

EXPERIMENTAL PARAMETERS OPTIMIZATION OF DIETHYL ETHER-JATROPHA BIODIESEL BLENDED FUEL WITH DIESEL IN VARIABLE COMPRESSION RATIO S.I. ENGINE USING GRAY RELATIONAL ANALYSIS

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ABSTRACT

Experimental analysis is done for different fuel blends Jatropha-10% Diethyl Ether (DEE)-10% + Diesel - 80% (A₁), Jatropha-15% + DEE-10% + Diesel - 75% (A₂), Jatropha-20% + DEE-10% + Diesel - 70% (A₃), and diesel using different compression ratios (CR) (16, 17, and 18) and at various loads (3 kg, 6 kg, 9 kg, and 12 kg) on constant speed VCR diesel engine. The experimental analysis was carried out to study the effects of load and CR on output parameters brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), emission parameters like CO, HC, NO_x, and smoke density on all the fuel blends, and diesel fuel (HSD). The present work aims to optimize the combination of fuel blends, CR, load of DEE, Jatropha, and diesel fuelled single-cylinder constant speed diesel engine to improve the performance and to reduce the emission characteristics. An orthogonal array L₂₇ was used to arrange the input factors and their levels in twenty-seven numbers of experiments. Grey based Taguchi method (GTM) has been used to optimize the responses and to identify the best combination of input parameters. The Minitab 17® software was employed for the analysis of experimental results. Further, the method of TOPSIS confirms the optimized results of GTM. This work has used two methods of optimization techniques for accuracy as well as for confirmation about the optimized operating parameters of the unmodified engine. Operation number 27 is the combination of fuel A₃ with CR 18, and load 100% (3.4 KW) which gives the best performance and emission characteristics..

Keywords: Diethyl Ether, Jatropha, CR, BTE, BSFC, VCR, Grey based Taguchi method, emissions

Introduction

Diesel engines have been used widely in various engineering applications such as automobile and shipping equipment. The diesel engine has different types of emissions such as CO, HC, NO_x, and smoke etc. The alternative fuels have now become a major research area in the engine design due to an increase in fuel economy, and more stringent emission regulations [1, 2].

The required emission regulations are difficult to obtain only with advanced diesel engine technology. It can be achieved by exhaust gas after-treatment, and by using different green fuels for the diesel engines [3]. Generally, alcohol fuels are decreasing engine emissions [3, 4].

Ethanol can be used as substitute fuel for engines [5]. The drawbacks of using ethanol for diesel engines are limited solubility with diesel, low cetane number, and lower viscosity than diesel [6]. To overcome these difficulties, Cetane number enhancers and co-solvent additives have wide scope as a diesel fuel blend for diesel engines [7]. The additives are

employed to improve the properties of fuel blends. Additives are used to compensate for a certain number, improve the viscosity and stabilize the fuel blend mixture [4].

It is also proved that vegetable oil fuels are found best alternatives as their properties are equivalent to diesel fuel and are produced from various crops which are easily available. Also, because of its high cetane number, it can be used in diesel engines without alterations in engine [18].

Biodiesel has several benefits over diesel fuel but difficulties in use due to higher viscosity, higher flash point, lower calorific value, poor oxidative stability, poor cold flow properties, and having greater NO_x emissions. The lower percentages of bio-diesel blends increase the BTE, reduced emission, and BSFC [23]. DEE can be used as a better substitute for diesel fuel owing to its good BTE and lower exhaust emissions. DEE has no stability problems in diesel, having a higher Cetane number and good solubility in the diesel fuel [19].

