes increased from 60 to 75 as well as up to 90, the yield has been increased continuously. Finally, the reaction temperature increased from 50°C to 55°C, the Yield increased more and with further increase in temperature up to 60°C, the Yield was decreased. The catalyst concentration as well as the Reaction temperature influenced more for the yield of biodiesel which was also clear from the Table:3 as well as Fig:3.

Table 3: Response Table for Signal to Noise Ratios for the Yield of biodiesel

Signal to Noise ratio: Larger is better

Level	Methanol-to-Oil molar ratio	Catalyst concentration, %wt	Reaction time, min	Reaction temperature, °C
-1	38.85	38.28	38.73	38.40
0	39.14	39.18	38.88	39.20
1	38.64	39.17	39.02	39.03
Delta	0.50	0.91	0.29	0.79
Rank	3	1	4	2

From the table: 4 and Fig: 2 Methanol to oil ratio at level -1 (4:1), Catalyst concentration at level 1 (1.5 %), reaction time at level -1 (60 min) , reaction temperature at level 1(60°C), the viscosity was minimum. Hence, when the Methanol to oil ratio is less, viscosity was lesser. Catalyst concentration maximum, viscosity was decreased, reaction time increased then viscosity was increased and then decreased. When reaction temperature was increased, the viscosity has been decreased to a great extent. This was evident from S/N ratios table as well as main effects plot. It is clear from the Fig:4 that the viscosity of biodiesel made from Kusum Oil is lowest at A-1 (4:1), B1 (1.5 % wt) , C -1 (60 min), D1 (60°C) and the order of ranking was Catalyst concentration %wt, Reaction temperature °C, Methanol-to-Oil molar ratio and Reaction time min.

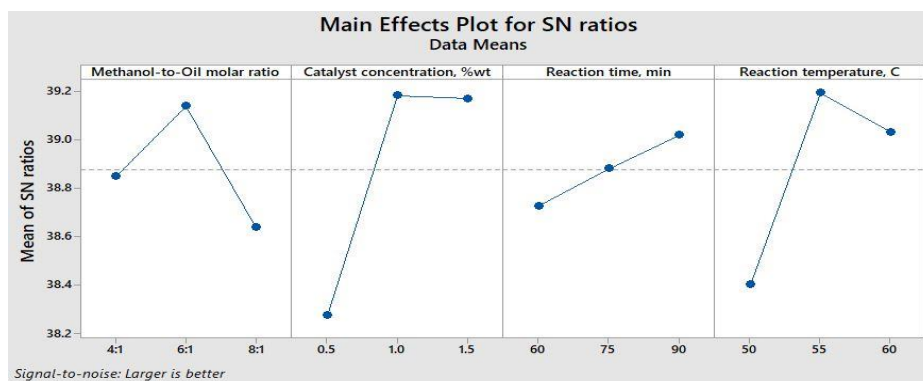


Fig:3 Main effects plot for S/N ratios for the Yield of biodiesel

Table:4 Response Table for Signal to Noise Ratios
Signal to Noise ratio: Smaller is better

Level	Methanol-to-Oil molar ratio	Catalyst concentration, %wt	Reaction time, min	Reaction temperature, °C
-1	-18.04	-21.00	-18.80	-20.68
0	-20.08	-19.84	-20.22	-19.03
1	-20.13	-17.41	-19.22	-18.54
Delta	2.09	3.58	1.42	2.14
Rank	3	1	4	2

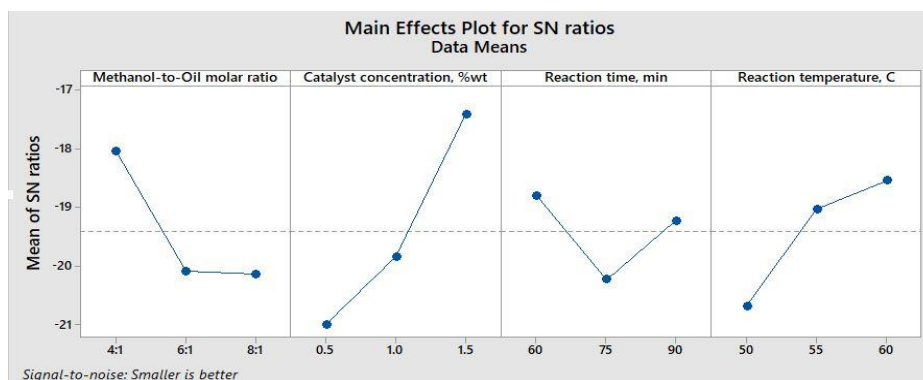


Fig:4 Main effects plot for S/N ratios for the Viscosity (Y₂) at 40°C in cSt.

