OPTIMIZATION OF PERFORMANCE AND EMISSION CHARACTERISTICS OF DUAL FLOW DIESEL ENGINE BY TAGUCHI METHOD

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Abstract

Depleting sources of fossil fuels coupled with after effects of exhaust gases on environment i.e. global warming and climate change has necessitated the need for development and use of alternate biodegradable fuels. In this present study optimization of performance and emission characteristics has been carried out using dual flow of CNG and Diesel with varying EGR under varying load by Taguchi method. Optimum values of output response parameters have been calculated with the help of regression equation and influence of various factors on output response has carried out with the help of analysis of variance.

Keywords: *Taguchi method, CNG, EGR, biodegradable fuels*

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1. INTRODUCTION

The serious impact of global warming, climate change and environmental changes caused by the emission of exhaust gases has forewarned the member countries of more devastating effects on the environment and the need to control the same. With this in mind, the Kyoto Protocol was established in December 1997 which regulated the member countries to emit fewer amounts of green house gases. Since then considerable amount of research is underway throughout the world for evolving alternate sources of fuels to replace the depleting fossil fuels. The review of technical literature has led to development of biodegradable fuels particularly bio diesel or its blend in the existing diesel engines without any modification.

The stiffer regulation of pollution control by the state authorities has resulted in replacing the use of diesel fuel driven vehicles with CNG based vehicles which has greatly helped in reducing the levels of CO, NOx and HC.

In our present study optimization of performance and emission Characteristics has been carried out by using dual flow of CNG and diesel on diesel engine by Taguchi Method.

2. DESIGN OF EXPERIMENT BY TAGUCHI

Dr. Genichi Taguchi of Japan developed a method for designing of experiments using orthogonal arrays with an objective of producing high quality product at low cost by designing experiments incorporating the concepts of designing quality into the process through system design, parameter and tolerance. The concept of signal (product quality) to noise (uncontrollable factors) ratio are log functions based on Larger the better, Smaller the better and Nominal the better are in practice. Out of these larger the better for optimization of brake thermal efficiency and smaller the better for optimization of CO, HC, BSFC and Nox emissions have been used in this investigation. Orthogonal array and selection of factor levels

The unique feature of Taguchi design of experiment is its utilization of orthogonal arrays which gives much reduced variance for experiments and also reduces the number of trials with optimum setting of control parameters. The selection of a suitable orthogonal array depends upon the total degree of freedoms which is defined as the number of comparisons between design parameters.

Degree of freedom, N = (L-1)*P where, P = number of engine operating parameters

The orthogonal array must be selected in such a way such as the number of trials must be equal to the N+1. An orthogonal array L9 containing 9 trials has been selected for this investigation.

Table-1 Process parameters and their levels

Parameters	Levels		
CNG flow rate (	5	10	15
Load (%)	20	60	100
EGR (%)	5	10	15

3. RESULTS AND DISCUSSIONS

The experiment consisting of 9 trials was carried out on the experimental set up based on design of experiment by Taguchi and the results were analyzed using Minitab software. The details of engine performance (BTE) and emission parameters BSFC, CO, Nox and HC have been mentioned in table-2and table-3

Table-2

Sr. No	CNG (LPM)	LOAD (%)	EGR (%)	BTE (%)	BSFC (kg/kw.hr)
1	5	20	5	10.8	0.36
2	5	60	10	24.0	0.26
3	5	100	15	26.0	0.32
4	10	20	10	11.6	0.42
5	10	60	15	24.0	0.22
6	10	100	5	26.0	0.36
7	15	20	15	8.9	0.22
8	15	60	5	25.8	0.24
9	15	100	10	23.9	0.20