Ethanol blended diesel engines have more emissions of hydrocarbon (HC), and less CO,

NO_x, and smoke emissions. The Cetane number improver additives have positive trends to reduce CO and NO_x emissions, and have adverse effect on HC emission [1]. Dogan observed the reduction of smoke density, CO, NO_x and increase in HC emissions with the increase in percentage of n-butanol. Also, observed an increase of the BTE and BSFC with an increase in percentage of n-butanol [3]. De Caro et al [4] compared blends, with or without additives on two diesel engines using direct and indirect injection. The engine performance was found improved using additives with reduction of diesel engine emissions. Ajav et al. [5] found that no significant reduction in power of engine using ethanol blends (up to 20%) in diesel. By adopting ethanol up to 20% with diesel BSFC increased by 9% compared to diesel alone. The lubricating oil temperatures, exhaust gas temperature, and emissions like CO and NO_x were reduced with ethanol. The results of Lu et al. [6] indicate that BTE increases while diesel equivalent BSFC decreases, with CN improvers. Also, the NO_x emissions and smoke density reduced using ethanol in diesel fuel and further the NO_x and smoke emissions decreases using CN improver. Lapuerta et al. [7] observed prevention of phase separation due to presence of ethanol with specific additives. In their another work [9], they obtained reductions in smoke density with ethanol-biodiesel blend in C.I. engine. Li et al. [10] compares the different blends of ethanol with pure diesel and found that the BTE and BSFC increases while decrease in smoke density with an increase percentage of ethanol. The HC emissions were increased but CO and NO_x emissions were reduced with ethanol–diesel blends. Bilgin et al. [12] obtained best efficiency at CR of 21 using ethanol blends with diesel. Muralidharan and Vasudevan [13] obtained lower CO, and HC emissions while increase in NO_x emissions with waste cooking oil methyl ester and its blends with a diesel. Cinar et al. [15] investigated the effects of DEE on HCCI-DI engine. They found that audible knocking recorded with a 40% DEE premixed fuel ratio and decrease in NO_x and smoke density while increase in CO and HC emissions. Rakopoulos et al. [19] studied the effect of different DEE blends with diesel and revealed

that DEE blend is a best alternative for diesel engines.

The combustion and emission characteristics of rapeseed plant oil (RSO) and its blends with diesel fuel have been investigated in a multi-cylinder direct injection diesel engine. Results show a significant reduction in NO_x and a relatively higher amount of soot for RSO compared to diesel fuel. Under diesel equivalent soot emission levels, it was also possible to achieve a further reduction in NO_x emissions by up to 22% for 30% RSO blend, this was achieved at the expense of THC, CO, and BSFC [20]. Jindal et. al [23] found that increase in CR and indicated power (IP) simultaneously resulted in an increase of the BTE and reduction in BSFC with lower emissions.

The design of the experiment's (DoE) Taguchi method was used for the analysis purpose of the experimental results of biodiesel fuelled diesel engines. This method was proposed by Dr. Genichi Taguchi (Taguchi, Genichi and Elsayed, Elsayed A and Hsiang, 1989) for optimization of the parameter, which provides the information about the best control parameters in the least number of experiments. The accuracy and reliability of the Taguchi method solely depend upon the way the factors and their values have been chosen. In Taguchi design, the robustness of any control element is measured by the way it is affected by the independent factors (noise level). The purpose of Taguchi design is to identify the best control element which has less variability due to the uncontrolled factors (noise level) such as ambient temperature, engine vibration, etc. The variability in control factors is measured by Taguchi's signal-to-noise ratio (S/N). The S/N ratio is the log function of the output measured parameter, and these are to be calculated for each output parameter. The higher the S/N ratio means better control factor and less variability due to the noise levels (Rao et al., 2008; Senthilkumar et al., 2014). The S/N ratio is calculated by the three design conditions namely larger the better, smaller the better, and nominal the better. The arrangement of control factors and their levels in a minimum number of experiments called orthogonal array to get the effect of control factors on given responses. However, the Taguchi method is used for

single-objective optimization. For more than one response/multi-objective (output parameters) the grey relational analysis method (GTM) method proposed by Deng (1989) is used. In the GTM method, all the responses are combined and converted into a single response optimization problem. The Taguchi and GTM methods are combined for the optimization of multi-objective responses.

