EXPERIMENTAL STUDY OF PERFORMANCE AND EMISSION CHARACTERISTICS OF NANO ADDITIVES-BASED GASOLINE-ALCOHOL BLENDS USING RESPONSE SURFACE METHODOLOGY

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Abstract

In this study, lighter alcohols ethanol and methanol were added to gasoline to formulate binary blend E10 (Ethanol 10% + Gasoline 90 %) and its equivalent iso-stoichiometric GEM blends. Alumina nanoparticles (10ppm) of size 40 nm were added to binary blend E10 and best performing GEM blend by means of Ultrasonication to disperse the nanoparticles homogeneously in the fuel blend. The fuel samples were tested on the PFI SI engine at different engine speeds ranging from 1700 rpm to 3300rpm at a constant load of 5.2kg. The results indicate that the presence of nanoparticles in the fuel blends increased engine performance by 26% and reduced the emissions of hydrocarbons, carbon monoxide, Nitrogen oxides by 64%, 78%, 39%, respectively for the optimized fuel blend G91.2E4M4.8A10. Response surface methodology technique is used to optimize fuel blends and the model is validated with experimental results. However, optimization results showed that higher optimization is obtained with a speed of 2700 rpm, 10ppm of Alumina. Under these conditions, the results of HC, CO, CO2, NOx emissions were 163.9 ppm, 0.7%, 9.8%, and 1304.6 ppm, respectively.

Keywords: Ethanol, Methanol, Nano-Alumina, Gasoline, air pollution.

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I. INTRODUCTION

Transportation sector is an integral component of the economy and society, this sector is sustainable by burning fossil fuels in internal combustion engines as it relies on the mobility of vehicles [1]. These fuels are nonrenewable and are not clean energy resources as they pollute the atmosphere [2]. More than half of the world's oil production is consumed in the transport sector leading to its depletion. Consequently, the transport sector is associated with concerns of global climate change, energy security, rising oil prices, depletion of fossil fuels [3]. About 72% of global transport emissions come from road vehicles, which accounted for 80% of the rise in emissions from, 1970-2010 [4]. The transport sector occupies a significant portion of the world's carbon budget. Emissions from the transport sector are a major contributor to climate change of about 14% of annual emissions and a quarter of CO_2 emissions from burning fossil fuels. These emissions are expected to grow at a faster rate than that from any other sector, posing a major challenge to efforts to reduce emissions in line with the Paris Agreement and other global goals Over the last few decades, carbon footprint and energy consumption have been the main interests of policymakers as it affects human health, the environment, and national economic development [5]. Therefore it is necessary to adopt the techniques which could reduce emissions and also improve performance characteristics of the engine. In this regard modifying the fuel by adding additives is known to be one of most efficient techniques. Based on their application additives are of different types. For example alcohols such as ethanol, methanol, and butanol are considered as oxygenated additives; promote complete combustion due to their higher oxygen content [6-7]. And also the inclusion of metal oxide nanoparticles can improve fuel thermophysical properties, including thermal conductivity, surface–area–to–volume ratio, mass diffusivity, and autoignition temperature, therefore enhancing the combustion process and reducing the emissions [8].

In recent years, several researchers studied the influence of alcohol fuels on engine performance, emissions and combustion characteristics. Nazzal et.al investigated the operating parameters by blending 12% of ethanol with pure gasoline, 12% of methanol with pure gasoline and reported that there was in increase in brake thermal efficiency, brake specific fuel consumption, decrease in exhaust gas temperature [9]. Yusuf et.al tested various gasoline-alcohol fuel blends on different engines at varying engine speeds and reported that there was a significant change in the combustion system with the addition of alcohols to pure gasoline [10]. Abinash Biswal studied ternary gasoline-ethanol –lemon peel oil blends and reported that the performance of the tested fuel samples was similar to gasoline with a reduction in co emissions by 60 % and NOx emissions by 15%. He also reported that the in-cylinder pressure was higher for biofuel blends due to their higher laminar flame velocity [11]. Ashraf Elfasakhany investigated various alcohol-gasoline-based biofuel mixtures at different volume proportions and reported the effect of blended fuels on engine performance and emissions. It is reported that methanol-gasoline blends present the highest volumetric efficiency, torque while ethanol-gasoline blends give the highest brake power. When ternary fuel blends were compared against dual alcohol gasoline mixtures it is found that ethanol-methanol –gasoline blends give moderate volumetric efficiency, torque, brake power and produce reduced CO and UHC emissions [12]. Simeon Iliev compared the blending of methanol and ethanol at various proportions using engine simulation technique and reported that with an increase in ethanol content brake power decreased and with an increase methanol content brake power increased up to a certain volume percent. Blending of ethanol and methanol to gasoline reduced CO and HC emissions but higher NOx emissions compared to gasoline [13]. In this regard Metal and Metal Oxide Nanoparticles were added to fuel mixtures by several researchers and investigations were carried out to improve the fuel properties.

