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Optimization of SFC Using Mathematical Model Based On RSM for SI Engine Fueled with Petrol-Ethanol Blend

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Abstract : *Due to the carbon residue and smoke opacity emission, automotive sector is one of the major contributors to air pollution and global warming. Today, the trend of decreasing sources of petroleum fuel it is require to innovate other resources such as alternative fuel which can be produced from biomass such as alcohol which is produced by fermentation of sugar, cane and corn. This experiment was performed to investigate the effects of Petrol-ethanol blend on gasoline engine performances. 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 performance of a Single Cylinder four stroke, Petrol engine.*
Keywords: *Petrol, Ethanol, Blended fuel, Engine performance, Parameters*

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

K. Manikandan et al., studied the effect of Gasoline –Ethanol Blends and Compression Ratio on SI Engine Performance and Exhaust Emissions. Results showed that Upto30% of ethanol blending with gasoline reduces the CO, CO2, HC and NOx emissions. Power output increases 4% and SFC increase about13% for E30 fuel at a compression ratio (6:1).

C.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. However, exhaust emissions at 25% open throttle sees a decrement of carbon monoxide (CO), carbon dioxide (CO2) and hydrocarbons (HC) whilst nitrogen oxide (NOX) emissions increase at the lower speeds.

A Y F Bokhary et al., gives an technical report on experimental Investigations on the Utilization of Ethanol-Unleaded Gasoline Blends on SI Engine Performance and Exhaust Gas Emission resulted in increase in Engine performance with using ethanol additive to gasoline, where the maximum increment in brake power, brake thermal efficiency, volumetric efficiency, brake torque and brake mean effective pressure were found to be higher than pure gasoline by about 11.06 %, 18.16 %, 1.54 %, 11.99 % and 11.99 % respectively.

Lim Soo King et al., did research on Performance and Emission Analysis of Ethanol-Gasoline Blended Fuel. . Results indicated that Ethanol-gasoline blended fuel (E5, E10, E15, and E20) has reduced CO and UHC emission up to 72.1 % and 58.1% respectively as compared to gasoline (RON 95).

S. Vanangamudi et al.,Shows Gasoline Ethanol Blends on Performance and Emission in Gasoline Engine. Authors concluded that most of the emissions are formed due to incomplete combustion of fuel due to lack of oxygen in combustion, gasoline has no oxygen content, as Oxygen for combustion is derived from the intake air, excess oxygen is supplied through ethanol blended in gasoline as ethanol.

III. Ethanol

3.1 Introduction

Ethanol is also known as ethyl alcohol or C2H5OH .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.

3.2 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

4.1 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.

4.1.1 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 specified and coefficients of the model equation are predicted. The test data and the predicted data are compared with each other to understand the whether the model is making a good prediction. 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

4.2 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

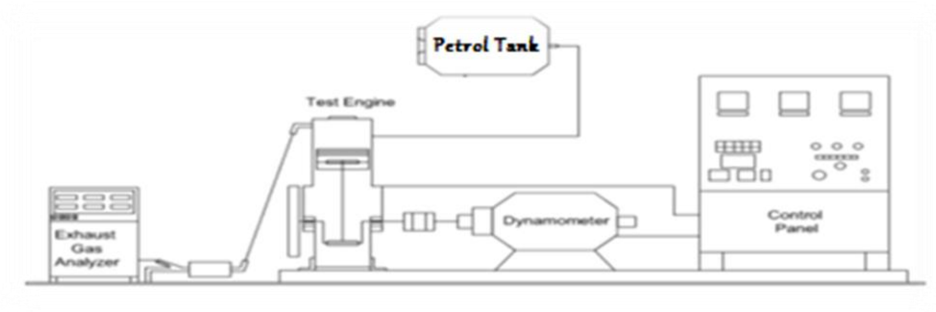
Table 4.1 Fuel Properties Comparison

4.3 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 control parameter for optimization of blend proportion from the analysis of data, 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.

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	≤ 25^0 BTDC

Table 4.2 Test Engine 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 4.3 Experiment Set Table

V. Results & Discussion

The Engine was started with zero load condition and run for a few minutes to reach normal working condition. After reaching 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 was recorded. The analysis experiments were performed, with the process parameter levels set as given in Table 4.3; Experimental results for Specific fuel consumption are given in Table 5.1.Mainly 15 experiments were conducted using response surface methodology.

