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Optimal Performance Parameter of CI Engine Fuelled with Biodiesel using Taguchi Method

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Abstract

The present paper deals with four biodiesel blend i.e. neem oil methyl ester, mahua oil methyl ester, polanaga oil methyl ester and simarouba oil methyl ester. Experimental investigation of the above oil has been performed in a CI engine. Permance analyisis and emission analysis have been carried out. The three control parameters selected were Compression ratio (CR), Fuel fraction, FF (in %), and Load, P (in kg) which have influence on the response. The three selected control parameters at three levels indicates nine trials of experiments have been conducted for each fuel,, with the level of each parameter for each trial run as indicated on the array. The optimal conditions for the control parameters gave optimum responses. The response variable have been optimized was Brake Thermal efficiency for maximum value, BSFC and NO_x with the least as much as possible. The signal optimum settings of the parameters were achieved from the signal to noise ratio (SN) which help in data analysis and prediction of the optimum result.

Keywords: *Optimal performance, parameter, biodiesel, Taguchi analysis.*

I. INTRODUCTION

CONSIDERING the oil contents of seeds and availability potential of neem, mahua, polanga and simarouba oils, the present investigation on biodiesel production; engine performance; emissions; utilization of energy with this biodiesel and its blends with diesel were undertaken with the following specific objectives i.e. to optimize the performance of biodiesel operated engine through Taguchi Analysis.

The author has carried out various investigations on CI engine using various fuels like kararnja, neem, polanga, mahua and simarouba [1]-[7]. Based on certain results an attempt was made to determine an optimum combination of input parameters that maximizes response characteristics. A brief discussion of some important research findings related to this field is presented below:

Irusta et al. (1994) described a statistical criterion for evaluation and selection of different testing methods for solid bio fuels taking into consideration accuracy, precision, sensitivity, re productivity, repeatability, testing costs and testing time. The signal-to-noise ratio suggested by Taguchi has been used in a way similar to a traditional method (analysis of variance, ANOVA) used for this purpose. Some simulated examples are described to illustrate the development of the proposed technique. Application to real situations can be made by treating experimental data in a similar way[8].

Kim et al. (2010) studied the optimization of experimental parameters, such as catalyst type, catalyst concentration, and molar ratio of alcohol to oil and reaction temperature on the transesterification for the production of rapeseed methyl ester. The Taguchi approach was adopted as the experimental design methodology, which was adequate for understanding the effects of the control parameters and to optimize the experimental conditions from a limited number of experiments. The optimal experimental conditions obtained from this study were potassium hydroxide as the catalyst, at a concentration of 1.5 wt % and a reaction temperature of 60^0 C. Concluded that according to Taguchi method, the catalyst concentration played the most important role in the yield of rapeseed methyl ester. Finally, the yield of rapeseed methyl ester was improved to 96.7% with the by optimal conditions of the control parameters which were obtained by Taguchi method[9].

Karnwal et al. (2011) presented an experimental study that involved an application of the Taguchi method and grey relational analysis to determine the optimum factor level to obtain optimum multiple-performance characteristics of a diesel engine run with different low-percentage thumba biodiesel- diesel blends. Four factors namely, low-percentage thumb a biodiesel-diesel blend, compression ratio, nozzle opening pressure and injection timing were each considered as three levels. An L9 orthogonal array was used to collect data for various engine performance-and emission-related responses under different engine loads. The signal-to-noise (S/N) ratio and grey relational analysis were used for data analysis. The results of the study revealed that the combination of a blend consisting of 30% thumba biodiesel (B30), a compression ratio of 14, a nozzle opening pressure of 250 bar and an injection timing of 20^0 produces maximum multiple performance of a diesel engine with minimum multiple emissions from the engine[10].

Sivaramakrishnan et al. (2012) optimized the direct injection single cylinder diesel engine with respect to brake power, fuel economy and emissions through experimental investigations and DOE methods. A single cylinder 5.2 kW diesel engine was selected for test. Five parameters, Power (P), static injection pressure (IP), injection timing (IT), fuel fraction (B) and compression ratio (CR) was varied at four levels and the responses brake power, fuel economy and emissions were investigated. The optimum n values of the response could be predicted using Signal-Noise ratio(S/N ratio) and optimum combination of control parameters were specified. The best results for brake specific fuel consumption, brake thermal efficiency were observed at increased CR, IP and IT. The emissions CO, HC were reduced while NO_x emission increases[11].

