THE TECHNIQUE PERFORMANCE EVALUATION AND EMISSION CHARACTERISTICS OF BIODIESEL

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Abstract

On a variable compression diesel engine, methyl ester mixed with diesel was tested for engine performance and emission characteristics. The Taguchi method and grey relational analysis were used to solve an issue involving multiple response optimisation in order to find the best process response through a small number of trial runs. A certain set of input parameters was predicted to produce the best response characteristics using the grey relational grade and signal-to-noise ratio as performance indices. The best mix for usage in a diesel engine without significantly changing the engine's performance and emissions characteristics was found to be 50%.

Keywords: Biodiesel, VCR diesel engine, CI engine,Taguchi,ANOVA,GRA

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1. Introduction

Due to growing worries about the depletion of fossil fuel resources and environmental problems like air pollution and climate change, the usage of alternative fuels has accelerated recently. Two well-known alternative fuels that have received a lot of attention are biodiesel and ethanol methyl ester (EME), which have various advantages over regular diesel fuel. Biodiesel is a renewable fuel that can be produced from a variety of materials, including used cooking oil, animal fats, and vegetable oils. In comparison to conventional diesel, it is biodegradable, non-toxic, and has a smaller carbon footprint. Contrarily, ethanol is a renewable fuel made from agricultural materials like corn and sugarcane. It is frequently used in flex-fuel vehicles as a stand-alone fuel and as an addition to petrol. The performance and emission characteristics of biodiesel and EME are two important elements that determine whether employing them in internal combustion engines is feasible. When evaluating the performance of alternative fuels, it's important to compare their combustion properties, fuel usage, and power output to that of standard diesel fuel. A number of experiments have been done to assess how well biodiesel and EME work in compression ignition (CI) engines. Depending on the type of fuel, the type of engine, and the operating circumstances, these investigations have reported a variety of outcomes. In comparison to diesel fuel, biodiesel has been found to have a greater cetane rating, a lower calorific value, and a lower viscosity. Due to the greater ignition delay and lower energy density of biodiesel, this leads to reduced engine power output and higher fuel consumption. Compared to biodiesel, EME has a lower viscosity and a higher calorific value, which increases engine power and decreases fuel usage. The higher oxygen content and lower cetane number of EME, however, can result in increased NOx emissions and engine deposits. An important component of evaluating the performance of alternative fuels is their emission characteristics. Particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO), and hydrocarbons (HC), which have a negative impact on both human health and the environment, are just a few of the toxic pollutants that diesel engines release. Alternative fuel usage may be able to lower these emissions and enhance air quality. The emission characteristics of biodiesel and EME in CI engines have been the subject of numerous investigations. When compared to diesel fuel, biodiesel has been found to reduce PM emissions by up to 60%, CO emissions by up to 50%, and HC emissions by up to 70%. However, due to its higher oxygen content and lower flame temperature, biodiesel can result in an increase in NOx emissions. When compared to diesel fuel, EME has been found to reduce PM emissions by up to 90%, CO emissions by up to 60%, and HC emissions by up to 70%. However, due to its higher oxygen content, EME has the potential to increase NOx emissions. In general, variables including the kind of fuel, engine, and operating circumstances have an impact on the performance and emission characteristics of biodiesel and EME. Alternative fuel use may cut emissions and enhance air quality, but it is important to carefully weigh the performance trade-offs involved. For the development of sustainable and effective alternative fuels, it is essential to evaluate the technique performance evaluation and emission characteristics of biodiesel and EME in CI engines.