Wei et al. studied the effect of aluminum oxide nanoparticles in diesel –methanol blends and reported Al2O3 contributed to the rise in in-cylinder pressure, brake thermal efficiency by 2.5% and 3.6% respectively, reduction in CO and HC emissions by 83.3 and 40.9% [14]. Nguyen et.al studied the influence of Al_2O_3 nanoparticles in gasoline- butanol blends and reported that engine power increased by 10 % with a reduction in CO, HC, NOx emissions [15]. Aravind et al conducted experiments on single-cylinder four-stroke SI engine by blending methanol, aluminum oxyhydroxide [AlO(OH)] nanoparticles with gasoline. It is reported that the total fuel consumption decreased, significant reductions were observed on engine surface temperature, exhaust gas temperature, and the exhaust emissions such as carbon monoxide, hydrocarbons, and nitrogen oxide when compared with pure gasoline [16]. Anand Srinivasan studied the effect of ethanol-gasoline blends with cerium oxide nanoparticles as additives on a Tata Nano twin-cylinder SI engine. In this work, combustion, performance and emission tests were conducted. It was found that there was an increase in brake thermal efficiency, in-cylinder pressures with a significant reduction in CO_2, HC and NOx, CO, for the nanoparticle's blends compared to base fuels [17].

From the above literature, it is observed that using Ethanol or Methanol has its own limitations when blended with gasoline. Therefore, the concept of ternary blends with Gasoline, Ethanol, and Methanol was introduced by Turner et al [18] in which all the formulated ternary blends have an iso-stoichiometric air-fuel ratio as that of an equivalent conventional binary gasoline-ethanol blend. Sileghem et al [19] experimentally investigated the E85 equivalent three GEM blends on1.8 L SI PFI 4-cylinder engine by varying the engine speed from 1500 to 3500 rpm for different fixed torques of 40 and 80 Nm. They reported that all three equivalent E85 GEM blends have identical brake thermal efficiency, volumetric efficiency, and heat release rates as binary E85 blend.

In the studies stated above, the impact of various fuel blends of diesel, gasoline, alcohol fuels, several additives, and nanoparticle-based fuels on the performance and emissions of the SI engine are analyzed. However, there has not been enough research on the ability of RSM to estimate and optimize the input-output parameters of Gasoline-Ethanol-Methanol-Al_2O_3in SI engines. In addition, there is no study in the literature to evaluate the effects of operating parameters on engine performance and emissions of a SI engine working with GEM-based nano fuel blends. For this reason, this study has been done to close this gap in the field. In this study, the impact of engine running parameters (i.e., Speed, load, nanoparticle concentration) were examined on the output factors (i.e. BTE, BSFC, and emissions such as NOx, HC, CO and CO2). RSM model was utilized as a convenient stage to optimize the performance and emissions of GEM-Al_2O_3 fuel mixtures with the objective of minimizing the emissions while maximizing the efficiency of the engine.

This paper presents the study of E10 (10% ethanol-90% Gasoline) equivalent is stoichiometric GEM blends with Al_2O_3 as nano additive. Different fuel blends were formulated by using a mathematical formulation of iso-stoichiometric blends given by Pearson et al. [20]. Fig.1 represents the formulation of ternary blends for the binary equivalent blend E10. The ternary fuel blends thus obtained are tested for the performance and emission characteristics and were optimized using Response surface methodology.

II. MATERIALS AND METHODS

Experiments have been conducted on a computerized four-stroke single-cylinder port fuel injection SI engine. The experimental setup consists of a PE 3 Series ECU (engine control unit), the main function of ECU is to use measurements from sensors to compute fuel and ignition parameters. Each Performance Electronics ECU is 100% adjustable using the appropriate Performance Electronics pe3 Monitor software. The detailed schematic diagram of the engine is shown in Fig. 2 and the specification of the engine is shown in Table 1. The performance and combustion data can be obtained by using I. C. Engine soft 9.0' software. The software helps to analyze the data at different test conditions. Ethanol and Methanol used in the experimentation were 99.9% pure and are procured from Amaravati scientific labs. Al2O3 Nanoparticles of size 40 nm are procured from Reinste nano ventures Pvt limited.

