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Parametric optimization of application of 2 Ehyle Hexyl-Nitrate on partial substitution of ethanol in diesel for fuel economy and emission control

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Abstract. The application of ethanol in CI Engine is getting attention due to low cost and characteristics suitable for C I Engine as an alternate fuel or blending agent but has limitation of low cetane number. The proposed work is to identify the proportion of cetane improver for partial substitution of ethanol with diesel to achieve fuel economy and emission control. In this Taguchi method is used to decide the proportion of blend in fuel sample to achieve maximum improvement with minimum number of fuel sample and grey relation analysis is done to identify the significant factor along with optimize fuel proportion. Using Taguchi method, nine different fuel samples containing mixture of ethanol, 2 ethyl hexyl-nitrate (2EHN) and diesel were prepared. Each sample was tested on computerized single cylinder CI engine test rig at constant speed and variable compression ratio at 16, 17 and 18. After Grey relation analysis of performance and emission result of experiments, it is observed that D80E10EHN7 is very effective fuel sample in emission control and reducing the running cost since Brake Specific Fuel Consumption (BSFC) of this sample less than that of diesel. It has observed that Taguchi approach has reduced the number of trials substantially and grey relation help us in identifying the significant factors considering combined effect of factors.

1. Introduction

The application of ethanol in CI Engine is getting attention due to low cost and characteristics suitable for CI Engine as an alternate fuel or blending agent but has limitation of low cetane number[1,2]. Uses of ethanol lower the cetane value of Diesel which has adverse effect of combustion characteristics. Possibility of improving these characteristics with application of cetane improver is checked here [3, 4, 5, 7]

Low cetane number fuels generally have a tendency to exhibit longer ignition delay due to their ignition quality. The ignition quality can be improved by adding small quantities of ignition improvers or cetane number improvers. Examples of ignition improvers are organic peroxides, nitrates, nitrites and various sulphur compounds. Earlier, alkyl nitrates (isopropyl nitrate, primary amyl nitrates, primary hexyl nitrates, octyl nitrate) were commercially used. By adding these improvers, the ignition characteristics of poorer quality diesel fuel, particularly alcohols, will be improved when they are used in CI engines[8,9]. The use of ignition improvers or cetane improvers offers two advantages when they are used with alcohols: firstly, an alcohol is used in CI engines without any major engine modification; and secondly, they offer total replacement of diesel fuel in diesel engines. An ignition improver of up to 15% by volume would normally be required to enable the ignition of alcohol fuels in CI engines. The cost of these additives is high, and hence, they are not largely used

2. Design Of Experiment

2.1 Taguchi Method

Taguchi method is scientifically disciplined mechanism for evaluating and implementing the improvement in product, process, material, equipment. The aim of this method is improving the desired characteristics and reducing the number of defects by studying the key variables. [10]

In present work Compression ratio, load, ethanol and 2EHN have been chosen as the design factors to identify their effects on the desired response variables of NOX, Smoke and BSFC. Each factor is assigned into three levels. To get optimal solution in minimum number of experiments, we chose three levels of each factor, because if we increase the number of levels, number of conducting experiment goes on increasing and it takes time for calculation. These design factors are important for understanding the effect on response variables.

Table 1. Design factors and their levels

Design factors	Level 1	Level 2	Level 3
C.R	16	17	18
Load (kg)	0	4.5	9
Ethanol (%)	10	15	20
2EHN (%)	3	5	7

2.2 Selection Of Orthogonal Array :

Before selecting the orthogonal array the minimum no. of experiment to be conducted shall be fixed based on the total no. of degree of freedom. In counting the total degree of freedom the investigator commits 1 degree of freedom to the overall mean of the response under study. So in our experiment, we have selected L9 array, because we have 3 levels and 4 factors i.e. compression ratio (C.R.), load, ethanol, 2EHN. That's why we selected L9 array and hence selected orthogonal array shall have 9 expt. [12]

Table 2. Array Selector [12]

Number of Levels	Number of Parameters (P): 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32
3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36	L36	L36	L36	L36	L36	L36	L36								
4	L'16	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32																					
5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50																			

From the table 1, It is cleared that for four number of parameter and three level, L9 is best orthogonal array as it limits the number of run to 9. Hence L9 orthogonal array has been used for my work.