Carraretto et al.'s [1] investigation of a CI engine was performed first on a test bench and subsequently on a city bus. They discovered that the consumption of specific fuels and nitrogen oxide (NOx) emissions both rose with the use of biodiesel. However, there were less carbon dioxide and carbon monoxide emissions. Raheman et. al. [2] noted that diesel methyl ester derived from karanja oil would be an appropriate alternative fuel. According to their emission analysis, there was a significant reduction in CO and NOx when compared to diesel. Agarwal et. al. [3] used methyl and ethyl alcohol to create biodiesel from Ratanjyot (Jatropha), Karanja, Nagchampa, and Rubber. Additionally, he asserted that since biodiesel does not require engine modification, it might be a superior substitute for petroleum diesel. Raheman and Ghadge [4, 5] conducted an experiment with Mahua biodiesel and its blends in a Ricardo E6 engine. The compression ratio was altered from 18 to 20. It had been found that while brake-specific fuel consumption increased with increased biodiesel content, brake thermal efficiency decreased. According to Rao et al.'s investigation [6], vegetable oils are suitable replacement fuels for agricultural diesel engines. These vegetable oils marginally underperformed, nonetheless, in terms of rising smoke emission. Kalbande et al. [7] conducted study on the effectiveness of biodiesel generated from jatropha and karanja and their blends with diesel. The two blends with the highest efficiency of Karanja biodiesel among the various combinations were found to be B20 (20% biodiesel and 80% diesel) and B40 (40% biodiesel and 60% diesel). For jatropha, B60 and B80 were the most productive. Fontaras et al. [8] investigated the combustion and emission characteristics of biodiesel in a diesel passenger automobile that met the EURO 2 emission standard using soybean biodiesel. They discovered that utilising soybean biodiesel had made cold starting more challenging.

According to Godiganur et al. [9], after trans-esterification, mahua oil showed characteristics similar to those of diesel. Among the mixtures, the 20% (B 20) combination was found to be the most effective. Baiju et al. [10] used Karanja oil to convert it into ethyl ester and methyl ester. Both of them had good emission characteristics, with the exception of the fact that the amount of NOx present was on the higher side. They also asserted that methyl ester outperformed ethyl ester in terms of performance. In a study conducted by Sahoo et al. [11], diesel was mixed with methyl esters from Jatropha, Karanja, and Polanga. B 50 blend was used to produce the highest power output. The use of biodiesel at full power was proven to lessen smoke emissions. In contrast to diesel, CO and NOx emissions slightly rose. According to Murugesan et al. [12], Karanja oil's methyl ester might be used in CI engines straight away without needing to be modified. In the case of biodiesel, it was discovered that brake-specific fuel consumption was higher than that of diesel and that the emission characteristics were altered. They said that the B 20 Blend was the best substitute for diesel. Duraisamy et al. [13] conducted an experiment using the methyl esters of Jatropha, Pongamia, Mahua, and Neem seed oil. B 40 biodiesel showed a thermal efficiency that was nearly similar to diesel in engine performance trials. According to the results of an emission analysis, carbon monoxide (CO) and hydrocarbons (HC) decreased at any proportion mix, but NOx and smoke density increased.

The analysis of the literature made it abundantly evident that researchers had made earnest efforts to identify the most appropriate alternative to diesel fuel that doesn't require significant engine modifications. They typically changed each input parameter individually while observing how the engine performed and produced emissions, such as the load, fuel mixture, and compression ratio. It should be noted that the system's response was not unidirectional and that there were more input parameters than one. In other words, some responses had lower values that were preferable, while others had greater values that were preferable. As a result, the study was transformed into a multiresponse optimization issue that called for a methodical methodology to determine how many tests would be necessary to cover the whole range of input parameters. Based on the data given above, an effort was made to identify the ideal set of input parameters that maximises response characteristics. The experiment was planned so that the maximum amount of data could be produced with the fewest number of experiments possible. Biodiesel was used as an experimental fuel in the current investigation. On an engine made by Kirloskar with a single cylinder and variable compression ratio, the performance of biodiesel was tested. The study's goal was to identify the ideal biodiesel and mithly ester mixture that would produce the best engine performance and the least amount of emissions. Using the weighting variables of grey relational analysis, a multiresponse problem was reduced to a single problem in accordance with the Grey-Taguchi technique. Finally, actual experimentation was used to validate the outcome.

2. Methodology

Finding the ideal mixture of biodiesel, diesel, and Methley ester for a variable compression ignition engine's performance and emission characteristics. Three significant input parameters—Fuel injection pressure, Fuel fraction, and Load—were regarded as the primary design variables. As stated in Table 1, each element was further separated into five tiers. Based on the prior findings as disclosed in the open literature, the levels and their ranges were chosen. Eight response (output) metrics in total were examined; three of them, namely brake power (BP), brake-specific fuel consumption (BSFC), and brake thermal efficiency (BTE), were associated with the engine's performance characteristics. The remaining five answers related to the engine's emission characteristics, specifically CO, CO_2, O_2, NOx, and HC. According to ASTM standards, tests were conducted on the important fuel qualities of biodiesel, diesel, and Methley ester.