The GTM concept uses two conditions of information. The condition at which not at all any information (black) is available for the system ultimately there is no solution. Another side is full of information (white) which could have a unique solution for the system of information. However, these kinds of extremities never exist in the real world, but somewhere in between. Therefore, GTM uses to solve the problems which have less or partially available information. That converts the multi-objective problem into a single objective and Taguchi is used for optimization. Many authors have used this combined technique of optimization for solving the problems (Tarng et al., 2002; Kuo et al., 2008; Tsao, 2009; Sahu and Pal, 2015; Pervez et al., 2016; Raju, 2016). An orthogonal array L27 was used to arrange the input factors and their levels in twenty-seven numbers of experiments. GTM has been used to optimize the responses and to identify the best combination of input parameters. The Minitab 17® software has been used for the analysis of experimental results. Further, the method of TOPSIS confirms the optimized results of GTM. This work has used two methods of optimization techniques for accuracy as well as for confirmation about the optimized operating parameters of the unmodified engine.

Methods

Fuel preparation

The different blends of Diethyl Ether (DEE) +Biodiesel (BD) +diesel (D) were prepared for the trials on single-cylinder variable compression ratio diesel engine as shown in Table 1. The properties of standard fuels and properties measured from laboratories in Indian Biodiesel Corporation (IBC), Baramati are as shown in the Table 2.

Experimental setup and methodology

The experimental setup is shown in Fig. 1 and its detail is given. The specification of the gas analyzer has tabulated in Table 3.

The rated power rating of the engine is 3.5 kW at 1500 rpm with a water-cooled eddy current dynamometer for loading the engine. The engine has a suitable sensing device for temperature, pressure, flow rate, and crank angle measurements with a data acquisition system. The engine has a compression ratio (CR) that ranges from 12:1 to 18:1. In the present work, the CR selected was 16:1, 17:1, and 18:1. For each CR, the load has been varied from 25 to 100%, in the step of 25%.

The combustion, performance, and emission characteristics were observed for each load and CR. Injection pressure and timing were kept constant at 210 bar and 23° bTDC for all observations. Rigorous warming experimental work was performed. In each test, the engine was run for 5 minutes to properly up the engine and stabilizing the set of all working parameters. For reliability and accuracy, a set of results were taken six times for ten cycles each, and the best result is taken for analysis purposes.

Taguchi and GTM technique for optimization

As mentioned, these two methods combined to solve the multi-objective related problem. This combined method's steps are shown in Fig 2. The left part of the figure indicates the Taguchi method and the right part is the GTM method.

Selection of factors and their levels

The selection of factors and levels for optimization entirely depends on the designer's level of understanding of the experimental setup and its effects on the output responses. In this study, the three input factors viz. fuel blend, CR, and load and their three levels have been selected as shown in Table 4.

These selected factors and levels are provided in Taguchi's orthogonal array (OA), in such a way that optimization should be in a minimum number of experiments/trials [39–41]. Based on the factors and their levels, these are arranged in a minimum number of trials (OA L27). These combinations along with their experimental results of responses are given the Table 5.

Signal to noise (S/N) ratio calculation

The analyses of results are carried out by calculating the S/N ratio. In this study, for

calculation of S/N ratios following two design conditions are used.

For larger the better characteristics

$$\eta_{ij} = -10 \times \log \left(\frac{1}{r} \sum_{k=1}^r \frac{1}{m_{ijk}^2} \right) \quad (3)$$

For smaller the better characteristics

$$\eta_{ij} = -10 \times \log \left(\frac{1}{r} \sum_{k=1}^r m_{ijk}^2 \right) \quad (4)$$

Where η_{ij} is the S/N ratio of experiment number i for response j and m_{ijk} is the simulation result for trial i for response j , in k th number of replication and r is the number of replication required. The BTE, taken as 'larger the better' responses and BSFC, CO, HC, NO_x, smoke are 'smaller the better' responses. The S/N ratio is calculated by using the equation 3 and 4 and represented in Table 6.