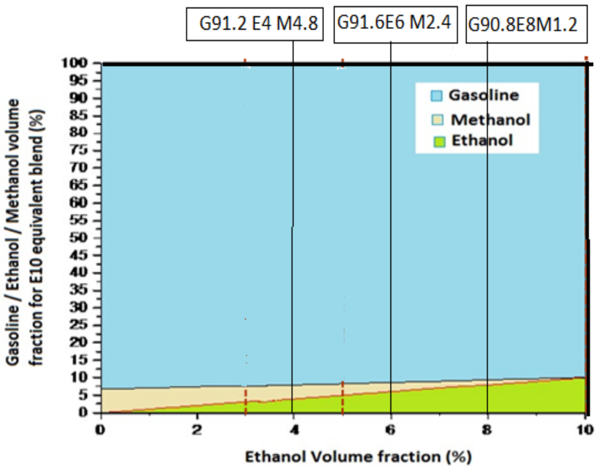


Figure 1: E10 Equivalent GEM Blends Formulation

Figure 2: Aluminum Oxide Nanoparticles

Table 1: Aluminum Oxide specifications

Specifications	Values
Size	40 nm
Density (g/cm3)	3.95e4.1
Specific Surface	>40 m^2/g
Particle shape	Spherical
Type	Powder

Emissions were measured using an AVL44N exhaust gas analyzer. The gas analyzer can detect gases such as HC, CO, CO_2, O_2, NOx. The properties of fuels used were shown in Table 3'

Gasoline was blended with 10% by volume of ethanol to formulate binary E10 blend G90E10M0, its equivalent iso-stoichiometric GEM blends were formulated by mixing the necessary volume proportion of alcohols as shown in figure 1. The fuel blends such as G91.2E4M4.8, G91.6E6M2.4, and G90.8E8M1.2 were formulated. Alumina is added to the best fuel blends among the above by means of Ultrasonication. Ultrasonication was done for 30 min to disperse the nanoparticles into the fuel blends. Thus, nano fuel blends were formulated. Each of the sample fuels was filled in the engine tank and experiments were conducted at part load condition of 75% i.e 5 kg at different speeds 1700 rpm, 2100 rpm, 2500 rpm, 2900 rpm, and 3300 rpm. By using Pe 3 software spark timing sweeping tests were conducted to determine the maximum brake torque (MBT) at each speed for every fuel sample. The results taken for investigation were recorded at MBT condition. The results are modeled and optimized by using Minitab 17 Software.

Test Fuels considered

	Test Samples	Composition	Name
1	Gasoline	G100 E0 M0	PG
2	Target Binary Blend	G90E10 M0	E10
3	GEM Blends	G90.8E8M1.2	E10B1
		G91.6E6M2.4	E10B2
		G91.2E4M4.8	E10B3
4	Nano Fuel Blends	G0E10M0A10	E10A10
		G91.2E4M4.8	E10B3A10

The RSM approach is used for predicting the best possible outputs that can be obtained from the input resources by reducing the experimental time. In this study, the objective of constructing the RSM model is to calculate the effect of nanoparticles in the test fuel and operating conditions at which the engine gives the best performance and less emissions. The initial step involves the selection of the input and output variables. Taking this into account, vol. % of gasoline, ethanol, methanol and engine speed (rpm) were selected as input and the parameters significantly affected by Input variables were considered as response variables (BTE, BSFC, CO, CO_2, HC and NOx). However, the least affected and uncontrolled parameters were neglected. Thereafter, the range of input parameters was identified. Based on an exhaustive literature survey, broader range values (upper and lower limits) with large intervals were selected and some preliminary experiments were conducted. Therefore, change in the response variable with each input value was analyzed and a specific range was selected in which most changes in responses were observed. The experimental results obtained were analyzed using the regression methods in the further stage. It involves fitting the responses in the second order's polynomial equations, which highlights the relation between the input and the response variables.