Table:5 Signal to Noise ratio for Yield (Y₁) and Viscosity (Y₂) at 40°C in cSt of biodiesel

Yield (Y ₁) of biodiesel	S/N ratio for Yield (Y ₁)	Viscosity (Y ₂) at 40°C in cSt	S/N ratio for Viscosity (Y ₂)
76.07	37.6243	10.31	-20.2652
94.21	39.4819	8.79	-18.8798
93.81	39.4450	5.60	-14.9638
86.12	38.7021	12.01	-21.5909
90.34	39.1176	11.99	-21.5764
95.54	39.6037	7.14	-17.0740
84.14	38.5001	11.39	-21.1305
88.66	38.9546	8.98	-19.0655
83.80	38.4649	10.23	-20.1975

Table: 5 shows the S/N ratio for yield (Y₁) by considering larger is better and Viscosity (Y₂) at 40°C in cSt by considering smaller is better.

Yield is the dominant response in production of biodiesel. For the "larger-the-better" characteristic like Yield, the original sequence can be normalized as follows:

$$x_i^*(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)}$$

where, $x_i^*(k)$ and $x_i(k)$ are the sequence after the data preprocessing and comparability sequence respectively, $k=1$ for Yield; $i=1, 2, 3, \dots, 9$ for experiment numbers 1 to 9.

The Viscosity (Y₂) is also important measures of biodiesel production. The selection of optimum process parameters for biodiesel production using Kusum oil as feedstock and their effects on viscosity has yet to be clarified. To obtain optimal properties for biodiesel production, the "smaller-the-better" quality characteristic has

been used for minimizing viscosity. When the “smaller-the-better” is a characteristic of the original sequence, then the original sequence should be normalized as follows:

$$x_i^*(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)}$$

where, $x_i^*(k)$ and $x_i(k)$ are the sequence after the data preprocessing and comparability sequence respectively, $k=2$ and 3 for viscosity; $i=1, 2, 3, \dots, 9$ for experiment numbers 1 to 9.

Table 6: The sequences of each performance characteristic after data processing

Expt. no.	Yield (Y_1) of biodiesel	Viscosity (Y_2) at 40°C in cSt
Reference sequence	1.0000	1.0000
1	0.0000	0.2652
2	0.9316	0.5023
3	0.9114	1.0000
4	0.5161	0.0000
5	0.7329	0.0031
6	1.0000	0.7597
7	0.4144	0.0967
8	0.6466	0.4727
9	0.3970	0.2777

Now, $\Delta_{0i}(k)$ is the deviation sequence of the reference sequence $x_0^*(k)$ and the comparability sequence $x_i^*(k)$, i.e.

$$\Delta_{0i}(k) = |x_0^*(k) - x_i^*(k)|$$

The deviation sequence $\Delta_{0i}(k)$ can be calculated using above equation

$$\Delta_{\max} = \Delta_{01}(1) = \Delta_{04}(2); \quad \Delta_{\min} = \Delta_{06}(1) = \Delta_{03}(2);$$

Table:7 The deviation sequences

Deviation sequences	$\Delta_{0i}(1)$	$\Delta_{0i}(2)$
1	1.0000	0.7348
2	0.0684	0.4977
3	0.0886	0.0000
4	0.4839	1.0000
5	0.2671	0.9969
6	0.0000	0.2403
7	0.5856	0.9032
8	0.3534	0.5273
9	0.6030	0.7223

Computing the Grey Relational Coefficient and the Grey Relational Grade:

After data pre-processing is carried out, a grey relational coefficient can be calculated with the pre-processed sequence. It expresses the relationship between the ideal and actual normalized experimental results. The grey relational coefficient is defined as follows:

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta \Delta_{\max}}{\Delta_{0i}(k) + \zeta \Delta_{\max}}$$

Where $\Delta_{0i}(k)$ is the deviation sequence of the reference sequence $x_0^*(k)$ and the comparability sequence is $x_i^*(k)$, ξ distinguishing or identification coefficient. If all the parameters are given equal preference, is taken as 0.5. The grey relational coefficient for each experiment of the L_9 OA can be calculated using Equation above and the same is presented in Table 6.

Table 8: The calculated grey relational grade and its order in the optimization process

Expt. No.	Grey relational coefficient		Grey relational grade $\gamma_i = 1/2 (\xi_i(1) + \xi_i(2))$	Rank
	$\xi_i(1)$	$\xi_i(2)$		
1	0.3300	0.4049	0.3674	9
2	0.8796	0.5011	0.6903	3
3	0.8494	1.0000	0.9247	1
4	0.5081	0.3333	0.4207	7
5	0.6518	0.3340	0.4929	5
6	1.0000	0.6754	0.8377	2
7	0.4605	0.3563	0.4084	8
8	0.5858	0.4867	0.5362	4
9	0.4533	0.4090	0.4311	6

After obtaining the grey relational coefficient, the grey relational grade is computed by averaging the grey relational coefficient corresponding to each performance characteristic. The overall evaluation of the multiple performance characteristics is based on the grey relational grade, that is:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^n \xi_i(k)$$

Where i the grey relational grade for the i^{th} experiment and n is the number of performance characteristics. Table 8 shows the grey relational grade for each experiment using L_9 OA. The higher grey relational grade

represents that the corresponding experimental result is closer to the ideally normalized value. Experiment 3 has the best multiple performance characteristics among nine experiments because it has the highest grey relational grade. It can be seen that in the present study, the optimization of the complicated multiple process parameters of biodiesel production has been converted into optimization of process parameters of a grey relational grade.