Grey relational generation

The GM optimization was used to solve the multi interdependent responses problem [42], the steps are shown in the right part of the flowchart of Fig. 2. In this part of optimization, the first step is to linear normalization of calculated S/N ratio between 0 and 1, known as grey relation generation.

The grey relation generation s_{ij} for trial i and response j has been calculated using Equations 5 and 6. Equation 5 is used for larger the better responses and 6 for smaller the better responses for calculating the grey relational generation

$$s_{ij} = \frac{\eta_{ij} - \min_j \eta_{ij}}{\max_j \eta_{ij} - \min_j \eta_{ij}} \quad (5)$$

$$s_{ij} = \frac{\max_j \eta_{ij} - \eta_{ij}}{\max_j \eta_{ij} - \min_j \eta_{ij}} \quad (6)$$

The grey relational generations for normalized S/N ratio. After calculating the grey relational generation, all the performance values are scaled up between 0 and 1. If the performance value s_{ij} for experiment number i of response is 1 or nearer to 1, then this performance value of i is best for response j . But, these kinds of situation never exist; hence a reference sequence X_0 (best/ideal value) = ($X_{01}, X_{02}, \dots$) = (1, 1, ...) is introduced for comparability.

Calculation of grey relational coefficient

The grey relational generation compared with reference sequence and determined how close s_{ij} to X_0 . This closeness is represented by the grey relational coefficient ω_{ij} and calculated as given in Equation 7.

$$\omega_{ij} = \frac{\Delta_{\min} + \zeta \cdot \Delta_{\max}}{\Delta_{ij} + \zeta \cdot \Delta_{\max}} \quad (7)$$

$$\Delta_{\min} = \min(\Delta_{ij}, i = 1, 2, \dots, m; j = 1, 2, \dots, n)$$

$$\Delta_{\max} = \max(\Delta_{ij}, i = 1, 2, \dots, m; j = 1, 2, \dots, n)$$

Where $\Delta_{ij} = |x_{0j} - s_{ij}|$ and ζ is the distinguishing coefficient used for compressing or expanding the range of ω_{ij} responses. m and n are the numbers of trials/ experiments and responses.

The value of ζ lies between 0 and 1, and most of the researchers have taken the value of it as 0.5. However, any value of it does not affect the ranking of an optimum experimental alternative.

Calculation of grey relational grade

Calculation of grey relational grade needs the suitable weighting factor for each response. The weighting factor is very crucial because it affects the grading of trials. Hence in this study, the weighting factor has been calculated judiciously and logical manner to avoid any error in the performance calculation. The weights (w_j) are based on decision-makers' judgment, but this must be $\sum w_j = 1$. These weights are decided by the priority matrix as explained in the section 4.1 and values are as follows, BTE=0.25, BSFC=0.16, EGT=0.02, CP=0.11, NHR=0.25, RPR=0.11, CO=0.02, HC=0.02, NO_x=0.02, Smoke=0.02. After calculating the weights, the grey relational grades are calculated by using equation 8.

$$\gamma_i = \sum_{j=1}^n w_j \omega_{ij}, \quad i = 1, 2, 3, \dots, m. \quad (8)$$

Where γ_i indicates the grey relational grade for its experiment and w_j is the weighting factor for the j^{th} response. Grey relational grade (GRG) calculation is converting the multi-objective to a single objective in the form of GRG. Using the above equation grey relational grade has been calculated considering the equal weights for all responses as shown in Table 6.

The grey relational grade implies the degree of closeness of the comparability sequence to the reference sequence. If the comparability sequence (GRG) value is higher, indicates mores closer to the reference sequence (best) [43]. Therefore, the particular experiment number will be the best choice whose GRG is the higher value. The values of GRG from Table 6 and Fig. 3, indicate that test number 27 has the highest value as compared to others and ranked 1. Similarly, the ranking of experiment number has been done as per the descending value of GRG as shown in Table 10. The operation number 27 is the combination of fuel A3 with CR 18, and load 100% which gives the best performance characteristics.