No. of cylinders	01
No. of Strokes	04
Fuel	Gasoline
Rated Power	4.1 kW @3600 rpm
Cylinder Diameter	68 mm
Stroke Length	54 mm
Connecting rod length	105mm
Compression Ratio	8.5: 1
Cooling type	Air Cooled

Table 2: Specifications of the engine

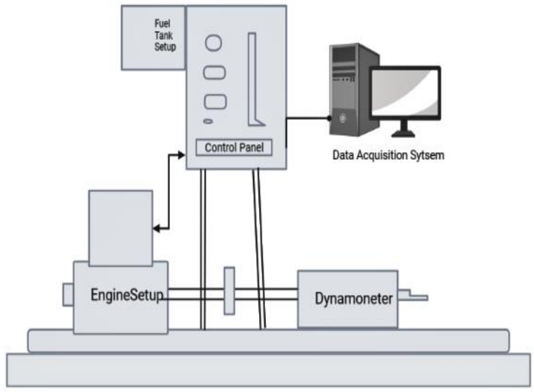


Figure 3: Schematic diagram of experimental setup

Property	Gasoline	Ethanol	Methanol
Molecular Formula	C4-C12	C_2H_5OH	CH_3OH
Molecular Weight	95-120	46	32
Oxygen content (%)	0	34.73	49.9
Density (kg/m^3)	731	789	791
LowerHeatingValue, LHV (MJ/kg)	45.2	26.9	20.09
Research Octane number	95.3	109	109
Motor Octane number	85	92	88.6
Stoichiometric A/F ratio	14.8	9.0	6.5
Latent heat of vaporization (kJ/kg)	305	840	1100
Boiling point,ºC	38-204	79	65

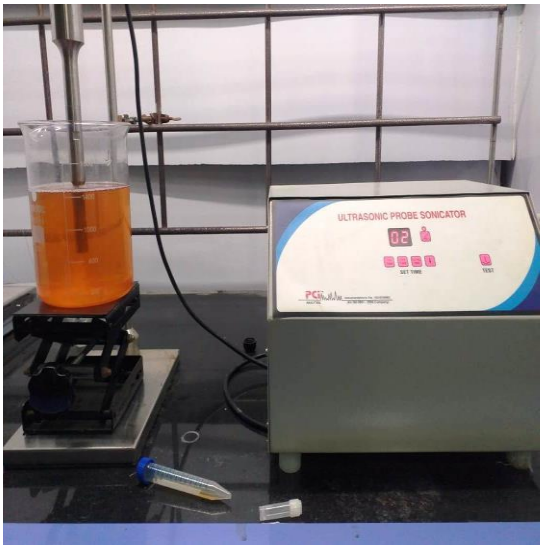


Figure 4: Ultrasonication Setup

Figure 5: Experimental Setup

Table 3: Properties of Fuels taken

III.RESULTS AND DISCUSSION

Brake Thermal Efficiency

Brake Thermal Efficiency is the ratio of brake power to the amount of heat energy supplied to the engine; it measures the efficiency of fuel burnt[20]. Brake thermal efficiency increases as speed increases reaching its maximum value and then slowly decreases [20,21]. Figure 4 shows the variation of BTE at a speed range of 1700- 3300 rpm. BTE increased from 1700rpm to 2500 rpm at a constant load of 5 kg for all the fuel samples tested. Maximum brake thermal efficiency was recorded at 2500 rpm and increased by 19.7%, 20.2% for the nano fuel blends E10A10, E10B2A10 blends compared to Pure gasoline. The addition of Al_2O_3 nanoparticles improved combustion by donating more number oxygen atoms thereby enhancing the flame speed. This led to an increase in BTE.

Brake Specific Fuel Consumption

BSFC is tested at constant load and at variable speeds ranging from 1700 rpm to 2500 rpm as shown in figure5. Blending of alcohol with gasoline led to a slight increase in specific fuel consumption for all the blends due to their less lower heating value compared to gasoline [22,23]. Adding aluminum oxide nanoparticles led to a reduction of heat losses and increases output power. As engine speed increases brake specific fuel consumption drops due to increased power to overcome friction losses developed. Minimum BSFC Value is recorded at 3300 rpm for the nano blend E10B2A10. It is observed that this parameter is almost similar to gasoline due to the presence of alumina in nano fuel blends.