Kawade et al. (2013) concluded that, the blends of biodiesel with small content by volume could replace diesel in order to help in controlling air pollution and improving engine performance of power and economy of engine when using biodiesel blending with diesel fuel. They have also concluded that, the Optimization of CI engine performance and operating parameters through different software is most suitable, more accurate and less time consuming technique as compared to experimental method. Use of Artificial Neural Networks (ANN) for optimizing the C.I. engine parameters is most suitable techniques. Therefore ANN will be a very good tool to optimize engines parameters in the future. Also they observed that, Taguchi method can be effectively used for the investigation of multiple performance characteristics of a diesel engine[12].

Kaliamoorthy et al. (2013) investigated the effects of engine parameters on the performance and emission characteristics of a single cylinder 5.2 kW diesel engine. The experiments were designed using a statistical tool known as design of experiments based on Taguchi. Five parameters, namely, power, static injection pressure, injection timing, fuel fraction, and compression ratio were varied at four levels and the responses brake power, fuel economy and emissions were investigated. The optimum values of the response could be predicted using signal-noise ratio and optimum combination of control parameters were specified. Results of confirmation tests showed good agreement with predicted quantities. A compression ratio of 17.7, blend of 20% karanja biodiesel, an injection pressure of 230 bar, injection timing of 27^0 before top dead centre and a 70% load were found to be optimal values for the karanja biodiesel blended diesel fuel operation in the test engine[13].

Naik et al. (2013) studied the optimum of effective parameters of Pongamia pinnata biodiesel using Taguchi Method. The optimum parameter for high percentage yield was selected by varying parameters through Taguchi method. With an orthogonal array (L-9) a total set of nine experiments having three parameters each at three levels indicated that the Taguchi method was a efficient method of determining the optimum parameters for high percentage yield of karanja oil methyl ester (KOME). ANNOVA helped to estimate the contribution of each noise factor[14].

Dhote et al. (2013) studied the most commonly used method for biodiesel preparation method via transesterification of vegetable oil using alkaline catalysts. The optimization of experimental parameters, such as catalyst type, catalyst concentration, oil to alcohol molar ratio and reaction time, on the transesterification for the production of Mahua oil methyl ester has also been studied. The Taguchi approach was adopted as the experimental design methodology, which was adequate for interpreting the effects of the control parameters and to optimise the experimental conditions from a limited number of experiments. The optimal experimental conditions obtained from this study were oil to the alcohol molar ratio 1:15, sodium hydroxide as the catalyst, as a catalyst concentration of 0.4 wt% and a reaction time of 5 min. According to Taguchi method, the catalyst type played the most important role in the yield of Mahua oil methyl ester[15].

Gorle et al. (2013) carried out experiments on biodiesel blends and compared it with diesel fuel characteristics. Studied the optimization of experimental parameters such as catalyst type, catalyst concentration, molar ratio of alcohol to oil and reaction temperature. The Taguchi method helped to understand the effect of control parameter and to optimize experimental conditions from a limited number of experiments and contribution of each noise factor calculated by ANOVA. Finally the yield of jatropha methyl ester could be improved using control parameter which was obtained by Taguchi method. The acquired data were analyzed for various parameters such as brake thermal efficiency (BTE), brake mean effective pressure (BMEP), brake specific fuel consumption (BSFC), exhaust gas temperature (EGT). The blends of BJ-10 and BJ-20 have superior emission characteristics than other blends and closer to diesel value[16].

Siju et al. (2013) investigated the combine effect of EGR and Injection Pressure for the performance of DICI engine by using Karanja biodiesel. To reduce number of experiments, Taguchi method of DOE has been carried out. Optimum parameters from Taguchi method were validated by experiments and compared the results[17].

In the present investigation neem oil methyl ester(NOME), mahua oil methyl ester (MOME), polanga oil methyl ester(POME) and simarouba oil methyl ester(SOME) was taken as fuel for experimentation. The performance test of biodiesel was conducted on a Kirloskar made variable compression ratio engine.