The experiment number 27 has following optimized parameters as blend –A3, Load -3.4 kW (100%), and CR-18. As load increases from 25 to 100 % on the diesel engine cylinder temperature also increases which causes more combustion efficiency and hence BTE is highest at full load(100%) which is 3.4KW(12kg). At higher CR 18, pick cylinder temperature is

highest and combustion efficiency is also more, which gives the highest BTE.

At higher load 3.4 KW and higher CR 18; more complete combustion occurs due to higher pick cylinder temperature, which causes a reduction in CO and HC emissions.

A₃ gives optimized results for emission and performance parameters. A₃ contains 10% DEE and 20% Jatropha biodiesel. Due to a higher percentage of biodiesel compared to A₁ and A₂ blends, the A₃ fuel blend having more oxygen contents which results in more complete combustion of the diesel engine, hence BTE is higher than A₁ and A₂ fuel blends. As higher O₂ content in the A₃ fuel blend causes more complete combustion, hence A₃ blend having minimum HC and CO emissions compared to other blends. A₃ gives less smoke density than A₁ and A₂ fuel blend, due to more O₂ contents. Nox emissions are less for more Cetane number fuels. DEE fuel blend having more Cetane number, and higher O₂ contents which cause reduced delay period of diesel.

Table 1 Fuel blends

S.N.	Blend Composition	Name
1	DEE-10% +Jatropha-10% +Diesel -80% -	A1
2	DEE-10% +Jatropha-15% +Diesel -75% -	A2
3	DEE-10% +Jatropha-20% +Diesel -70%	A3
4.	100% Diesel (Reference)	D

Table 2 Fuel properties

Properties	Standard	Diesel	Ethanol	Biodiesel	DEE	A1	A2	A3
Density(Kg/m ³ at 20°C)	ASTM D4052	840	789	880	710	865	869	874
Lower heating value (MJ/Kg)	ASTM D5865	42.5	27.0	39.9	34.0	37.50	34	31.50
Liquid viscosity (CP at 20°C)	ASTM D445	3.03	1.20	3-4	0.23	3.10	3.30	3.70
Cetane number	ASTM D613	45-50	5-8	40-50	125	44	49	55
Auto-ignition temperature (°C)	ASTM D93	235	423	-	160	244	249	259

Table 3 INDUS (PEA 205N) Five Gas Analyzer specification

Measurand	Range	Resolution	Accuracy
CO	0 to 15% Vol	0.01% Vol	± 0.02% Vol; ± 3% O.M
CO ₂	0 to 20% Vol	0.01% Vol	± 0.3% Vol; ± 3% O.M
HC	0 to 30000 ppm	≤2.000: 1 ppm vol.	< 2000 ppm vol.: ±4 ppm vol. ±3 O.M.
O ₂	0 to 25%	0.01% vol	± 0.02 % vol.

NO_x	0 to 5000 ppm	1 ppm vol.	± 5 ppm vol.
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Table 4 Factors and their levels

Factors	Level 1	Level 2	Level 3
A: Fuel blend	A1	A2	A3
B: CR	16	17	18
C: Load (%)	25	50	100

Table 5 Arrangement of factors and levels in an orthogonal array (L27) with experimental results