Also in current work we are interested on effect of individual effect of parameter on response and not on their interrelation hence for this case L = 2N+1 where N is number of parameter and L is number of trail so L9 array will be selected. [20]

Table 3 Allocation of variable Factor in L9 Array

No. of exp.	A	B	C	D	Code
1	1	1	1	1	D80E10EH3
2	1	2	2	2	D80E15EH5
3	1	3	3	3	D80E20EH7
4	2	1	2	3	D80E15EH7
5	2	2	3	1	D80E20EH3
6	2	3	1	2	D80E10EH5
7	3	1	3	2	D80E20EH5
8	3	2	1	3	D80E10EH7
9	3	3s	2	1	D80E15EH3

For selected L9 orthogonal array , BSFC which determines fuel economy of engine is selected as Response. Similarly for emission characteristics, Smoke and NOx were selected as they are dominating for responses.

Table 4. L9 Orthogonal Design Matrix Of Experimental Data [17]

Exp. No.	Factor				Response		
	C.R	Load (Kg)	Ethanol (ml)	2EHN (ml)	NO_x (ppm)	Smoke (%)	BSFC (kg/kW-hr)
1	16	0	80	24	--	--	--
2	16	4.5	120	40	--	--	--
3	16	9	160	56	--	--	--
4	17	0	120	56	--	--	--
5	17	4.5	160	24	--	--	--
6	17	9	80	40	--	--	--
7	18	0	160	40	--	--	--
8	18	4.5	80	56	--	--	--
9	18	9	120	24	--	--	--

2.3 Sample Preparation:

Using L9 Orthogonal array Fuel Samples were prepared using 2EHN and Ethanol based on their level assigned. Table 5 shows details composition of fuel Sample

Table 5. Details composition of Fuel Sample (all in ml)

Sample No.	Samples	Quantity of Diesel	Quantity of Ethanol	Quantity of 2EHN
1	D80E10EH3	800	80	24
2	D80E15EH5	800	1200	40
3	D80E20EH7	800	160	56
4	D80E15EH7	800	120	56
5	D80E20EH3	800	160	24
6	D80E10EH5	800	80	40
7	D80E20EH5	800	160	40
8	D80E10EH7	800	80	56
9	D80E15EH3	800	120	24

2.4 Experimental Procedure:

A typical computerized single cylinder 4-stroke diesel engine is used for experimentation work. Table No1 present the specification of engine test rig specification. The actual photograph of the experimental set up and gas analyzer is as shown in figure 1 and figure 2 respectively. An AVL 444Di gas analyzer was used for measuring the CO, HC, NO_X emission and smoke density was measured using AVL 437 smoke meter.

Table 6 Engine Specification

Parameter	Specification
Engine type	Single cylinder DI, water cooled
No. of cylinder	01
Rated power	5.20 kW, 1500rpm
Displacement	661.45 cc
Bore*stroke length	87.50 mm*110 mm
Compression ratio	18:1
Orifice diameter	20 mm
Orifice coefficient of discharge	0.60
No. of cycle	10
Dynamometer arm length (mm), hydraulic	185 mm

Figure 1. Picture of Actual Test Setup

Figure 2. Picture of Smoke Meter AVL 437

3. Taguchi Grey Relation Analyses

3.1 Statistical Modeling

Table 7. Signal to Noise ratio for the response variables

Exp. No.	NO_X(ppm)	Smoke(%)	BSFC(kg/kW-hr)
1	-31.1260	20	-24.9643
2	-48.399	6.020	-37.1466
3	-49.1878	-7.604	-39.2757
4	-36.3908	13.97	-349637
5	-41.1138	6.02	-37.346
6	-38.8896	-9.82	-38.8896
7	-35.1174	4.456	-31.5956
8	-44.7609	-4.082	-28.9431
9	-49.3964	-13.4419	-33.9794

3.2 . Normalizing:

In GRA, the S/N ratio of response parameter were normalized in the range between 0 and 1 using Lower The Better (LTB) characteristic called grey relational generation [10,12].

$$Y_i(p) = [\max (S/N)_i(p) - (S/N)_i p)] \ / \ [\max (S/N)_i(p) - \min (S/N)_i(p)]$$

where p is trial number for that particular response

Table 8 Grey relation generation of each response variance

Exp. No.	NO_X(ppm)	Smoke(%)	BSFC(kg/kw-hr)
1	0	0	0
2	0.9454	0.418	0.8512
3	0.9885	0.825	1
4	0.2881	0.1803	0.6987
5	0.5466	0.4180	0.8678
6	0.4249	0.8197	0.9730
7	0.2184	0.4654	0.4633
8	0.04084	0.7201	0.2780
9	1	1	0.6299

