Mathematical Modeling of NOX for SI Engine Working with Petrol-Ethanol Blend

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Abstract— Today, the trend of decreasing sources of petroleum fuel so it's prime need to innovate other resources such as alternative fuel which can be produced from biomass such as alcohol. This experiment was performed to investigate the effects of Petrol-ethanol blend on gasoline engine exhaust emissions. A four stroke, single cylinder Multi-fuel, research Engine is to be tested by different range of ethanol volume percentages i.e. 5% (E05), 10% (E10), 15% (E15) blended with fossil gasoline. The experiment is to be carried out at variations of engine Load and Compression Ratio. From the analysis of data, selected sets of parameters is to be achieved by Design of Experiments. The purpose of the experiment is to analyse the pollutant emissions of a Single Cylinder four stroke, Petrol engine.

Key words: Petrol, Ethanol, Blended fuel, Engine performance, Emissions

I. INTRODUCTION

Depleting fossil fuel reserves and continuously increasing cost of the petroleum products is the big troubles of today's world. Researchers are continuously finding the best alternative solution, which gives maximum efficiency and fuel characteristics. The research is about gasoline and ethanol blend. Different methods and techniques are applied to reduce the emissions. One such method is blending ethanol in gasoline. Due to incomplete combustion of fuel and due to lack of oxygen in combustion most of the emissions are formed, gasoline has no oxygen content and Oxygen for combustion is derived from the intake air. Thus, secondary oxygen is supplied through ethanol blended in gasoline as ethanol.

II. LITERATURE REVIEW

Hsieh et al. (2002) did research on Engine performance and pollutant emission of an SI engine using ethanol–gasoline blended fuels. The aim of this study is to experimentally investigate the engine performance and pollutant emission of a commercial SI engine using ethanol–gasoline blended fuels with various blended rates (0%, 5%, 10%, 20%, 30%).Experimental Outcomes indicated that using ethanol–gasoline blended fuels, NOx emission is closely related to the equivalence ratio in such way that NOx emission reaches a maximum near the stoichiometric condition; and that NOx emission depends on the engine operating condition rather than the ethanol content.(Hsieh, Chen, Wu, & Lin, 2002).

Manikandan et al. (2013) had studied The Effect of Gasoline–Ethanol Blends and Compression Ratio on SI Engine Performance and Exhaust Emissions. In this research the effects of gasoline-ethanol blends(E10,E20 and E30) and two different compression ratio(6:1 and 8:1) on single cylinder four stroke air cooled variable compression ratio SI engine have been experimentally tested From the experimental outcomes, it was determined that. Upto30 percent of ethanol blending with gasoline reduces NOx emissions. At higher compression ratio(8:1) the power output increases 15% and SFC decreases5% for E30 fuel compared to when the engine operate at lower compression ratio(6:1) with E0 fuel E30 fuel operate with higher compression ratio(8:1),the NOx emission increases. (Manikandan, 2013)

Argakiotis et al., in this Paper Effect of using an Ethanol blended fuel on Emissions in an SI Engine is shown. The Authors concluded that the blend E30 slight increment in the engine's torque and power after mid-engine speeds together with fuel consumption. exhaust emissions at 25% open throttle sees nitrogen oxide (NO_X) emissions increase at the lower speeds.(Argakiotis, Mishra, Stubbs, & Weston, 2014)

Vadivel et al. (2014) did Experimental Investigation on the Performance and Combustion Characteristics of a Gasoline Engine run with Ethanol Blend. From the study, it is concluded that Using of ethanol blended gasoline leads to a significant reduction in exhaust emissions. For all engine speeds the values of NOx has been reduced. It is also concluded that.The NOx emission is 582 ppm for E40+A10 at 2600 rpm. (Vadivel, 2014)