Since the experimental design is orthogonal, it is then possible to separate out the effect of each machining parameter on the grey relational grade at different levels. For example, the mean of the grey relational grade for the pulse-on time at levels 1, 2 and 3 can be calculated by averaging the grey relational grade for the experiments 1 to 3, 4 to 6 and 7 to 9 respectively as shown in Table 9.

Table 9: Response table for the grey relational grade

Symbol	Input parameters	Grey relational grade			Main effect (max-min)	Rank
		Level 1	Level 2	Level 3		
A	Methanol-to-oil molar ratio	0.6608*	0.5837	0.4586	0.2022	3
B	Catalyst concentration, wt%	0.3988	0.5731	0.7311*	0.3323	1
C	Reaction time, min	0.5804	0.5140	0.6086*	0.0946	4
D	Reaction temperature	0.4305	0.9454*	0.6272	0.2149	2
Total mean value of the grey relational grade =0.5926						* Levels for optimum grey relational grade

Figure 5 shows the grey relational grade obtained for different process parameters. The mean of grey relational grade for each parameter is shown by horizontal line. Basically, the larger the grey relation grade is, the closer will be the product quality to the ideal value. Thus, larger grey relational grade is desired for optimum performance. Therefore, the optimal parameters setting for better Yield and lesser viscosity are (A1B3C3D2) as presented in Table 9. Optimal level of the process parameters is the level with the highest grey relational grade.

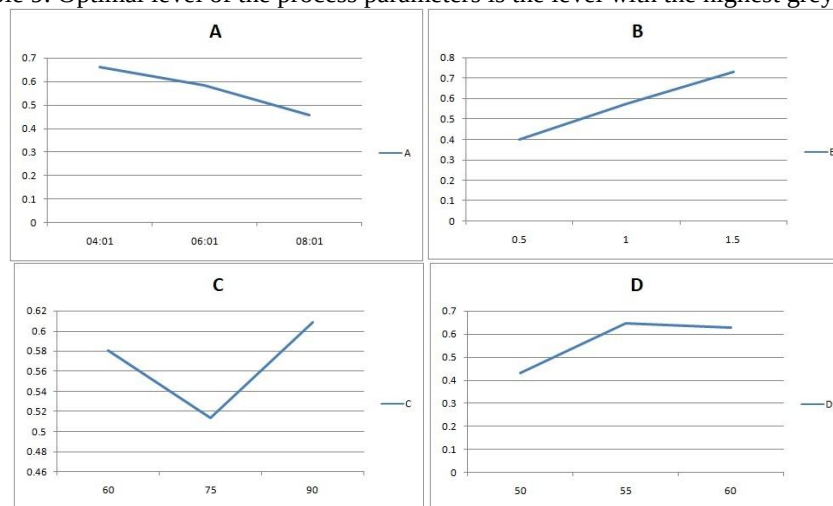


Fig: 5 Effect of biodiesel production parameters on the multi-performance characteristics

3.1 Analysis Of Variance (ANOVA)

The purpose of ANOVA is to investigate which machining parameters significantly affect the performance characteristic. This is accomplished by separating the total variability of the grey relational grades, which is measured by the sum of the squared deviations from the total mean of the grey relational grade, into contributions by each machining parameter and the error. First, the total sum of the squared deviations SST from the total mean of the grey relational grade γ_m can be calculated as:

$$SS_T = \sum_{j=1}^p (\gamma_j - \gamma_m)^2$$

where p is the number of experiments in the OA and j is the mean of the grey relational grade for the j_{th} experiment.

The total sum of the squared deviations SS_T is decomposed into two sources: the sum of the squared deviations SS_d due to each machining parameter and the sum of the squared error SS_e . The percentage contribution by each of the machining parameter in the total sum of the squared deviations SST can be used to evaluate the importance of the machining parameter change on the performance characteristic. SS_e is the sum of squared error without or with pooled factor, which is the sum of squares corresponding to the insignificant factors. Mean square of a factor (MS_j) or error (MS_e) is found by dividing its sum of squares with its degrees of freedom. Percentage contribution (ρ) of each of the design parameters is given by following equation.

$$\rho_j = \frac{SS_j}{SS_T}$$

In addition, the Fisher's F test can also be used to determine which machining parameters have a significant effect on the performance characteristic. Usually, the change of the machining parameter has a significant effect on the performance characteristic when F is large.