S. No	Jatropha	CR	L	BTE	BSFC	CO	HC	Nox	Smoke opacity
	%		Kg		kg/kWh	%	ppm	ppm	%
1	10	16	3	16.64	0.58	0.285	154	51	3.04
2	10	16	6	24.37	0.39	0.158	109	146	3.49
3	10	16	12	31.23	0.31	0.027	62	752	5.98
4	10	17	3	18.75	0.52	0.121	73	94	4
5	10	17	6	26.81	0.36	0.074	82	280	3.54
6	10	17	12	33.85	0.28	0.015	60	782	4.46
7	10	18	3	18.66	0.51	0.05	53	209	2.21
8	10	18	6	26.27	0.37	0.032	62	419	2.1
9	10	18	12	34.62	0.28	0	79	904	1.54
10	15	16	3	17.91	0.59	0.158	109	45	1.42
11	15	16	6	27.11	0.39	0.082	99	175	0.94
12	15	16	12	35.82	0.3	0.015	67	664	0.35
13	15	17	3	19.1	0.51	0.098	92	115	3.76
14	15	17	6	29.31	0.36	0.041	83	203	1.46
15	15	17	12	37.88	0.28	0.014	82	712	1.58
16	15	18	3	20.27	0.51	0.04	67	223	1.14
17	15	18	6	28.69	0.37	0.025	80	441	2.25
18	15	18	12	37.45	0.28	0	75	858	0.92
19	20	16	3	19.22	0.59	0.127	99	78	0.56
20	20	16	6	30.78	0.37	0.064	89	295	0.79
21	20	16	12	41.24	0.28	0.012	97	710	2.18
22	20	17	3	20.37	0.56	0.069	96	166	1.29
23	20	17	6	30.39	0.38	0.04	103	428	1.29
24	20	17	12	39.37	0.29	0.01	106	789	2.59
25	20	18	3	22.03	0.52	0.038	65	262	0.59
26	20	18	6	31.62	0.36	0.016	88	564	0.82
27	20	18	12	42.54	0.27	0	79	870	1.17

Table 6 Grey relational grade (GRG)

S.No.	GRG	Rank
1	0.4730003	27
2	0.5363789	26
3	0.622416	17
4	0.5554747	24
5	0.5833466	21
6	0.682887	7
7	0.6362812	15
8	0.6458529	13
9	0.70967	6
10	0.5584836	23
11	0.6300285	16

12	0.7663015	2
13	0.5374495	25
14	0.6644683	9
15	0.7183232	4
16	0.636552	14
17	0.6197124	18
18	0.7554769	3
19	0.6002797	20
20	0.6517096	12
21	0.7175191	5
22	0.578004	22
23	0.6116868	19
24	0.6729102	8
25	0.6600889	11
26	0.6636608	10
27	0.7961523	1

The table 1 gives different descriptive statistics of center of gravity and wrist joint. The mean and standard deviation of long service in elbow joint is 144.40 ± 17.54 . The mean and standard deviation of flick service elbow joint is 148.20 ± 15.54 . The mean and standard deviation of short service in elbow joint is 143.80 ± 19.56 . The

mean and standard deviation of long service in shoulder joint is 45.60 ± 19.95 . The mean and standard deviation of flick service in shoulder joint is 42.30 ± 11.49 . The mean and standard deviation of long service in shoulder joint is 40.10 ± 18.48 .