3.2 *Grey Relational Coefficient*:-

The higher grey relational coefficient implies that the corresponding experimental result is closer to the optimal (best) normalized value for the single response. [17]

$$\xi i(p) = \frac{\Delta(k)min + \zeta \Delta(k)max}{\Delta oi(k) + \zeta \Delta(k)max}$$

where, $\Delta oi(k)$ = |y0(p)-yi(p)||=difference in absolute value of y0(p) and yi(p)

ζ = Distinguishing coefficient ($0 \leq \zeta \leq 1$) (0.5 is value used in most situation)

Δmin=Smallest value of |y0(k)-yi(k)|

Δmax =Largest value of $|y0(k) - yi(k)|$

Result of grey relation using above formula is tabulates in table. 9

Table 9 Grey Relation Coefficient of each output parameter

Exp. No.	NO_X(ppm)	Smoke(%)	BSFC(kg/kw-hr)
1	0.3333	1	0.3333
2	0.9015	0.5446	0.7706
3	0.9775	0.3773	1
4	0.4125	0.734	0.62369
5	0.5244	0.5446	0.7908
6	0.4650	0.3592	0.9487
7	0.3901	0.5179	0.4822
8	0.3426	0.4098	0.4091
9	1	0.3333	0.5716

After calculating the grey relational coefficients, the overall grey relational grade is calculated .The higher the value of grey relational grade is, the greater is the desirability

A grey Relation Grade obtains from the grey relational analysis was used to optimize the process parameters of performance characteristic. The experimental result shows that parameter compression ratio has the most significant effect on the performance characteristic. Therefore, the integration of grey relational analysis and the Taguchi method can be applicable for the optimization of process parameter and help to improve process efficiency.

$$\gamma i = 1/n \sum_{k=1}^{n} Wp\ \xi i\ (k) \quad n=1\text{-}3$$

where n is number of output response

Wp = weighting value for each grey relation coefficient ranging from 0 to 1 and sum of Wp is always 1. In present study since each response factor is equally important hence assign 0.33

Grey Relation grade calculated by above formula is tabulated as below. The higher grade correspond to a better S/N ration respectively as it's is closer to computed ideal S/N Ration.

Table 10 Grey Relational Grades with Rank

Exp no.	Grey relational coefficient			Grey relation grade G=1/3(a+b+c)	Rank
	NO_x (a)	Smoke (b)	BSFC (c)		
1	0.3333	1	0.3333	0.555	7
2	0.9015	0.5446	0.7706	0.7389	2
3	0.9775	0.3773	1	0.7836	1
4	0.4125	0.734	0.62369	0.5901	6
5	0.5244	0.5446	0.7908	0.6199	4
6	0.4650	0.3592	0.9487	0.5909	5
7	0.3901	0.5179	0.4822	0.4634	8
8	0.3426	0.4098	0.4091	0.3871	9
9	1	0.3333	0.5716	0.6349	3

4. Results And Discussion:

Its observed from the table 10 that the experimental run No. 3 scored the first rank hence can be considered as the best experimental sequence to provide the best strategy to obtain the optimal solution of satisfying the set multiple objective simultaneously.

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 e.g., design Factor CR is at Level 1 for experimental run no. 1-3 so Response grade for CR at level 1 is average of Grade from table No.10 for these runs which is equal to 0.1019. Similarly for all other design factor at respective level grades are calculated and tabulated in table.11

Table. 11 Response table for grey relational grade

Symbol	Design Factors	Grey Relational Grade			Max. effect (max.-min.)	Rank
		Level 1	Level 2	Level 3		
A	C.R	0.1019	0.6003*	0.4951	0.4984	1
B	Load	0.5363	0.5819	0.6698*	0.1335	2
C	Ethanol	0.6034*	0.5977	0.5869	0.0165	4
D	2EHN	0.5933	0.5869	0.6977*	0.1108	3

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 BSFC and lesser NOx and Smoke are (A2B3C1D3) as presented in table No 11. Optimal level of the process parameters is the level with the highest grey relational grade.

5. Conclusion

During this it has been found that DOE method is important tool in Improvement of CI Engine Performance and reduction of emissions. Taguchi approach of DOE along with Grey Relation methods helps in limiting the number of trials for multiple variables which is not possible in normal test conditions. Also it helps in identifying the significant factor with its level for optimizing the BSFC and limiting the NOx and BSFC. From the work it's been found that

- The optimum results will be possible with experimental run with test conditions CR at level 2, Load at level 3, ethanol at level 1 and 2EHN at Level 3.
- So its concluded that It most efficient to run the C I Engine by blend of Diesel with 15% Blend of Ethanol along with 7% addition of 2EHN.

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