Table-3

Sr. No	CNG (LPM)	LOAD (%)	EGR (%)	CO (gm/kw.hr)	Nox (gm/kw.hr)	HC (gm/kw.hr)
1	5	20	5	26.74	13.03	1.363
2	5	60	10	23.20	10.538	0.31
3	5	100	15	126.58	96.85	0.188
4	10	20	10	31.26	7.32	4.30
5	10	60	15	7.71	13.84	0.477
6	10	100	5	101.30	8.896	0.233
7	15	20	15	59.10	7.728	5.962
8	15	60	5	19.80	12.235	0.62
9	15	100	10	23.20	6.12	0.229

Analysis of Output Response

Output responses are represented by Main Effects Plot curves which are pictorial view of variation of each factor and its effect on system performance when a parameter shifts from one level to another. The performance of parameters is measured by the maximum value of S/N ratios and the difference between the highest and lowest value represent Delta. Delta defines the ranking and dominance of parameters on the output response. The regression equation helps to calculate the optimum value and the analysis of variance indicates the variability and the fit of the experiment.

Analysis of Brake Thermal Efficiency verses CNG, Load and EGR

Table-4 Response Table for Signal to Noise Ratios Larger is better

Level	CNG	Load (%)	EGR (%)
1	25.52	20.32	25.73
2	25.73	27.81	25.49
3	24.93	28.06	24.96
Delta	0.80	7.74	0.77
Rank	2	1	3

Table-5: Response Table for Means

Level	CNG	Load (%)	EGR (%)
1	20.27	10.43	20.87
2	20.53	24.60	19.83
3	19.53	25.30	19.63
Delta	1.00	14.87	1.23
Rank	3	1	2

Regression Analysis and analysis of variance: BTE (%) versus CNG, Load (%), EGR (%)

The regression equation is

BTE (%) = 10.9 - 0.073 CNG + 0.186 Load (%) - 0.123 EGR (%)

Table-6

Predictor	Coef	SE Coef	T	P	Effect
Constant	10.928	5.927	1.84	0.125	Non-significant
CNG	-0.0733	0.3588	-0.20	0.846	Non-significant
Load (%)	0.18583	0.04485	4.14	0.009	Non-significant
EGR (%)	-0.1233	0.3588	-0.34	0.745	Non-significant

S = 4.39395 R-Sq = 77.6% R-Sq (adj) = 64.2%

The optimum value of BTE is achieved with CNG at 10 %, Load at 100 % and EGR at 5 % corresponding to maximum value of S/N ratios are 25.73, 28.06 and 25.73 respectively. The optimum value of BTE is calculated from the regression equation by substituting the optimum values of CNG, Load and EGR which comes out to be 11.08.

Optimum value of BTE (%) as per regression equation = BTE (%) = 10.9 - 0.073 CNG + 0.186 Load (%) - 0.123 EGR (%) = 10.9 – 0.073 * 25.73 + 0.186 * 28.06 – 0.123 * 25.73= 11.08

Measuring the fit of our investigation

S = 4.393 R – Sq = 77.6 % R – Sq (AdJ) = 64.2 %

S is the standard error of our results of experiment and is the squared difference of the error in the actual to the predicted values i.e. square root of the mean squared error. The lower the value of S, the stronger is the linear relationship.

R – Sq = 77.6 % represents that almost 77.6 % of the variability in the BTE is explained by the predictors. R – Sq

(Adj) = 64.2 % the version of R – squared that has been adjusted for the number of predictors when more than one independent variables are included. It is slightly lower than R – Sq which indicates that even with the adjustments for more variable, the association is still stronger.