Aydoğan et al.(2015) did research on A Study of the Effects of Bioethanol-Gasoline Blends on Vehicle Emissions. In this study, bioethanol produced from sugar beet was used as a blending component. Gasoline-bioethanol blends containing 2% and 5% ethanol by volume were used as fuel in a gasoline engine vehicle and 95 octane gasoline was accepted as the control fuel. NOx emission values of E2 and E5 blends at low speeds were observed to be generally higher compared to gasoline. NOx emission values obtained through using E2 decreased at rates exceeding 20% at low and high speeds. NOx emission values measured in the exhaust gases as the result of using E5 blend showed a decrease at high speeds. It is inevitable that the amount of NOx in the exhaust gas increases due to the increase in the amount of oxygen taken into the cylinder, because bioethanol fuel contains oxygen. At high vehicle speeds, NOx values obtained as the result of the use of ed gasoline were found to be 20-50% higher when compared to E2 and E5 blends.(Aydoğan & Acaroğlu, 2015)

III. ETHANOL

A. Introduction

Ethanol is also known as ethyl alcohol or C_2H_5OH .Ethanol is a renewable, domestically produced alcohol fuel made from plant material like corn, sugar cane, or grasses. Using ethanol can reduce oil dependence and greenhouse gas emissions. Ethanol is produced from biomass. mostly via a fermentation process using glucose derived from sugars, starch or cellulose (forest products) as raw materials. In this formation, it is renewable. Synthetic ethanol can also be produced from non-renewable sources like coal and gas.Etahnol is extracted by using Dry or Wet Milling Methods.

B. Ethanol In India's Automobile Sector

The Government of India's policy mandating 5 percent ethanol blending in petrol is currently being implemented in the country. A significant target of minimum 20 percent ethanol-blended petrol across the country has been set for the year 2017. The preparedness of the automobile industry is a major Part in the successful implementation of this policy, given the fact that petrol-run vehicles account for the majority of vehicles registered in India.

IV. MATERIAL AND METHOD

A. Response Surface Methodology

Minitab software includes four types of designed experiments: (1) factorial, (2) response surface, (3) mixture, and (4) Taguchi. The procedure to get an experimental design with graphs is same for all types of design. Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. By using design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables).The selected process variables were varied up to three levels and Box-Behnken design was adopted for developing the experiments. Response Surface Methodology was used to develop second order regression equation relating response characteristics and process variables.

1) Selection Of The Experimental Design, And Prediction And Verification Of Model Equation

Experimental design is generated as per selection of experimental points, number of runs and blocks. Then the model equation is defined and coefficients of the model equation are predicted. To understand the whether the model is making a good prediction, the test data and the predicted data are compared with each other. In order to compare these data the statical method of root mean square error (RMSE) and coefficient of multiple determination (R^2) values are used. These values are determined by following equation:

(1) RMSE = $[1/n\sum_{j=1}^{n} |aj - pj|2\ ]^{1/2}$

(2) $R^2 = 1 - |\sum_{j=1}^{n} |aj - pj|2\ ]/ \sum_{j=1}^{n} |pj|2|$

Where, aj =Experimental Specific consumption
pj = Predicted Specific consumption

B. Ethanol-Petrol Properties

Fuel Properties	Gasoline	Ethanol
Density [kg/m^3] at 15^{0}C	765	788
Specific Gravity	0.737	0.788
Gross Calorific Value [KJ/kg] at 15ºC	44000	29421
Octane number (RON)	97	108
Stoichiometric AFR [kg air/kg fuel]	14.7	9.0
Viscosity [CP]	0.6	1.093
Reid Vapour Pressure [psi]	10.877	2.30

Table 1: Fuel Properties

C. Experimental Setup

The setup consists of single cylinder, four stroke, Multi-fuel, research Engine connected to the Eddy Current dynamometer. The engine is to be tested by a different range of ethanol volume percentages. i.e. 05% (E05), 10% (E10) and 15% (E15) blended with fossil gasoline. The experiment is to be carried out at variations of Load and Compression Ratio. The Load of 1, 5, and 9 NM and Compression ratio 7, 8 and 9 were to be experimented. It contains selected sets of parameters, are to be achieved by Box-Behnken. Conduct experiment for optimum set of parameters and compare experimental value and predicated value.