RUN	**Variable properties**			**SFC**
	Compression Ratio	Blend Ratio	Load	
1	7	10	1	2.528217088
2	8	10	5	0.539357731
3	8	5	1	2.442624629
4	8	15	9	0.361972301
5	9	10	1	2.353724491
6	8	5	9	0.316649339
7	9	15	5	0.571056897
8	8	10	5	0.539357731
9	9	5	5	0.501234957
10	9	10	9	0.391657562
11	8	15	1	2.66600209
12	8	10	5	0.539357731
13	7	5	5	0.610855272
14	7	10	9	0.420746882
15	7	15	5	0.629435651

Table 5.1: Experimental Layout of BBD and Its Observed Values of SFC.

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

SFC=0.53936-0.0929*A4+0.04464*B4-1.06244*C4+0.03112*A4*A4+0.03101*B4*B4+0.87645*C4*C4+0.02562*A4*B4+0.0727*A4*C4+-0.04451*B4*C4……………………………………………………………………………………………(5.1)

Below table 5.2 shows the value of R^2 and RMSE from target and predicted value of SFC. Here error is show the difference between the target and predicted value of SFC.

RUN	SFC	Predicted SFC	Error	R^2	RMSE
1	2.528217	2.67497	-0.146753	0.998298	0.056585
2	0.539358	0.53936	-0.000002		
3	2.442625	2.42011	0.022515		
4	0.361972	0.38451	-0.022538		
5	2.353724	2.34377	0.009954		
6	0.316649	0.38425	-0.067601		
7	0.571057	0.57885	-0.007793		
8	0.539358	0.53936	-0.000002		
9	0.501235	0.43833	0.062905		
10	0.391658	0.36429	0.027368		
11	2.666002	2.59841	0.067592		
12	0.539358	0.53936	-0.000002		
13	0.610855	0.67537	-0.064515		
14	0.420747	0.40469	0.016057		
15	0.629436	0.71341	-0.083974		

Table 5.2: Target vs. Predicted SFC

Here error is show the difference between the targeted and predicted value of SFC. The value of R^2 and RMSE are calculated by equation (1) and (2). The value of R^2 is 0.998 which are close to the 1 and the value of RMSE is 0.0565 which is close to 0. So, the model is making a good prediction.

5.1 Comparison of Results

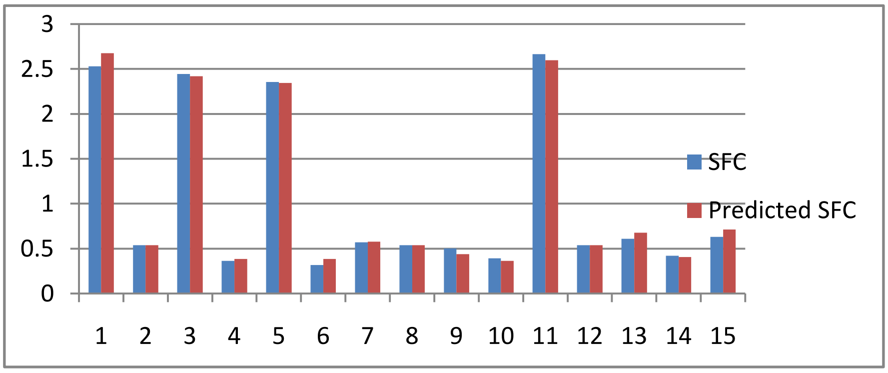


Figure 5.1: Experimental & Predicted SFC

The predicted value of Specific fuel consumption of model was compared with the actual target value of experiment which is shown in Fig.6.1 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.