Figure 1 Single cylinder 4- Stroke VCR Diesel Engine Setup

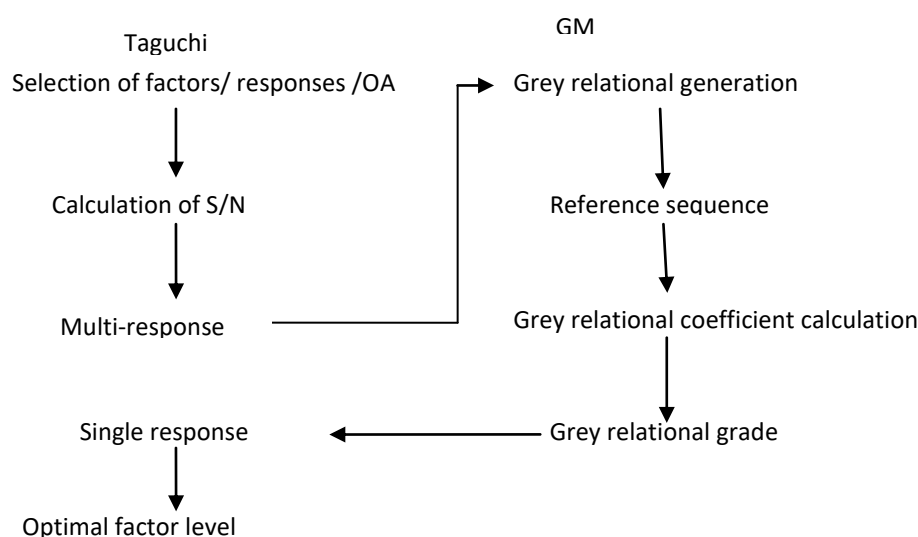


Figure 2 Steps in GTM method

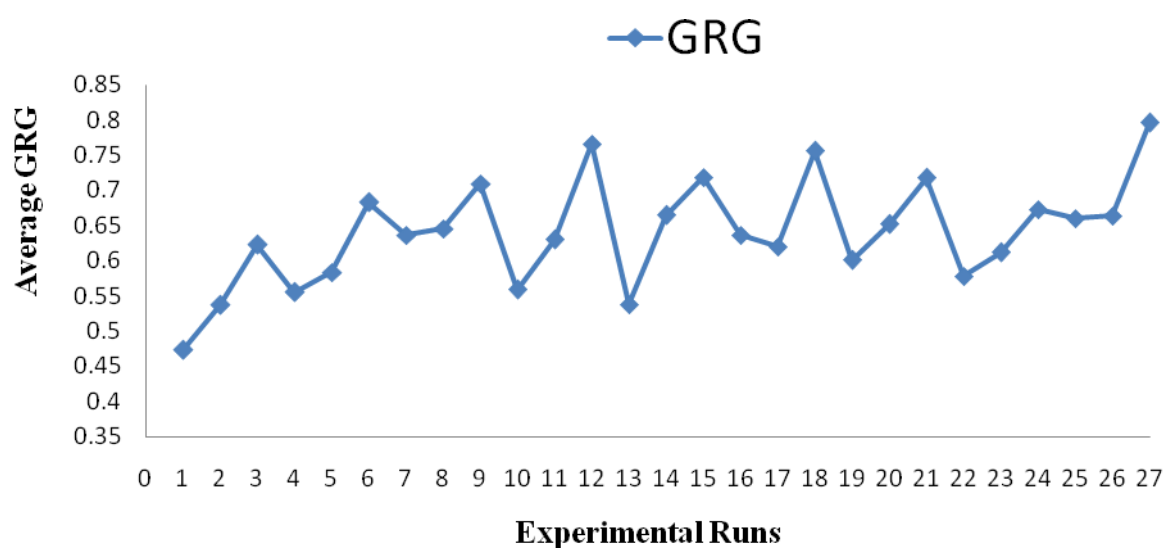


Figure3 Variation of GRG

In the table 2 elbow joint is insignificant as the p-value is 0.834 which is more than 0.05 hence researcher cannot reject the null hypothesis. It can be said that there is no difference among long service, short service, and flick service in elbow joint.

In shoulder table the p-value was found to be insignificance as the p-value is 0.77 which is more than 0.05 hence researcher cannot reject the null hypothesis. It can be said that there is no difference among long service, short service, and flick service in shoulder joint.

Conclusion

Taguchi's Gray Relational Analysis (GTM) is applied to optimize diesel engine input parameters like fuel blend, load, and CR. An orthogonal array L_{27} was used to arrange the input factors and their levels in twenty-seven numbers of experiments. GTM has been used to optimize the responses and to identify the best combination of input parameters and from this following conclusions can be drawn:

- The A_3 with CR 18, and load 100% which gives the best performance characteristics.
- A_3 blend shows the highest value of BTE compared to A_1 and A_2 at higher load 3.4 kW (100%) and highest CR 18.
- A_3 blend shows the lowest value of BSFC
- compared to A_1 and A_2 at 100% load and CR18.
- (4) A_3 gives the lowest CO and HC emissions than A_1 and A_2 due to higher O₂ contents.
- (5) A_3 gives lower smoke density than A_1 and A_2 due to higher O₂ contents.
- (6) From the above results, it is seen that the engine gives good performance at higher load and higher CR.

The performance of the A_3 blend is better than A_1 and A_2 blends for the diesel engine.

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