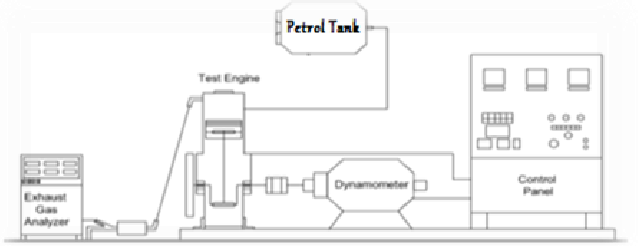

Fig. 1:

Engine Model	TV1
Make	Kirlosker Oil Engines
Type	Four stroke, Water cooled, Diesel-Petrol
No. of cylinder	One
Bore	87.5 mm
Stroke	110 mm
Compression ratio	12 to 18
Power rating	7.5 HP
Injection timing	$\leq 25^0$ BTDC

Table 2: Test Engine With its Specifications

By using Minitab-17 software, insert the 3 factors with 3 Level in Response Surface Method of Box- Behnken got the following design of steps to perform experiment.

- Box-Behnken Design L15 (3*3)
- Factors: 3
- Runs: 15

Factors	Level 1	Level 2	Level 3
Compression Ratio	7	8	9
Blend Ratio	5	10	15
Load	1	5	9

Table 3: Experiment Set Table

V. RESULTS & DISCUSSION

Engine was started with zero Load condition and run for few minutes to reach normal working condition. After reached steady running condition, fuel supply source for engine changed from fuel tank to measuring burette by closing the knob availed in the setup. Data such as Specific fuel consumption, torque applied and exhaust temperature were recorded.

The analysis experiments were performed, with the process parameter levels set as given in Table 4.3; Experimental results for NOx are given in Table 5.1.Mainly 15 experiments were conducted using response surface methodology.

RUN	Variable properties			NOx
	Compression Ratio	Blend Ratio	Load	(ppm)
1	7	10	1	26
2	8	10	5	29
3	8	5	1	8
4	8	15	9	110
5	9	10	1	2
6	8	5	9	51
7	9	15	5	39

8	8	10	5	29
9	9	5	5	91
10	9	10	9	125
11	8	15	1	3
12	8	10	5	29
13	7	5	5	60
14	7	10	9	102
15	7	15	5	39

Table 4: Experimental Layout of BBD and Its Observed Values of NOX

The second-order polynomial models used to express the NOx as a function of independent variables (Eq. 5.1) is shown below in terms of coded level:

$$NOx=29+7.5*X1-2.375*X2+43.625*X3+98*X1*X1+3.75*X2*X2+10.25*X3*X3-15.5*X1*X2+23.5*X1*X3+16*X2*X3 \quad \ldots\ldots(5.1)$$

Below table 5.2 shows the value of R2 and RMSE from target and predicted value of NOx. Here error is show the difference between the target and predicted value of NOX.

RUN	NOx	Predicted NOx	Error	R^2	RMSE
1	26	109.625	-83.6250		
2	29	29	0.00000		
3	8	17.75	-9.75000		
4	110	100.25	9.75000		
5	2	77.625	-75.6250		
6	51	73	-22.0000		
7	39	120.375	-81.3750		
8	29	29	0.00000	0.7330	55.58
9	91	156.125	-65.1250		
10	125	211.875	-86.8750		
11	3	19	-16.0000		
12	29	29	0.00000		
13	60	110.125	-50.1250		
14	102	149.875	-47.8750		
15	39	136.375	-97.3750		

Table 5: Target vs. Predicted NOX

Here error is show the difference between the targeted and predicted value of NOx. The value of R2 and RMSE are calculated by equation (1) and (2). The value of R2 is 0.733016 which are close to the 1 and the value of RMSE is 55.58132. So, the model is making a good prediction.

A. Comparison of Results

The predicted value of NOx of model was compared with the actual target value of experiment which is shown in Fig 5.1 by different colours. It is clear from graph that predicted results are very close to actual target values. It also concludes that model has good prediction capability.

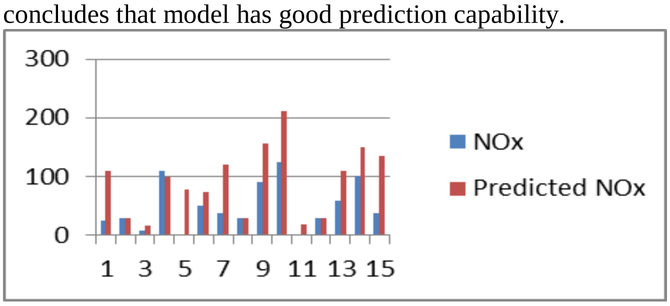

Fig. 2: Experimental & Predicted NOx

The errors of the experiments are shown in Fig. 5.2, which are above and below the 0 value. Which indicate the good prediction of NOx Model with respect to experimental data.