Table 1 Setting levels for design parameters

Controlled factors	Level 1	Level 2	Level 3
Fuel injection pressure (bar)	210	230	250
Fuel fraction (% by volume)	30	70	50
Load (%)	30	60	90

To cover the full area, numerous experiments had to be run because there were so many input and output variables. Compared to an unplanned experiment, a well-designed experiment could generate substantially more data with fewer runs. In order to comprehend how various input parameters affect response, Taguchi's parameter design method was used. The traditional Taguchi technique, however, could successfully determine the best parameter settings for a particular performance characteristic. Given the presence of several performance characteristics with competing purposes, the Grey-Taguchi method was used to combine the various performance characteristics into a single response.

2.1 Taguchi Analysis.

Dr. Taguchi's Taguchi approach entailed using a robust design of tests to reduce variation in a process. Based on the total number of degrees of freedom, the number of factors, and the level of each component, a typical orthogonal array might be used to build the experimental plan. In the current investigation, an orthogonal array with 3 columns of input parameters, each with 5 levels, and 9 rows, or the total number of tests, was taken into consideration.

2.1.1 Grey Relational Analysis.

When comparing the amount of a desired signal to the level of background noise, scientists and engineers employ the signal-to-noise ratio (S/N) measurement. The greater S/N ratio for one performance characteristic may show a lower S/N ratio for another characteristic because the current study intended to optimise eight response parameters. Consequently, for the optimisation of numerous performance characteristics, the S/N ratio's overall evaluation was necessary. Grey relational analysis was discovered to be a useful method for studying this type of issue. The system's essential components and their relationships were ascertained using it. The input and output sequences revealed which parameters were crucial. The experimental data in the current paper were initially normalised in the range between zero and one. The grey relationship coefficients were then calculated from the To describe the relationship between the desired and actual experimental data, normalised experimental data is used. Finally, by averaging the grey relational coefficients corresponding to each chosen process response, the overall grey relational grade was determined. The grey relational grade served as the foundation for the evaluation of the multiple process response. With the objective function of overall grey relational grade, this method was used to transform a multiple response process optimisation problem into a single response problem. The ideal process parameter was determined to be the level of parametric combination with the highest grey relational grade. Since "the higher-the-better" was the original sequence's target value, it was normalised as follows.

$$a^{*}(k) = \frac{a^{i}(k) - \min a^{i}(k)}{\max a^{i}(k) - \min a^{i}(k)} \quad (1)$$

When "the lower-the-better" was the goal, the original order was normalised as follows.

$$a^{*}(k) = \frac{\max a^{i} - a^{i}(k)}{\max a^{i}(k) - \min a^{i}(k)} \quad (2)$$

yi(k) is the initial reference sequence, xi(k) is the comparison sequence, and i = 1, 2,..., m, k = 1, 2, 3,..., n are the total number of experiments and replies. The values of yi(k) are min yi(k) and max yi(k) from lowest to highest.

The value following the grey relational generation in this case was xi(k). The perfect sequence was x0(k). The related degree between the experimental run sequences [x0(k) and xi(k), i = 1, 2,... m] was indicated by the grey relational grade.

One might compute the grey relational coefficient i(k) as

$$\varepsilon(k) = \frac{\Delta_{\min} + \gamma\, \Delta_{\max}}{\Delta_{o}(k) + \gamma\, \Delta_{\max}} \quad (3)$$

$$\Delta_{i}(k) = [x_{o}(l) - x_{i}(l)] \quad (4)$$

was the difference between x0(k) and xi(k)'s absolute values. The absolute differences (0i) of all comparison sequences were expressed as min, max, respectively. The distinction coefficient (0–1) was created to reduce the impact of the maximum effect when it grew to be too great. The value of was set at 0.5 for the purposes of this investigation. The grey relational grade o was determined after averaging the grey relational coefficients. The stronger the relationship between the ideal sequence x0(k) and the actual sequence xi(k), the higher the grey relational grade value was thought to be. The optimal process response in the experimental design was expected to be represented by the ideal sequence x0(k). The closer to the ideal the appropriate parameter combination was, the higher the relational grade signified.

$$y_{i} = \frac{1}{n} \sum_{k=1}^{n} \epsilon_{i}\ (k) \quad (5)$$

2.2. Grey Relational Grade Generation

Engine performances exhibited a declining tendency as fuel blend increased, whereas emission characteristics showed an upward trend. Since different external equipment types, like exhaust gas recirculation (EGR), can reduce engine emissions, the analysis was done in a way that the engine's performance wouldn't be negatively impacted even when diesel was replaced with a blend of biodiesel and methyl ester. As a result, while converting numerous grey relation grades, engine performance was given a higher weighting factor than emission parameters. Weighting factors were employed with the sequence values when suitable, and the general shape of grey relationship grades changed.