Table-7: Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	334.62	111.54	5.78	0.044
Residual Error	5	96.53	19.31		
Total	8	431.15	2.2090		

Analysis of Brake Specific Fuel Consumption (BSFC) (kg/kw.hr) versus CNG, Load (%) and EGR (%)

Table-8 Response Table for Signal to Noise Ratios, Smaller is better

Level	CNG	Load (%)	EGR
1	0.3133	0.3333	0.3200
2	0.3333	0.2400	0.2933
3	0.2200	0.2933	0.2533
Delta	0.1133	0.0933	0.0667
Rank	1	2	3

Table-9: Response Table for Means

Level	CNG	Load (%)	EGR (%)
1	10.157	9.854	10.048
2	9.854	12.416	11.072
3	13.176	10.917	12.067
Delta	3.322	2.562	2.019
Rank	1	2	3

Regression Analysis and analysis of variance: BSFC (kg/kw.hr) versus CNG, Load (%), EGR (%)

The regression equation is

BSFC (kg/kw.hr) = 0.479 - 0.00933 CNG - 0.000500 Load (%) - 0.00667 EGR (%)

S = 0.0731513 R-Sq = 45.3% R-Sq (Adj) = 12.4%

Table-10

Predictor	Coef	SE Coef	T	P	Effect
Constant	0.47889	0.09867	4.85	0.005	Significant
CNG	-0.009333	0.005973	-1.56	0.179	Non-significant
Load (%)	-0.0005000	0.000746	-0.67	0.533	Non-significant
EGR (%)	-0.006667	0.005973	-1.12	0.315	Non-significant

Table-11: Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.022133	0.007378	1.38	0.351
Residual Error	5	0.026756	0.005351		
Total	8	0.048889	2.2090		

Results

- CNG plays a dominant role in achieving lower BSFC followed by Load and EGR.
- Optimum value of BSFC is achieved with CNG at 15 %, Load at 60 % and EGR 15 % corresponding to maximum values of S/N ratios are 13.176, 12.416 and 12.067
- Optimum value of BSFC is calculated by regression equation and is 0.273 kg/kw.hr
- Larger the value of p (> 0.05, 5% confidence level) suggests the changes in predictor values are not associated with changes in the response values i.e. the predictors are not significant
- Smaller value of standard error, S indicates a stronger linear relationship
- Large values of R -Sq and R – Sq (Adj) indicates poor fit

Analysis of CO (gm/kw.hr) versus CNG, Load (%), EGR (%)

Table-12 Response Table for Signal to Noise Ratios Smaller is better

Level	CNG	Load (%)	EGR (%)
1	-19.82	-19.12	-21
2	-19.70	-21.68	-17.83
3	-18.42	-17.14	-19.10
Delta	1.41	4.53	3.18
Rank	3	1	2

Table-13: Response Table for Means

Level	CNG	Load (%)	EGR (%)
1	-19.82	-19.12	-21
2	-19.70	-21.68	-17.83

3	-18.42	-17.14	-19.10
Delta	1.41	4.53	3.18
Rank	3	1	2

Regression Analysis and analysis of variance: CO (gm/kw.hr) versus CNG, Load (%), EGR (%)

The regression equation is

CO (gm/kw.hr) = 22.7 - 2.48 CNG + 0.558 Load (%) + 1.52 EGR (%)

S = 42.9884 R-Sq = 31.6% R-Sq (adj) = 0.0%

Table-14

Predictor	Coef	SE Coef	T	P	Effect
Constant	22.67	57.99	0.39	0.712	Non-significant
CNG	-2.481	3.510	-0.71	0.511	Non-significant
Load (%)	0.5582	0.4387	1.27	0.259	Non-significant
EGR (%)	1.518	3.510	0.43	0.683	Non-significant

Table-15: Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	4261	1420	0.77	0.559
Residual Error	5	9240	1848		
Total	8	13501	2.2090		

Results

- Load plays a dominant role in achieving lower CO followed by EGR and CNG.
- Optimum value of CO is achieved with CNG at 10 %, Load at 60 % and EGR 10 % corresponding to maximum values of S/N ratios are -29.25, -23.66 and -28.17
- Optimum value of CO is calculated by regression equation and is 39.22 gm/kw.hr
- Higher value of standard error, S indicates a poor linear relationship
- Lower values of R -Sq and R – Sq (Adj) indicates poor fit