ANOVA for grey relational grade is presented in Table 9. Percentage contributions for each term affecting grey relational grade are shown in Figure 7. The figure clearly shows that catalyst concentration is the dominant parameter that affects grey relational grade and hence contributes in improving Yield and reducing viscosity. This shows that when the catalyst concentration is increased, the activation energy becomes high that consequently increases the yield. The increase in activation energy also attributes to the decrease of viscosity.



Fig: 6 (a) Biodiesel produced from Kusum plant (b) Kusum flower (c) Seeds of Kusum plant

Table 10: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% contribution (p)
A	2	0.06250	0.031249	0.73	0.577	19.07
B	2	0.16579	0.082895	1.94	0.340	40.39
C	2	0.01416	0.007078	0.17	0.858	4.32
D	2	0.01562	0.034521	0.32	0.358	10.32
Error	2	0.08525	0.042627			26.01
Total	8	0.32770				100

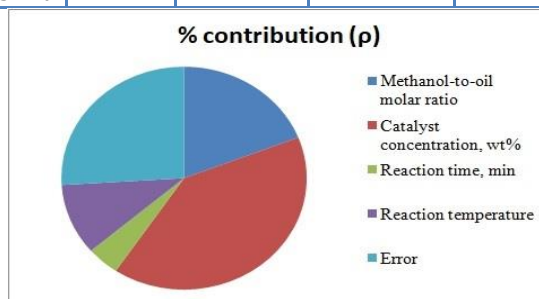


Fig: 7 Percentage contribution of grey relational grade of biodiesel parameters as a pie chart

It can be seen from Figures 7 and table 10 that catalyst concentration is the most significant factor that affects the grey relational grade. Grey relational grade is directly proportional to the concentration of catalyst as the reaction mostly depends on the chemical reaction between the catalyst and the oil to decrease the viscosity. Hence the catalyst concentration contribution is 40.39% which is the major share in biodiesel production. Methanol to oil ratio is also the input parameter which affects the Grey relational grade to some extent i.e. 19.07%. The remaining parameters i.e. reaction time and reaction temperature contributed very less in the order of 10.32% and 26.01% respectively.

3.3 confirmation test

Confirmation test has been carried out to verify the improvement of performance characteristics in preparation of kusum oil biodiesel. The optimum parameters are selected for the confirmation test as presented in Table 11. The estimated grey relational grade $\hat{\gamma}$ using the optimal level of the production parameters can be calculated using following equation

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^q (\gamma_i - \gamma_m)$$

where γ_m is the total mean of the grey relational grade γ_i is the mean of the grey relational grade at the optimal level, and q is the number of the machining parameters that significantly affect multiple-performance characteristics.

Table 11:Improvements in grey relational grade with optimized biodiesel production parameters

Condition description	Optimal production parameters	
	Biodiesel production parameters in third trial of OA	Grey theory prediction design
Level	A ₁ B ₁ C ₁ D ₁	A ₁ B ₁ C ₁ D ₀
Yield (Y1) of biodiesel	93.81	-
Viscosity (Y2) at 400C in cSt	5.60	-
grey relational grade	0.9247	1.1681

With the Grey Relational Analysis, the improvement of Grey Relational grade is improved to 1.1681 from 0.9247. Hence the optimal values for the input parameters for biodiesel production are Methanol-to-oil molar ratio 4:1, Catalyst concentration 1.5 wt% , Reaction time, 90 min, Reaction temperature 55°C.

IV. Conclusion

The GRA based on the Taguchi method's response table has been proposed as a way of studying the optimization of preparation of biodiesel process parameters for Kusum oil. The optimal biodiesel production parameters have been determined by the grey relational grade for multi performance characteristics that is yield and viscosity. Nine experimental runs based on OA's have been performed. The following conclusions can be drawn from this study. The work has successfully evaluated the feasibility of biodiesel production using Kusum oil. From the response table of the average grey relational grade, it is found that the largest value of grey relational grade Methanol-to-oil molar ratio, Catalyst concentration, (wt%), Reaction time, (min), Reaction temperature are 4:1, 1.5 wt%, 90 min and 55°C respectively. These are the recommended levels of controllable process factors when better Yield, lesser viscosity are simultaneously obtained. The ANOVA of grey relational grade for multi-performance characteristics reveals that the catalyst concentration is the most significant parameter. It is shown that the performance characteristics of the biodiesel production process such as Yield and viscosity are improved together by using the method proposed by this study. The effectiveness of this approach has been successfully established by validation experiment.

V. References

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