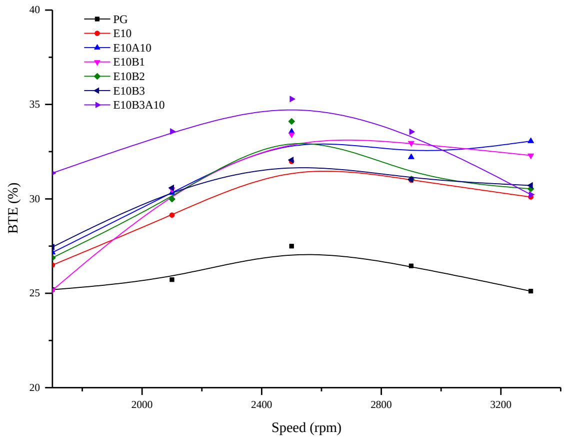


Figure 6: Brake Thermal Efficiency at varying speeds

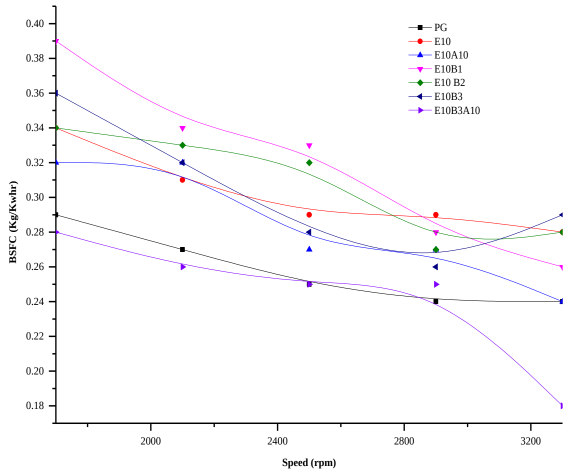


Figure 7: Brake specific fuel consumption at varying speeds

Emissions: Hydrocarbon Emissions

Hydrocarbon Emissions mainly occur due to incomplete combustion, heterogeneous fuel mixture, and lower combustion temperature [24]. The variation of HC emissions is shown in Figure 6. Hydrocarbon emissions decreased with increasing speed due to a longer valve overlap period. Gasoline has the highest HC emissions compared to all the fuel blends. Blending alcohols make the fuel oxygen-rich which promotes complete combustion thereby advancing the wall quenching by reducing the number of hydrocarbons. Further, the presence of alumina nanoparticles contributed to the decrease of emissions by 64% for the E10B2A10 blend compared to gasoline.

Carbon monoxide and carbon dioxide emissions

Carbon monoxide is one of the most harmful pollutants that affect human health. Carbon monoxide is mainly produced due to insufficient oxygen inside the combustion chamber. Pure gasoline fuel has less amount of oxygen in its structure, adding of alcohol fuels and metal oxide nanoparticles would increase the amount of oxygen [25]. Due to the presence of more oxygen atoms combustion is more complete and the production of CO is lesser. As a result, it is done more complete, and the carbon oxides are changed into carbon dioxides. The variations of CO emission under different engine speeds are shown in Figure 7. For all the tested fuels, the CO emission increases with the rise in engine load. Further, with the inclusion of methanol, ethanol increases the oxygen content of the tested fuels, which arouses more complete combustion with a lower concentration of CO emitted emission is decreased by the addition of Al_2O_3 nanoparticles into fuel blends, and the reduction of CO shows more significance with increasing speed. In detail, the CO emissions from E10A10 and E10B3A10 are 40.7% and 78% less than that of gasoline, respectively. The lower CO emissions with Al_2O_3 added blends may be due to the breaking of fuel homogeneity during the fuel injection to improve air-fuel mixing by the interaction of nanoparticles Moreover, the chemical reactivity is raised by the large surface–contact areas of Al_2O_3 nanoparticles and the ignition delay is shortened significantly. The shortened Ignition Delay and improved fuel-air mixing can produce more complete combustion. As a result, carbon monoxide emissions are reduced, and CO_2 emissions increase. The variation of CO_2 emissions is shown in Figure 8.