II. METHODOLOGY

When biodiesel is used as a substitute for diesel, it is necessary to understand the parameters that affect the combustion phenomenon which have an impact on thermal efficiency and emissions. Researchers have made lots of efforts on improving the thermal efficiency and reducing emissions as found in [9]. The most common optimization techniques used for engine analysis are response surface methodology, grey relational analysis, nonlinear regression, Taguchi analysis and genetic algorithm as reflected in [10].

Taguchi technique has been popular for parameter optimization in design of experiments (DOE). DOE has introduced the loss function concept which combines cost, target and variations into one metric. The signal to noise ratio (S/N) is a figure of merit and relates inversely to the loss function. It is the ratio of the amount of energy for intended function to the amount of energy wasted as demonstrated in [13]. There are three types of S/N ratios- the lower the better, the higher the better and the more nominal the better.

The S/N ratio with lower the better characteristics can be expressed as

$$\frac{S}{N} = -10 \log\left[\frac{1}{r}\sum_{i=1}^{r} y_i^2\right] \tag{1}$$

Where,

y_i = measured value of the response variable i.

The SN ratio with higher the better characteristics can be expressed as:

$$\frac{S}{N} = -10 \log\left[\frac{1}{r}\sum_{i=1}^{r} \frac{1}{y_i^2}\right] \tag{2}$$

Where,

y_i = measured value of the response variable i

r = number of repetitions of each experiment

The steps involved in DOE method are mentioned in [11] as

- Identifying the response functions and control parameters to be evaluated
- Determining the number of levels of the control parameters
- Selecting the appropriate orthogonal array,
- Assigning the parameters to the array and conducting the experiments
- Analysing the experimental results
- Selecting the optimum level of control parameters

The objective of the study was to establish the optimum conditions for the BTE, BSFC and NO_x. Matrix experiment through Taguchi analysis uses orthogonal array technique which gives more reliable estimates of factor effect with less number of experiments.

The columns of an orthogonal array represent factors and the rows represent levels. In the study orthogonal array was used to design experiments with three factors at 3 levels. Minitab 17 was used to analyse the results and optimize the experimental conditions for setting the control variables.

The three control parameters selected were Compression ratio (CR), Fuel fraction,FF (in %), and Load, P (in kg) which have influence on the response. The three selected control parameters at three levels indicates L_9 i.e. nine trials of experiments to be conducted, with the level of each parameter for each trial run as indicated on the array. Design parameters are shown in TABLE I. L_9 Orthogonal Array is shown in TABLE II.

TABLE I
Design Parameters

Controlled Factors	Level-1	Level-2	Level-3
A: Compression Ratio(CR	value	value	value
B:Fuel fraction(FF)	value	value	value
C:Load(P)	value	value	value

TABLE II
Orthogonal Arrays

Run Number	CR	FF	P
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The next step is to determine optimal conditions for the control parameters to give the optimum responses. The response variable to be optimised was Brake Thermal efficiency for maximum value, BSFC and NO_x with the least as much as possible. The signal optimum settings of the parameters were achieved from the signal to noise ratio (SN) which help in data analysis and prediction of the optimum result.

III. RESULTS AND DISCUSSIONS

Design parameters and L_9 Orthogonal Array are shown in TABLE III and TABLE IV respectively.

TABLE III
Design Parameters

Controlled Factors	Level -1	Level-2	Level -3
A: Compressio n Ratio(CR)	17.5	17.7	17.9
B:Fuel fraction (FF)	10	20	30
C:Load (P)	2	4	6

TABLE IV
Orthogonal Arrays

Run Number	CR	FF	P
1	1	1	1

2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Experimental data are shown in TABLE V