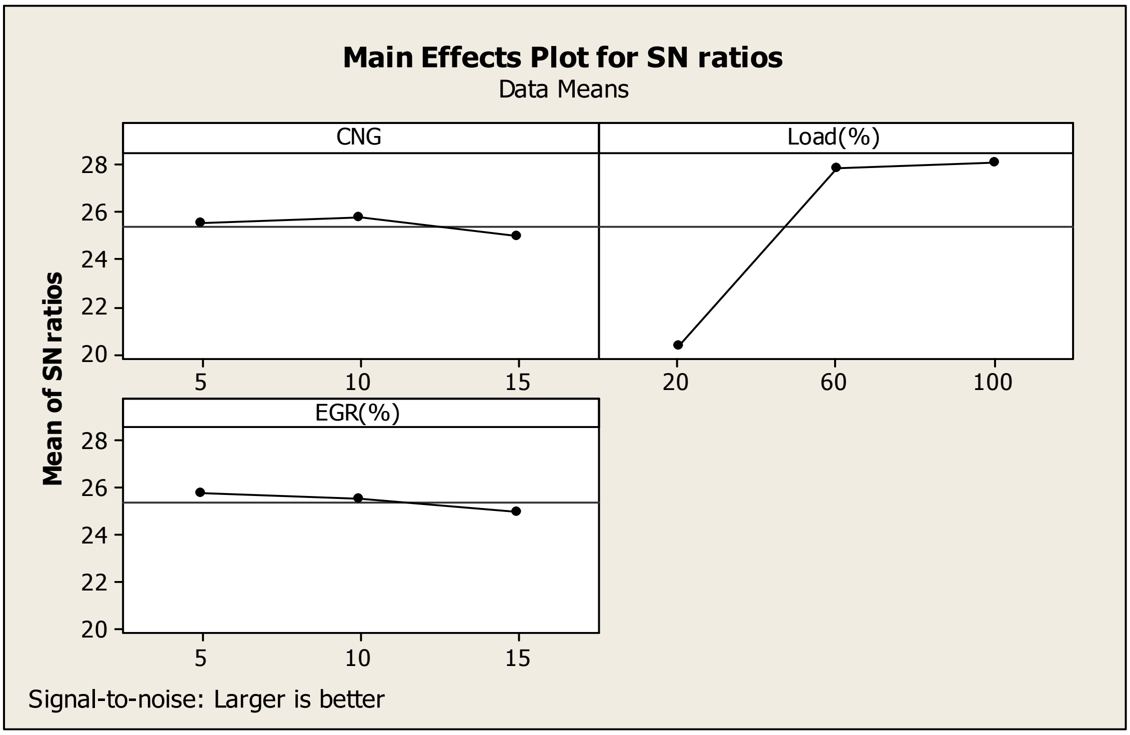

Fig-1 Brake thermal efficiency verses CNG, Load and EGR

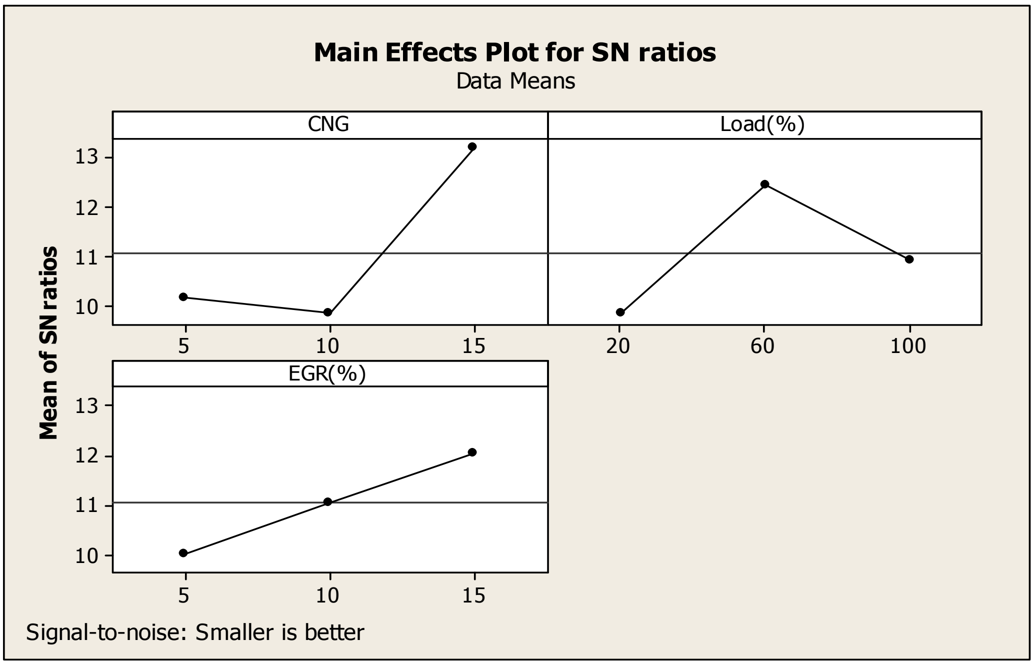

Fig-2 BSFC verses CNG, Load and EGR

Analysis of Nox (gm/kw.hr) versus CNG, Load (%), EGR (%)

Table-16: Response Table for Signal to Noise Ratios Smaller is better

Level	CNG	Load (%)	EGR (%)
1	-32.63	-31.29	-31.53
2	-29.25	-23.66	-28.17
3	-29.56	-36.49	-31.74
Delta	3.38	12.83	3.57
Rank	3	1	2

Table-17: Response Table for Means

Level	CNG	Load (%)	EGR (%)
1	10.139	9.359	11.387
2	10.019	12.204	7.993
3	8.694	7.289	9.473
Delta	1.445	4.916	3.394
Rank	3	1	2

Table-18

Predictor	Coef	SE Coef	T	P	Effect
Constant	14.530	4.324	3.36	0.020	Significant
CNG	-0.1445	0.2617	-0.55	0.605	Non-significant
Load (%)	-0.02588	0.03272	-0.79	0.465	Non-significant
EGR (%)	-0.1914	0.2617	-0.73	0.497	Non-significant

Regression Analysis and analysis of variance: Nox (gm/kw.hr) versus CNG, Load (%), EGR (%)

The regression equation is

Nox (gm/kw.hr) = 14.5 - 0.145 CNG - 0.0259 Load (%) - 0.191 EGR (%)

S = 3.20542 R-Sq = 22.7% R-Sq (adj) = 0.0%