Experience might be used to provide the distinct sequence value of the weighting component (), or appropriate weights could be generated using techniques like singular value decomposition and preliminary grey relational grade values. The use of weighting factors would not be equal to changes in the sequence value units employed or the decision to adopt sequence normalisation, it should be noted.

Experimental Set up

Flexible connection was used to connect the engine directly to an eddy current dynamometer (Figure 1). For measuring the load placed on the engine, the output of the eddy current dynamometer was fixed to a strain gauge load cell. Oxygen (O2), carbon dioxide (CO2), nitrogen oxides (NOx), unburned hydrocarbons (HC), and carbon monoxide (CO) were also measured using a gas analyzer. NOx, HC, and CO were measured as parts per million (ppm) of nhexane equivalent and % volume, respectively. At the fuel tank, a glass burette was available for measuring the volume of fuel consumed each minute. A stopwatch was used to measure the diesel and biodiesel fuel separately for this reason. The engine was put under various loads, with the lowest load level being 20% and the highest level being 100%. The torque applied to the engine was calculated using the length of the dynamometer shaft. For both methyl ester and biodiesel, all experiments were conducted at a speed that maintained BTDC (before top dead centre). The engine was used in the experiments under various load circumstances. There were different compression ratios (CR). Every time gasoline was changed during the experiment, the fuel lines were cleaned, and the engine was run for 30 minutes to stabilise at the new state. The entire engine assembly used for the experiment is seen in Figure 1.engine and eddy current dynamometer specs. By using an AVL DIG AS gas analyzer equipped with a DIGAS SAMPLER at the exhaust, the engine exhaust (CO, HC, CO2, O2, and NOx) was analysed and estimated. the gas analyzer's specifications.

Figure 1 Experimental Setup with engine and analyzer

3. Result and Discussion

Six output responses (outputs) were created by considering different combinations of the three input variables fuel injection pressure, fuel fraction, and load. Taguchi's L9 orthogonal array was chosen so that a small number of experiments could be used to find the ideal process condition. Consequently, a total of 9 tests were carried out. The experimental results were normalised in the range of zero to one using grey relation approaches. However, it was found that out of the eight responses, three of them had higher goal values, while the remaining five had lower values, which were preferable. As a result, during data normalisation, the goal values for the parameters BP, BTE, were computed using (1), while the rest were acquired from (2). Additionally, the grey relation coefficients i(k) for each response were assessed using (3). Grades from four were utilised to determine the grey relations. The overall grade for grey relations after taking into account the proper weighted criteria.

Table 2 Experimental results

Exp No.	Cutting Parameter Level								
	A	B	C	Brake specific fuel consumption	CO	HC	NOx	smoke density	Brake Thermal Efficiency
	Fuel injection pressure (bar)	Fuel fraction (% by volume)	Load (%)						
1	210	30	30	501	0.110	51	591	51	23.05
2	210	50	60	654	0.098	37	606	43	31.45
3	210	70	90	551	0.102	45	584	32	15.65
4	230	30	60	426	0.114	33	606	28	29.75
5	230	50	90	321	0.099	46	624	19	14.28
6	230	70	30	691	0.107	47	639	37	18.15
7	250	30	90	582	0.104	31	612	21	23.65
8	250	50	30	473	0.102	54	658	40	21.45
9	250	70	60	491	0.096	42	752	23	14.28

Table 3 Normalized values

Brake specific fuel consumption	CO	HC	NOx	smoke density	Brake Thermal Efficiency
0.486486486	0.777778	0.869565	0.041667	1	0.489225
0.9	0.111111	0.26087	0.130952	0.75	0
0.621621622	0.333333	0.608696	0	0.40625	0.92021
0.283783784	1	0.086957	0.130952	0.28125	0.09901
0	0.166667	0.652174	0.238095	0	1
1	0.611111	0.695652	0.327381	0.5625	0.774607
0.705405405	0.444444	0	0.166667	0.0625	0.454281
0.410810811	0.333333	1	0.440476	0.65625	0.582411
0.459459459	0	0.478261	1	0.125	1