TABLE V
Experimental Data

Fuel	Factors (Run Number)	Compression Ratio	Fuel Fraction (%)	Load (kg)	BTE (%)	BSFC (kg/kW-hr)	NO_X (ppm)
NOME	1	17.5	10	2	17.0	0.50	150
	2	17.5	20	4	16.5	0.54	120
	3	17.5	30	6	14.0	0.62	148
	4	17.7	10	4	18.0	0.52	184
	5	17.7	20	6	17.5	0.56	150
	6	17.7	30	2	14.0	0.74	90
	7	17.9	10	6	17.5	0.52	240
	8	17.9	20	2	17.0	0.74	100
	9	17.9	30	4	15.0	0.76	80
MOME	1	17.5	10	2	17.5	0.52	153
	2	17.5	20	4	16.5	0.55	121
	3	17.5	30	6	14.5	0.61	151
	4	17.7	10	4	17.5	0.51	184
	5	17.7	20	6	17.5	0.56	152
	6	17.7	30	2	14.0	0.74	100
	7	17.9	10	6	17.5	0.52	230
	8	17.9	20	2	16.0	0.73	100
	9	17.9	30	4	16.0	0.76	92
POME	1	17.5	10	2	18.0	0.53	151
	2	17.5	20	4	16.5	0.54	121
	3	17.5	30	6	14.5	0.60	151
	4	17.7	10	4	18.0	0.51	184
	5	17.7	20	6	17.5	0.56	151
	6	17.7	30	2	14.0	0.74	100
	7	17.9	10	6	17.5	0.53	230
	8	17.9	20	2	16.0	0.73	100
	9	17.9	30	4	15.5	0.75	90
SOME	1	17.5	10	2	17.2	0.49	152
	2	17.5	20	4	16.8	0.53	125
	3	17.5	30	6	14.2	0.63	150
	4	17.7	10	4	18.3	0.55	186
	5	17.7	20	6	17.3	0.54	153
	6	17.7	30	2	14.3	0.85	100
	7	17.9	10	6	17.6	0.53	240
	8	17.9	20	2	17.5	0.75	102
	9	17.9	30	4	15.2	0.73	102

By applying the experimental data of TABLE V , the SN ratio graphs are shown in Fig. 1 to Fig. 12

Optimal Performance parameter BTE

Different experiments have been used for Taguchi method where variable compression ratios are taken. The signal to noise ratio graph for BTE of NOME, MOME, POME and SOME are shown in Fig. 1 to Fig. 4

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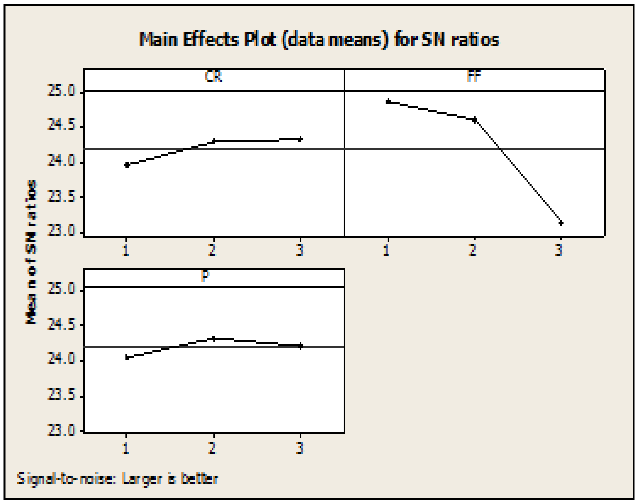