Table-19: Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	15.06	5.02	0.49	0.705
Residual Error	5	51.37	10.27		
Total	8	66.43	2.2090		

Results

- Load plays a dominant role in achieving lower Nox followed by EGR and CNG.
- Optimum value of Nox is achieved with CNG at 10 %, Load at 100 % and EGR 10 % corresponding to

maximum values of S/N ratios are -18.42, -17.14 and -17.83

- Optimum value of Nox is calculated by regression equation and is 21.02 gm/kw.hr
- Lower value of standard error, S indicates a stronger linear relationship
- Large values of R -Sq and R – Sq (Adj) indicates poor fit

Analysis of HC (gm/kw.hr) versus CNG, Load (%), EGR (%)

Table-20 Response Table for Signal to Noise Ratios Smaller is better

Level	CNG	Load (%)	EGR (%)
1	7.3332	-10.2890	4.7050
2	2.1377	6.9182	3.4356
3	0.4825	13.3243	1.8129
Delta	6.8507	23.6134	2.8922
Rank	2	1	3

Table-21: Response Table for Means

Level	CNG	Load (%)	EGR (%)
1	0.6203	3.8750	0.7387
2	1.6700	0.4690	1.6130
3	2.2703	0.2167	2.2090
Delta	1.6500	3.6583	1.4703
Rank	2	1	3