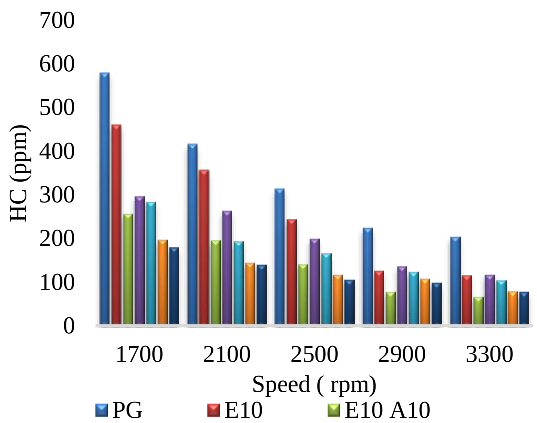


Figure 8: Hydrocarbon emissions at varying speeds

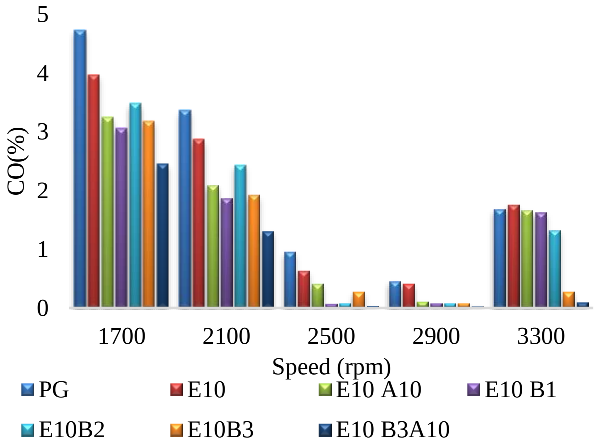


Figure 9: Carbon monoxide emissions at varying speeds

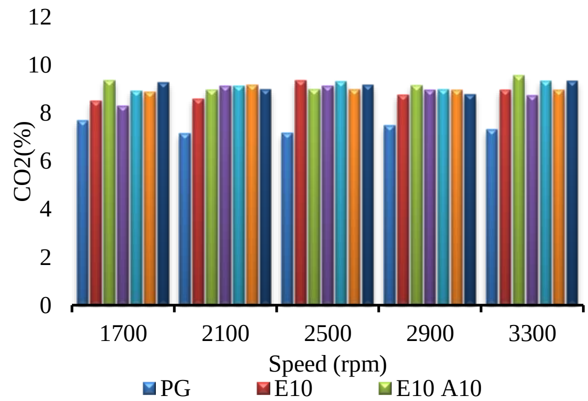


Figure 10: Carbon dioxide emissions at varying speeds

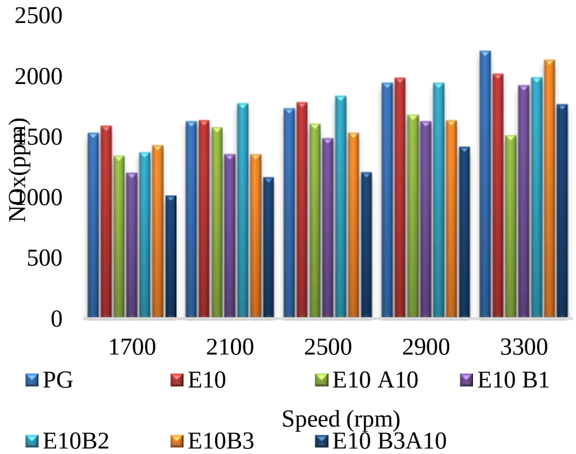


Figure 11: Nitroxide emissions at varying speeds

The variations of NOX emissions in correlation to engine speed for all the tested fuels are presented in Fig. 11. NOx emissions Increased with increasing engine speed. At lower engine speed the emissions are relatively lower for all the blends. As the speed increases the temperature inside the combustion chamber increases and nitrogen content in the air reacts with oxygen molecules forming Nitrogen oxides [26]. Due to the catalytic activity of nano alumina more oxygen atoms were absorbed by CO to form CO_2 thereby reducing NOx emissions also. Figure 7 clearly shows that NOx emissions for E10B3A10 are very low compared to other fuel blends and reduced by 39.2% compared to gasoline.

Response Surface Methodology

The RSM is commonly used in divorce cases and extraction processes. A response surface design is generated after initial screening research, which provides data that must be primarily modeled using least-squares fitting. The desirability function is the most popular method to use when multiple responses need to be optimized [27]. RSM plays an essential role in engineering applications for achieving a solution when it is difficult or impossible to describe appropriately. It is based on the use of multivariate DoE followed by optimization through mathematical modeling [28]. RSM is a collection of statistical approaches for modeling and evaluating problems of interest that are influenced by a variety of factors, with the goal of determining the relationship between responses and a variety of factors and optimizing these factors [29]. The major goal of optimization in this study is to find the best working characteristics for a gasoline engine by boosting BTE while decreasing BSFC, NOx, CO, CO2, and HC. Engine Speed, blend ratios, and Alumina concentration was chosen as input parameters in this study because they have a significant impact on the answers. Based on the effects of the three parameters, three-dimensional interactive charts were constructed.