Fig. 1. SN Ratio for BTE of NOME

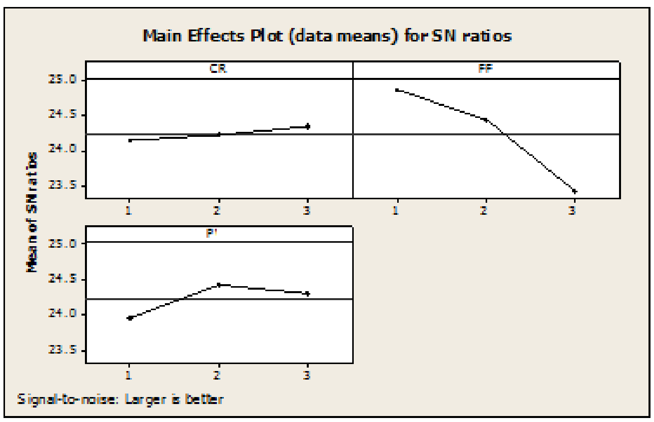

Fig. 2. SN Ratio for BTE of MOME

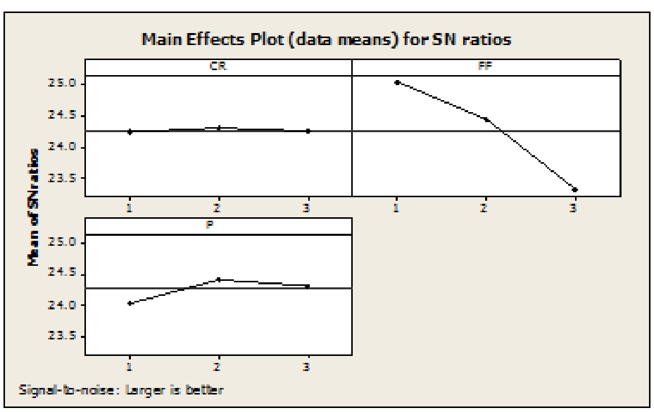

Fig. 3. SN Ratio for BTE of POME

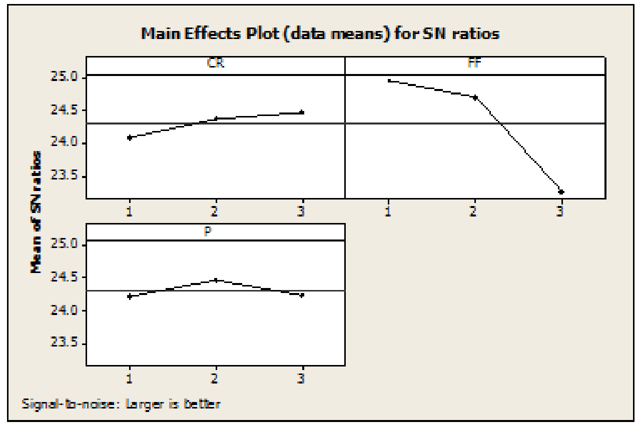

Fig. 4. SN Ratio for BTE of SOME

Considering the higher the better criteria the main effect plat for Brake Thermal efficiency is drawn which is shown in Fig. 1 to Fig 4 From the above fig all the optimize combination for BTE is shown in TABLE VI.Design parameter with subscript indicates the LEVEL- No.

TABLE VI
Optimum combination for Response for BTE

Fuel	CR	FF	P
NOME	CR_3	FF_1	P_2
MOME	CR_3	FF_1	P_2
POME	CR_2	FF_1	P_2
SOME	CR_3	FF_1	P_2

Optimal Performance Parameter BSFC

The signal noise ratio graph for BSFC of NOME, MOME, POME and SOME are shown in Fig. 5 to Fig. 8.