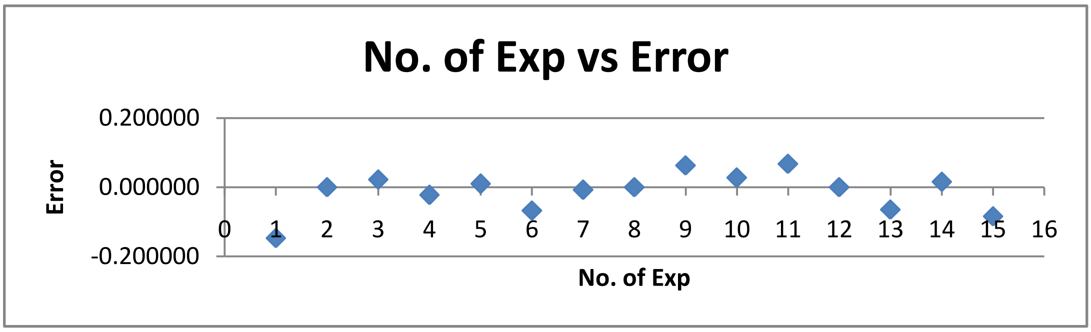


Figure 5.2: Experiments vs. Error

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 SFC Model with respect to experimental data.

Fig. 5.3 shows the experimental versus predicted Specific fuel consumption 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 Specific fuel consumption

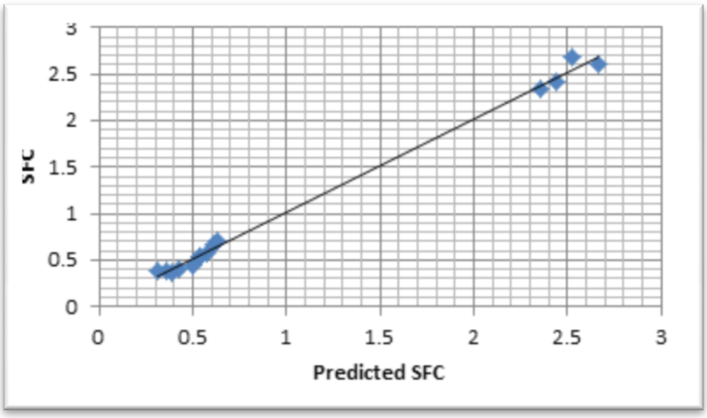


Figure 5.3: Experimental vs. Predicted SFC

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.

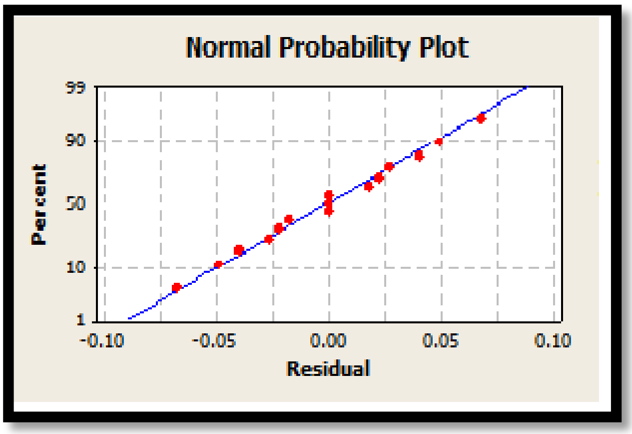


Figure 5.4: Normal Probability of Residuals

Surface and contour plots for Specific fuel consumption show the effect of different parameters on Specific Fuel Consumption (SFC). 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.

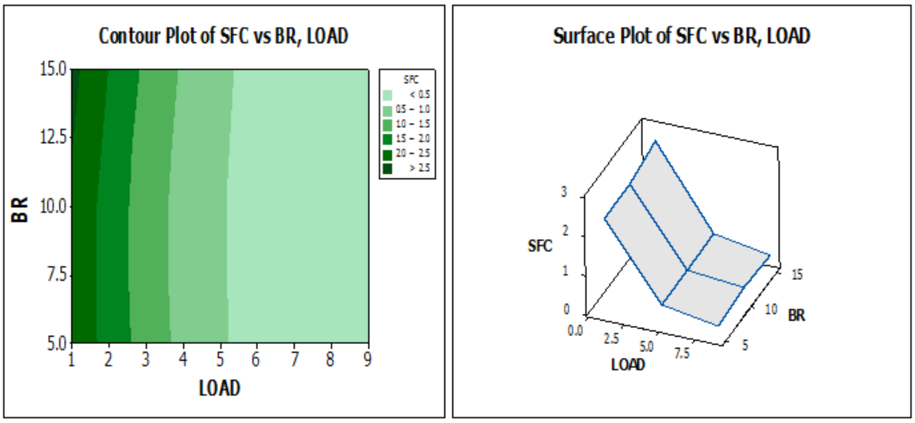


Figure 5.6: Contour and Surface Plots of SFC vs. BR, LOAD from Minitab

The effect of BR and Load on SFC is shown in Fig. 5.6. It shows that, when load is minimum When SFC is maximum But, When LOAD is Maximum, SFC is Minimum.