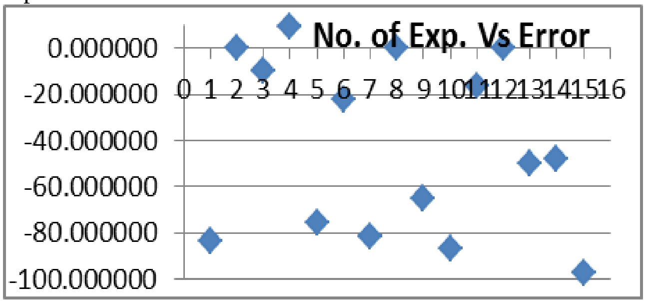

Fig. 3: Experiments vs Error

Fig. 5.3 shows the experimental versus predicted NOx obtained from Eq. (5.1). A linear distribution in figure indicates well-fitting of model. The values predicted from Eq. (5.1) were close to the observed values of NOX.

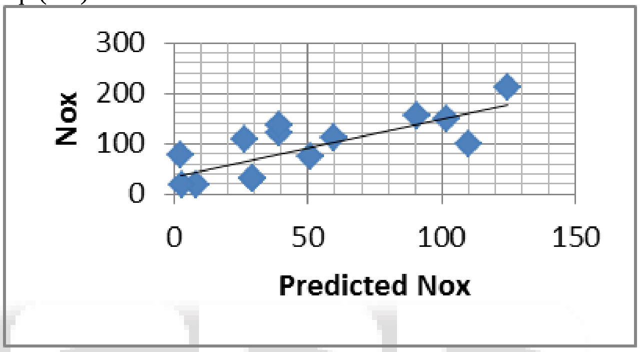

Fig. 4: Experimental vs Predicted NOX

The normal probability plot is also presented in Fig.5.4.The plot indicates that the residuals (difference between actual and predicted values) follow a normal distribution and form an approximately straight line.

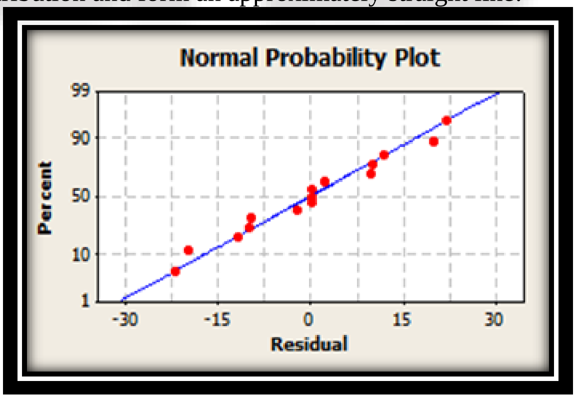

Fig. 5: Normal Probability of Residuals

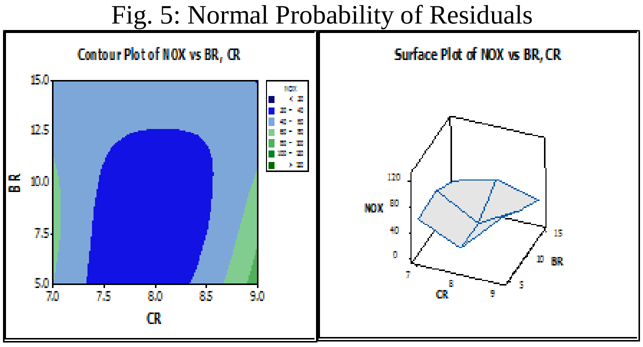

Fig. 6: Contour and Surface Plots of NOx Vs CR, BR from Minitab

Surface and contour plots for NOx show the effect of different parameters on NOX. This Graph shows effect of two parameters while holding other one parameters at constant for one combination. The hold values are also shown in each figure.

The effect of BR and CR on NOx is shown in Fig. 5.5 It shows that, at lower BR ratio and CR is at 8, Nox is to be minimum. But ,At higher CR ratio and BR ,NOx is to be Maximum.