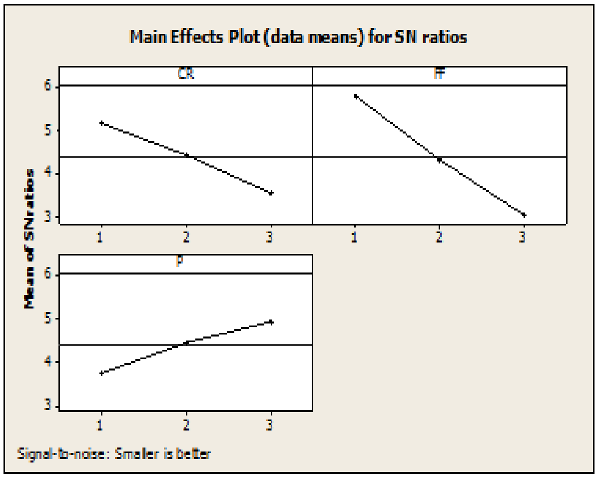

Fig. 5. SN Ratio of BSFC for NOME

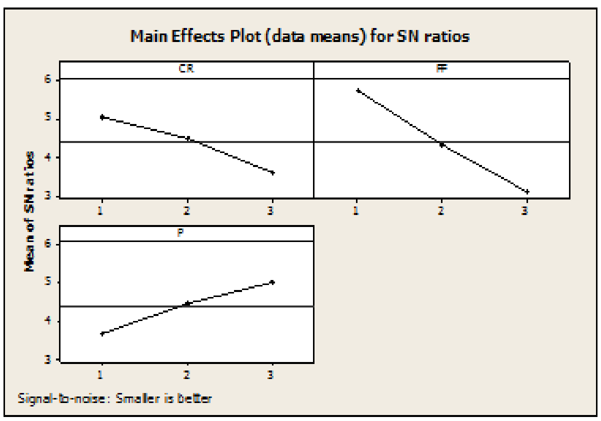

Fig. 6. SN Ratio for BSFC of MOME

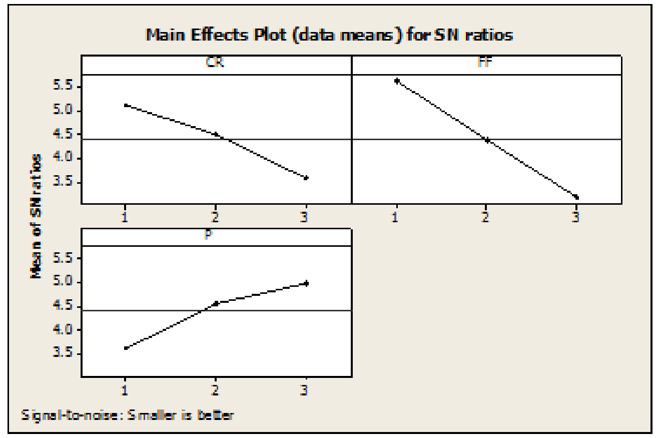

Fig. 7. SN Ratio for BSFC of POME

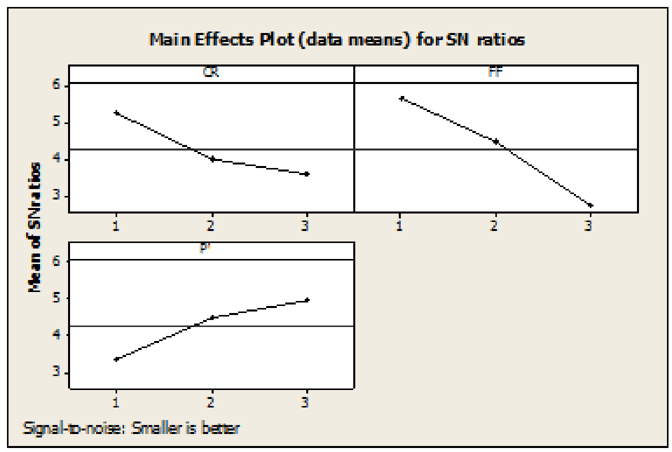

Fig. 8. SN Ratio for BSFC of SOME

Considering the smaller the better criteria the main effect plat for Brake specific fuel consumption is drawn which is shown in Fig. 5 to Fig 8. From the above fig all the optimize combination for BSFC is shown in TABLE- VII.

TABLE VII
Optimum combination for Response of BSFC

Fuel	CR	FF	P
NOME	CR_1	FF_1	P_3
MOME	CR_1	FF_1	P_3
POME	CR_1	FF_1	P_3
SOME	CR_1	FF_1	P_3

Optimal Emission Profile NO_X

The signal to noise ratio graph for NO_x of NOME, MOME, POME and SOME are shown in Fig. 9 to Fig. 12.