Table 4 Deviation sequences of responses

Brake specific fuel consumption	CO	HC	NOx	smoke density	Brake Thermal Efficiency
0.513513514	0.222222	0.130435	0.958333	0	0.510775
0.1	0.888889	0.73913	0.869048	0.25	1
0.378378378	0.666667	0.391304	1	0.59375	0.07979
0.716216216	0	0.913043	0.869048	0.71875	0.90099
1	0.833333	0.347826	0.761905	1	0
0	0.388889	0.304348	0.672619	0.4375	0.225393
0.294594595	0.555556	1	0.833333	0.9375	0.545719
0.589189189	0.666667	0	0.559524	0.34375	0.417589
0.540540541	1	0.521739	0	0.875	0

Table 5 Grey relational coefficients

Brake specific fuel consumption	CO	HC	NOx	smoke density	Brake Thermal Efficiency
0.493333	0.692308	0.793103	0.342857	1	0.49467
0.833333	0.36	0.403509	0.365217	0.666667	0.333333
0.569231	0.428571	0.560976	0.333333	0.457143	0.862381
0.411111	1	0.353846	0.365217	0.410256	0.35689
0.333333	0.375	0.589744	0.396226	0.333333	1
1	0.5625	0.621622	0.426396	0.533333	0.689281
0.629252	0.473684	0.333333	0.375	0.347826	0.47814
0.459057	0.428571	1	0.47191	0.592593	0.544906

0.480519	0.333333	0.489362	1	0.363636	1

Table 6 Grey relational grade

Exp. No.	Grey relational grade	Rank
1	0.64	9
2	0.99	7
3	1.07	4
4	0.97	8
5	1.01	5
6	1.28	1
7	1.00	6
8	1.22	2
9	1.22	3

4.1. Analysis of Signal-to-Noise Ratio

Signal-to-noise ratio was established to analyse the grey relation grade because the conventional method was unable to capture the results' variability.From (6) shown below, the signal-to-noise ratio for the overall grey relation grade was determined. The higher-the-better (HB) criteria was used to sort data because the experiment's primary goal was to find the highest S/N ratio for the outcome. A high S/N score indicated that the signal outweighed the random effects of the noise variables by a significant amount:

$$\text{S/N ratio}\ (\eta) = -10\log_{10}\frac{\mu^2}{\sigma^2} \qquad (6)$$

where i denotes the experiment's number, u the trial's number, and Ni the experiment's total number of trials.

Using JMP Minitab software, the output response was analysed. The average of the chosen characteristics for each level of the design factors is shown in Table 6. The major effect plot (Figure 2) illustrates the S/N ratio for three variables, including load, fuel injection pressure, and fuel fraction.

When a parameter's line is almost horizontal, the parameter's influence on response is minimal. On the other hand, a parameter's influence will be greatest for which the line has the greatest inclination. The plot had shown that, out of the three parameters, parameter A (load) had the most impact. The maximum value of the signal-to-noise ratio for each input parameter identified the best process parameter combination that would result in the lowest emission and greater engine performance. As a result, Table 6 and Figure 2 revealed that A5B3C4, or 100% load and 100% mix of fuel, was the best combination of process parameters.

Table 7 the signal-to-noise ratio

Exp. No.	Grey relational grade	S/N Ratio
1	0.64	-3.87640052
2	0.99	-0.087296108
3	1.07	0.5876755537
4	0.97	-0.264565315
5	1.01	0.0864274757
6	1.28	2.144199393
7	1.00	0
8	1.22	1.7271966135
9	1.22	1.7271966135

Table 8 Response for the signal-to-noise ratio.