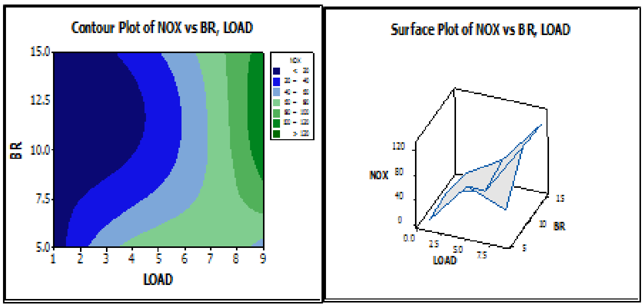

Fig. 7: Contour and Surface Plots of NOx Vs BR, LOAD from Minitab

The effect of BR and Load on NOX is shown in Fig. 5.6. It shows that when Load and BR are minimum, NOx is to be minimum. But, when Load and BR is maximum, NOx is to be maximum.

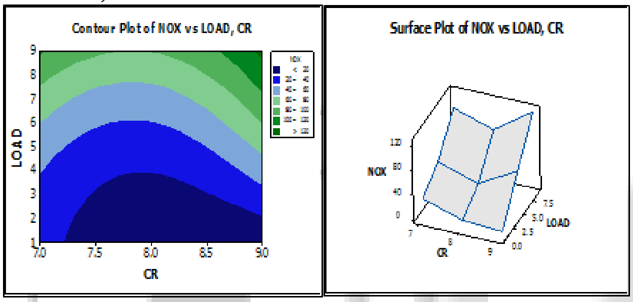

Fig. 8: Contour and Surface Plots of NOX vs Load, CR from Minitab

The effect of Load and CR on NOx is shown in Fig. 5.7. It shows that NOx is mainly affected by Load. When Load is to increase, NOx is also to be increase.

Below table 5.3 show the all possible combination of input variables (% of Ethanol, compression ratio, Load) and NOx related to them.

Sr No.	CR	BR	Load	Predicted NOX
1	7	5	1	116.25
2	7	5	5	110.125
3	7	5	9	124.5
4	7	10	1	109.625
5	7	10	5	119.5
6	7	10	9	149.875
7	7	15	1	110.5
8	7	15	5	136.375
9	7	15	9	182.75
10	8	5	1	17.75
11	8	5	5	35.125
12	8	5	9	73
13	8	10	1	4.375
14	8	10	5	29
15	8	10	9	82.875
16	8	15	1	19
17	8	15	5	30.375
18	8	15	9	100.25
19	9	5	1	115.25
20	9	5	5	156.125
21	9	5	9	217.5
22	9	10	1	77.625
23	9	10	5	134.5
24	9	10	9	211.875
25	9	15	1	47.5
26	9	15	5	120.375
27	9	15	9	213.75

Table 6: show the all possible combination of input variables and NOx related to them

The optimum value set is shown by different color in table 5.3 and given below output of experiment.

– Optimum set of NOx for this experiment is 4.375 ppm when compression ratio, Blend Ratio and Load are at 8, 10 and 1 kg.

VI. CONCLUSION

The present investigation aimed at Exhaust Effect 0n NOx for SI engine. This analysis is carried out by developing Experiment models based on L15 BBD array in Response surface optimization technique. Model for Experiment prediction draws the following conclusions.

It has been proved that predicted NOx values are closer to the experimental results. It has been also conclude that the RSM may be used as a good alternative for the analysis of the effects on engine exhaust emission. And Load is the significant variable in this experiment.

Optimum set of NOx for this experiment is 4.375 ppm when compression ratio, Blend Ratio and Load are at 8, 10 and 1 kg.

VII. SCOPE OF WORK

In our experimental work, it was optimized parameters for minimizing NOx also prove the possibility of ethanol as fuel in the blend for a petrol engine.

– The effect of emulsifier like octanol with the blend of ethanol and petrol, the performance and emission characteristics of petrol engine can be checked.
– Extensive studies on nozzle flow and atomization characteristics of blending of petrol and ethanol in the S.I engine.
– Extensive studies on EGR (exhaust gas recirculation) using a blend of petrol and ethanol.

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