Fig. 9. SN Ratio for NO_x of NOME

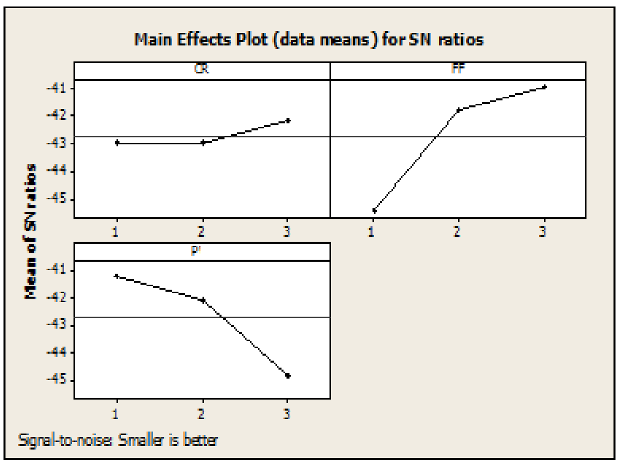

Fig. 10. SN Ratio for NO_x of MOME

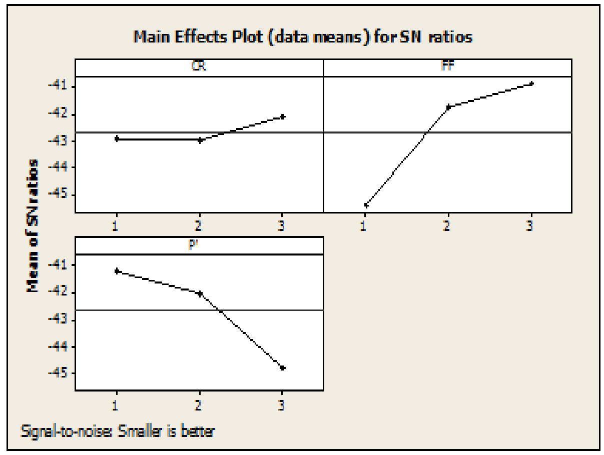

Fig. 11. SN Ratio for NO_x of POME

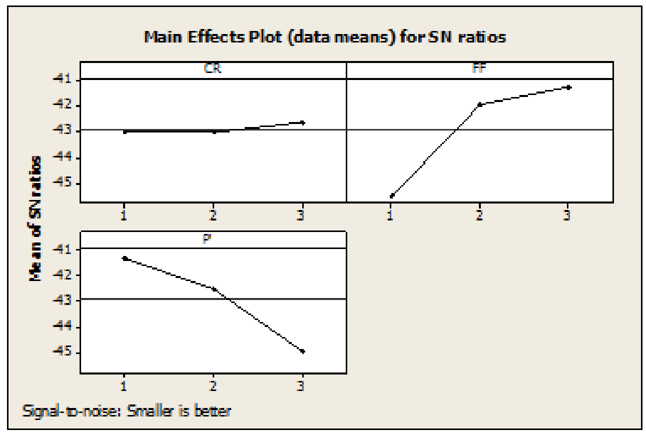

Fig. 12 SN Ratio for NO_x of SOME

Considering the smaller the better criteria the main effect plat for Nitrogen Oxide emission is drawn which is shown in Fig. 9 to Fig 12. From the above fig all the optimize combination for NO_x is shown in TABLE VIII.

Table VIII
Optimum combination for Response of NOx

Fuel	CR	FF	P
NOME	CR_3	FF_3	P_1
MOME	CR_3	FF_3	P_1
POME	CR_3	FF_3	P_1
SOME	CR_3	FF_3	P_1

The above trends of graph can be compared with some of the research articles [11] and [14]-[17].

BTHE, BSFC, … can also be calculated by Regression model. It is a predication model within the influence space, for the response variable BTE, BSFC and NO_xRegression model is given by the above equation. Using the above equation the values of the response variable are calculated and compared with the results. By using Regression Analysis, a mathematical model is developed. Here BHE is taken as output and the process parameter like Compression ratio (C.R), Fuel Fraction (FF) and Load (P) are considered as the input parameter for the developed mathematical model using MINITAB-16as shown below:

$$OPT\ BTE = \bar{Y} + (\bar{A}_3 X\bar{Y}) + (\bar{B}_1 X\bar{Y}) + (\bar{C}_2 X\bar{Y})$$

The experimental value (which was calculated from S to N ratio curve) and the Mathematical Model value (above equation) is compared and the difference is calculated. The difference should be as minimum as possible.

IV. CONCLUSION

The optimisation of engine parameters for Brake Thermal efficiency of NOME, MOME, and SOME were CR-17.9- FF -10 - Load-4kg. For POME the optimisation of engine parameters obtained for BTE was CR-17.7- FF-10 - Load-4 kg. That means BTE increases with increase in CR.

Regarding BSFC the optimisation of engine parameters are CR-17.5, FF-B10-Load 6 kg for all the tested fuels.

For NO_x the optimization values are CR-17.9, FF- 30, and Load- 2 kg for all the tested fuels.

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