The following is the simplest model based on a first-degree polynomial that can be utilized in RSM.

$$y = \beta_o + \sum_i^k \beta_i x_i + \varepsilon \qquad (1)$$

If there is any curvature in this model, quadratic model is utilized as follows:

$$y = \beta_o + \sum_i^k \beta_i x_i + \sum_{i=1}^k \sum_{j\geq 1}^k \beta_{ij} x_i x_j + \varepsilon$$
(2)

where y denotes the estimated response, k denotes the number of factors, x_i and x_j are independent variables, and r denotes random experimental error [30]. The linear and quadratic coefficients are denoted by i and j, respectively. β_o is constant,. β_i is linear coefficient, β_{ij} *is* the interactive coefficient

The model was evaluated in this investigation using a probability value with a confidence level greater than 95%. The analysis variance (ANOVA), fitness test (R2) evaluation was conducted. According to the ANOVA analysis engine, load and Alumina concentration have a significant impact on brake thermal efficiency, brake specific fuel consumption, and other emission responses compared to other input parameters. On the basis of input parameters at different ranges and their respective output responses the following equations were regression equations were developed using Minitab software.

BTE (%) = -14.8 + 0.04104 S + 0.178 G (%) + 0.455 M(%) - 2.39 Al_2O_3- 0.000004 S *S - 0.000221 S*G(% - 0.000092 S *M(%)+ 0.000032 S*Al2O3 + 0.0262 G(%)*Al_2O_3 (3)

BSFC (kg/kwhr) = 1.298 - 0.000332 S - 0.00752 G(%) - 0.00072 M(%) + 0.0576 Al_2O_3+ 0.000000S*S + 0.000001S*G(%)+0.000001S*M(%) + 0.000000S* Al_2O_3- 0.00067 G(%)*Al_2O_3 (4)

HC(ppm) = -413 - 0.171 S + 16.38 G(%) - 89.2 M(%) - 444 Al_2O_3+ 0.000049 S*S - 0.00308 S(*G(%)+ 0.02387 S*M(%) + 0.00341 S*Al2O3 + 4.77 G(%)*Al_2O_3 (5)

CO (%) = -3.0- 0.00521 S + 0.225 G(%)- 0.279 M(%) - 3.44 Al_2O_3+ 0.000002 Speed (rpm)*Speed (rpm)- 0.000061 S*G(%)+ 0.000007 S*M(%) + 0.000028 S* Al_2O_3 + 0.0367 G(%)*Al_2O_3 (6)

CO_2(%) = 108.1 - 0.05250 S - 1.183 G(%) + 0.560 M(%) + 1.91 Al_2O_3 - 0.000001 S*S

+ 0.000645 S*G(%)- 0.000237 S*M(%) + 0.000000 S* Al_2O_3- 0.0208 G(%)*Al_2O_3 (7)

NOx(ppm) = 4198 - 1.392 S - 25.0 G(%) - 81.3 M(%) + 851 Al_2O_3+ 0.000158 S*S + 0.01019 S*G(%) + 0.0170 S*M(%)-0.00676 S* Al_2O_3 - 9.40 G(%)*Al_2O_3 (8)

The contour and surface plots from Figure 12 to Figure 17 show the effect of input parameters on responses. It is observed that holding methanol content to 2.4% and gasoline content to 95% the increasing or decreasing trend of outputs were developed. The R^2 values for BTE, BSFC, HC, CO,NOx,CO_2 97.44,96.90,97.03, 97.77, 95.39, 98.11 indicates that the model developed is accurate compared to experimental values. The results of ANOVA are mentioned in Table 4.