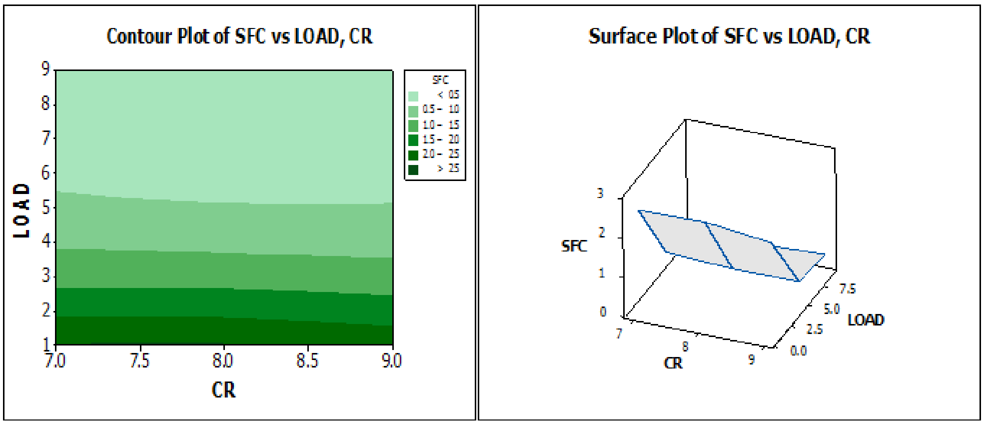


Figure 5.7: Contour and Surface Plots of SFC vs. LOAD,CR from Minitab

The effect of Load and CR on SFC is shown in Fig. 5.7. It shows that, SFC is not mainly affected by CR.But at higher load SFC is higher.

Below **table 5.3** show the all possible combination of input variables (% of Ethanol, compression ratio, and load) and specific fuel consumption related to them.

Sr No.	CR	BR	LOAD	PREDICTED SFC
1	7	5	1	2.64245
2	7	5	5	0.67537
3	7	5	9	0.46119
4	7	10	1	2.67497
5	7	10	5	0.66338
6	7	10	9	0.40469
7	7	15	1	2.76951
8	7	15	5	0.71341
9	7	15	9	0.41021
10	8	5	1	2.42011
11	8	5	5	0.52573
12	8	5	9	0.38425
13	8	10	1	2.47825
14	8	10	5	0.53936
15	8	10	9	0.35337
16	8	15	1	2.59841
17	8	15	5	0.61501
18	8	15	9	0.38451
19	9	5	1	2.26001
20	9	5	5	0.43833
21	9	5	9	0.36955

22	9	10	1	2.34377
23	9	10	5	0.47758
24	9	10	9	0.36429
25	9	15	1	2.48955
26	9	15	5	0.57885
27	9	15	9	0.42105

The optimum value set is shown by different color in table 5.3 and given below output of experiment. Optimum set of SFC for this experiment is 0.35337 kg/kWh when compression ratio, Blend Ratio and load are at 8, 10 and 9 kg.

VI. Conclusion

The present investigation aimed at Performance Effect of SFC for SI engine. This analysis is carried out by developing Experiment models based on L15 BBD array in Response surface optimization technique. A Model for Experiment prediction shows the following conclusions.

It has been proved that predicted SFC values are closer to the experimental results. It has also been also conclude that the RSM may be used as a good alternative for the analysis of the effects of engine parameters on the SFC.

- Optimum set of SFC for this experiment is 0.35337 kg/kWh when compression ratio, Blend Ratio and load are at 8, 10 and 9 kg.

VII. Scope of Work

- In our experimental work, it was optimized parameters for maximizing specific fuel consumption and 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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