Table-22

Predictor	Coef	SE Coef	T	P	Effect
Constant	1.144	1.763	0.65	0.545	Non-significant
CNG	0.1650	0.1067	1.55	0.183	Non-significant
Load (%)	-0.04573	0.01334	-3.43	0.019	Significant
EGR (%)	0.1470	0.1067	1.38	0.227	Non-significant

Regression Analysis and analysis of variance: HC (gm/kw.hr) versus CNG, Load (%), EGR (%)

The regression equation is

HC (gm/kw.hr) = 1.14 + 0.165 CNG - 0.0457 Load(%) + 0.147 EGR(%)

S = 1.30705 R-Sq = 76.2% R-Sq (adj) = 62.0%

Table-23: Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	27.402	9.134	5.35	0.051
Residual Error	5	8.542	1.6130		
Total	8	35.944	2.2090		

Results

- Load plays a dominant role in achieving lower HC followed by CNG and EGR.
- Optimum value of HC is achieved with CNG at 5 %, Load at 100 % and EGR 5% corresponding to maximum values of S/N ratios are 7.33, 23.61 and 4.70
- Optimum value of Nox is calculated by regression equation and is 1.96 gm/kw.hr
- Lower value of standard error, S indicates a stronger linear relationship
- Higher values of R -Sq and R – Sq (Adj) indicates stronger fit