Grey relational grade			
CONTROL FACTOR	**Fuel injection pressure**	**Fuel fraction**	**Load**
LEVEL 1	0.9000	0.8700	0.9567
LEVEL 2	1.0867	1.0733	**1.0900**

LEVEL 3	**1.1467**	**1.1900**	1.0867
MAX	1.1467	1.1900	1.0900
MIN	0.9000	0.8700	0.9567
MAX-MIN	0.2467	0.3200	0.1333
RANK	2	1	3

Table 9 ANOVA

Grey relational grade						
FACTOR	**DEGREE OF FREEDOM**	**SUM OF SQUARE**	**MEAN SQUARE**	**F - VALU E**	**PERCENTAGE CONTRIBUTION**	**RA NK**
Fuel injection pressure	2	0.09928	0.04964	0.3408	17.06193717	2
Fuel fraction	2	0.1573	0.07865	0.5400	27.03306524	1
Load	2	0.034	0.017	0.1167	5.843129168	3
ERROR	2	0.2913	0.14565			
TOTAL	8	0.58188				

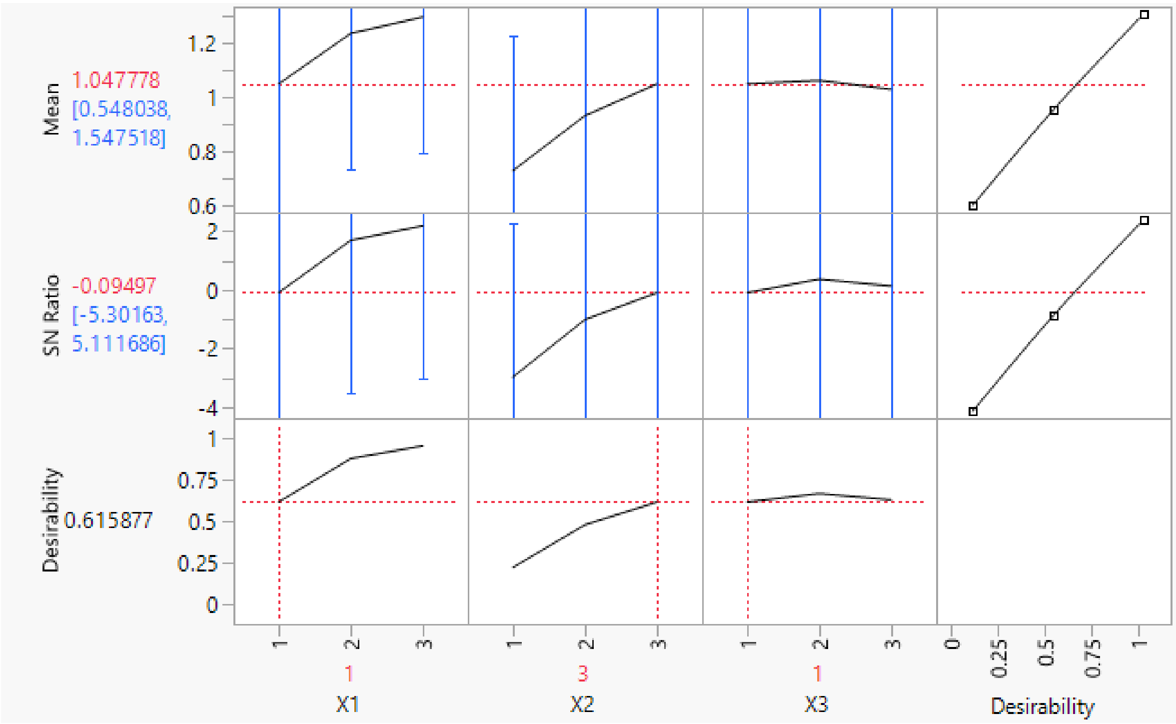

Figure 2 The main effect plots for *S/N* ratio

4. Conclusion

- The impact of methyl ester diesel fuel blends on engine performance and exhaust emissions was examined in this experimental investigation. The engine efficiency and emission characteristics had been examined in relation to the potential use of methyl ester blended with regular diesel as a suitable alternative fuel source.
- Six different engine response parameters were attempted to be optimised in the study while three input parameters were changed at once. Since the inquiry unmistakably suggested that a large number of test combinations were possible, the experiment was designed using the Taguchi method to reduce the number of experiments by creating an orthogonal array, but without losing important data.
- The responses were not unidirectional, which demonstrated the complexity of the optimization challenge. Following the application of weighting factors from grey relational analysis, the multi-response problem was reduced to a single one, and the best solution was found using the test data.

	Initial parameter combination	Optimal parameter combination	
		Prediction	Experimentation
Grey relation grade	230,70,30	1.28	1.19

- The results of actual experimentation were used to validate the experimental study's findings. It was determined that the mixture was the best blend for diesel engines, not significantly impacting the engine's emissions or performance, or the associated fuel injection pressure, fuel fraction, or engine load.

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