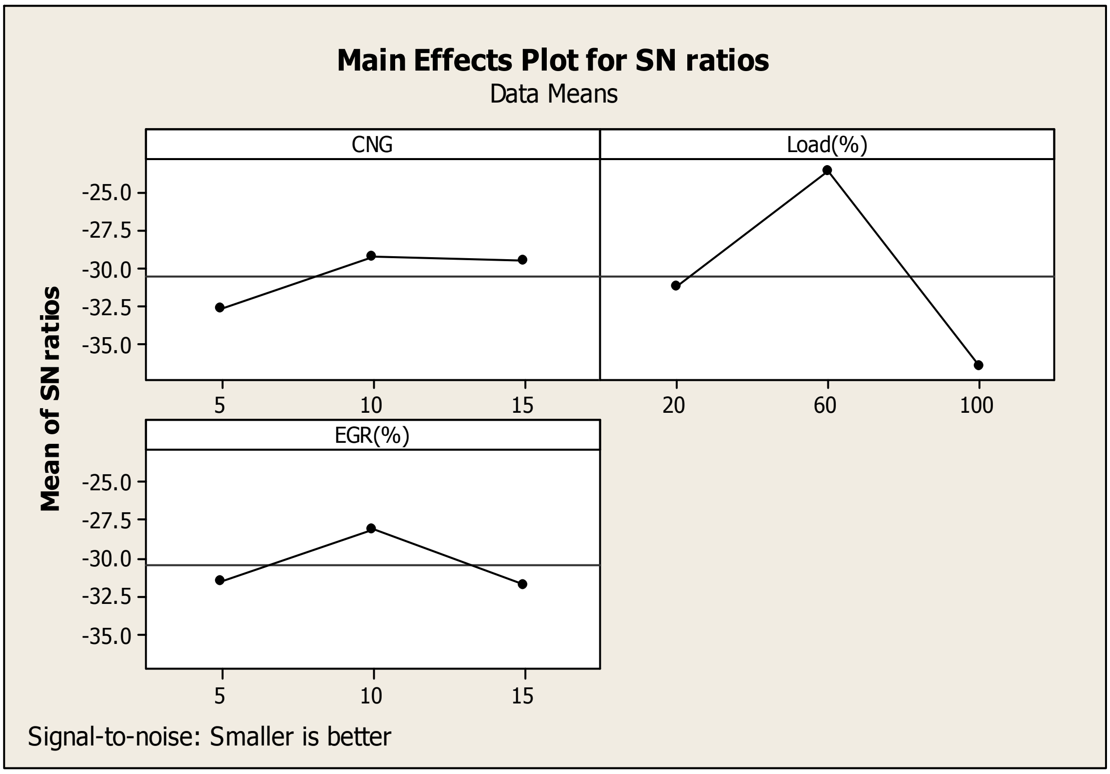

Fig-3 CO (gm/kw.hr) versus CNG, Load

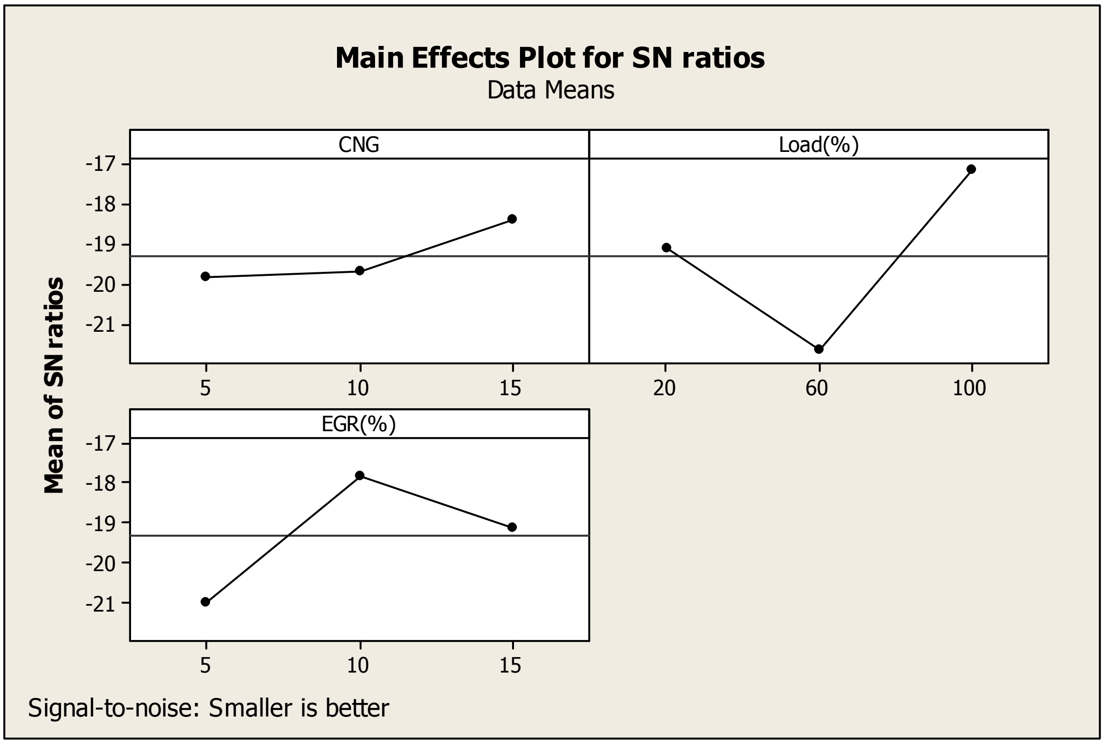

Fig-4 Nox verses CNG, Load and EGR

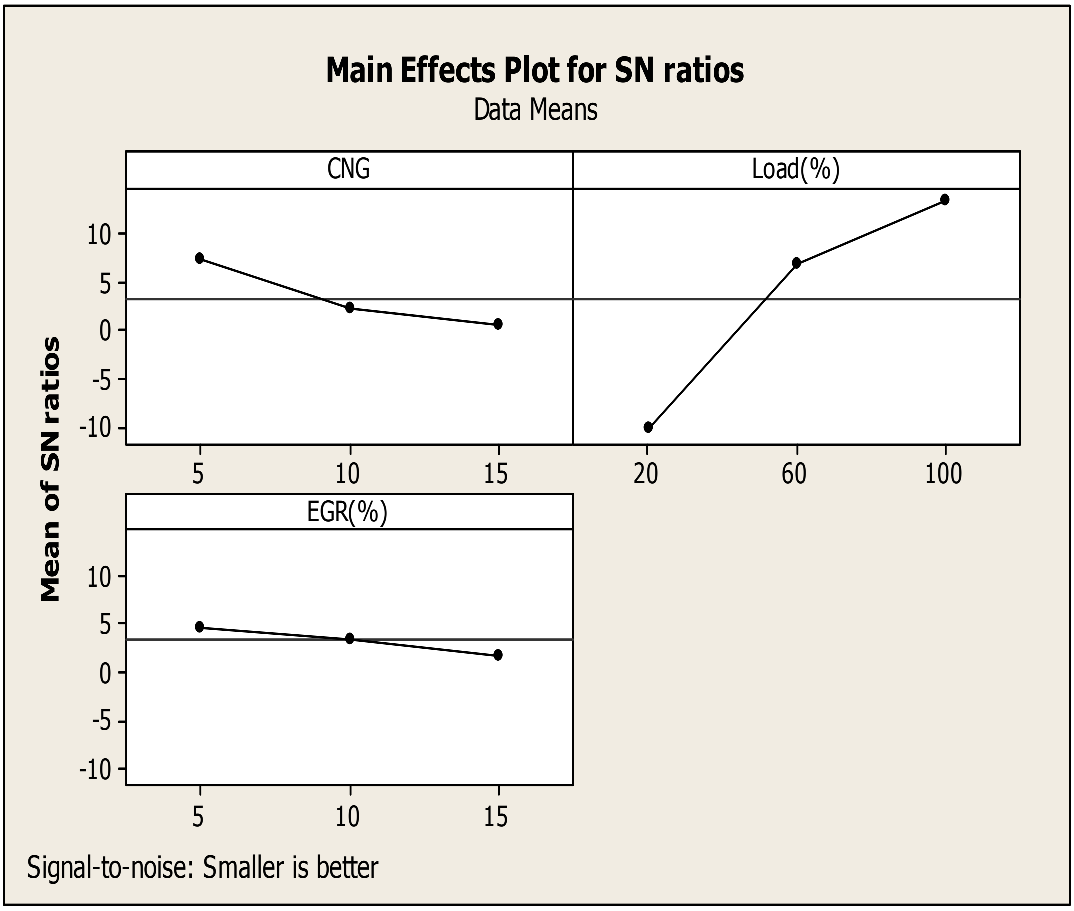

Fig-5 HC verses CNG, Load and EG

4. CONCLUSION

The present study has been carried out with an objective of assessing the performance and emission characteristics of C I engine using CNG alternative fuel.

Following conclusions have been observed:

- It has been observed that effect of all the three parameters i.e. CNG, Load and EGR are insignificant on BTE as main purpose of using CNG was to control emission.
- As has been observed that CNG plays a dominant role in achieving lower BSFC followed by Load and EGR which satisfies our presumption.
- As regards to CO emissions, experimental results indicate larger value of p (> 0.05, 5% confidence level) which suggests that the changes in predictor values are not associated with changes in the response values i.e. the predictors are not significant.
- With regard to HC emissions, our results show lower value of P (< 0.05, s & confidence level) which suggest that changes in predictor influences the output response and null hypothesis is rejected that there is no change in the output from the predefined value and Larger the value of p (> 0.05, 5% confidence level) suggests the changes in predictor values are not associated with changes in the response values i.e. the predictors are not significant
- Lower value of P (< 0.05, s & confidence level) suggest that changes in predictor influences the output response of Nox and null hypothesis is rejected that there is no change in the output from the predefined value and Larger the value of p (> 0.05, 5% confidence level) suggests the changes in predictor values are not associated with changes in the response values i.e. the predictors are not significant

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