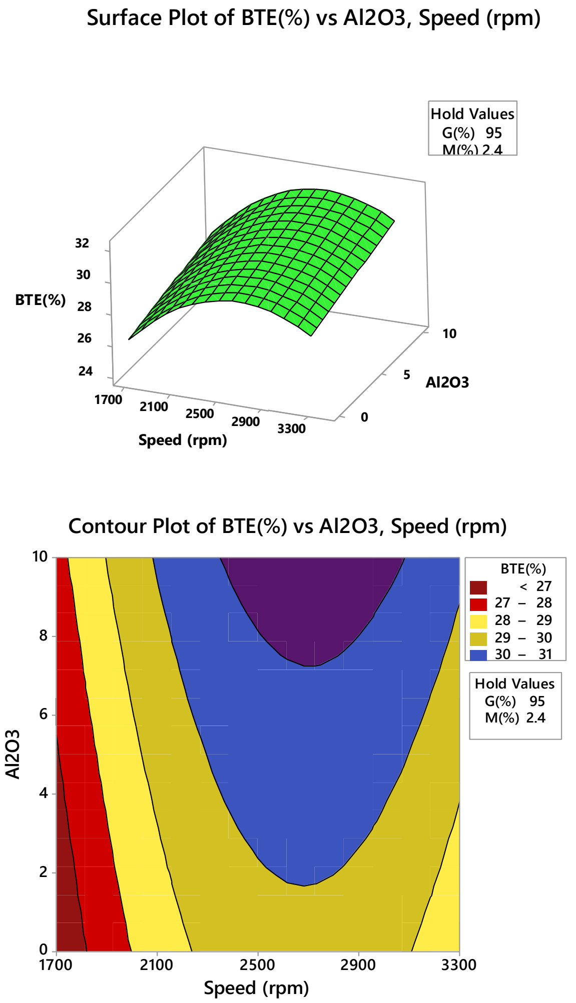
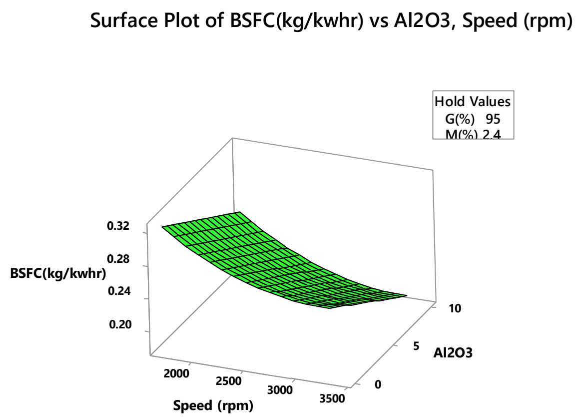


Figure 12: Interactive effect of Speed and Al_2O_3 on Brake thermal efficiency

The interaction effect of speed and Al_2O_3 nanoparticle concentration on brake thermal efficiency is shown in figure 12. It is observed that from the figure 12 BTE increased with the percentage of Al_2O_3 concentration at all ranges of speed. But the Speed has a variable effect on BTE. BTE increased as the engine speed increased from 1700 rpm to 2500 rpm and then reduced as speed increased to 3300 rpm. Variation in BTE can also be observed in the contour plot of Figure 12. Here also it is observed that BTE increased between 2500-2900 rpm at 8 ppm to 10ppm concentration of Aluminium oxide particles. This model is significant as it has a p-value of 0.000 and a confidence level supported by R2 value of 97.44 from ANOVA as shown in Table 4.

The interaction effect of speed and Al_2O_3 nanoparticle concentration on brake-specific fuel consumption is shown in Figure 13. At lower speeds BSFC is higher and as the speed increased BSFC got reduced [31]. It is observed that from figure 13 BSFC decreased with the percentage of Al_2O_3 concentration at all ranges of speed. Variation of BSFC can also be seen in the contour plot of Figure 13 and it noticed that the lowest value got recording in the speed range of 2900 rpm to 3300 rpm at 8ppm to 10 ppm concentration of Al_2O_3. This model is significant as it has the p-value of 0.001 and a confidence level supported by an R2 value of 96.90 from ANOVA as shown in Table 4. Therefore, it is clear from the above results that brake-specific fuel consumption reduces with an increase in nanoparticle concentration.



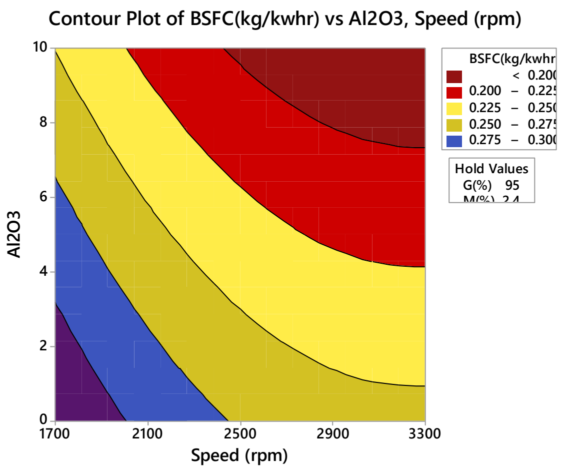


Figure 13: Interactive effect of Speed and Al_2O_3 on BSFC

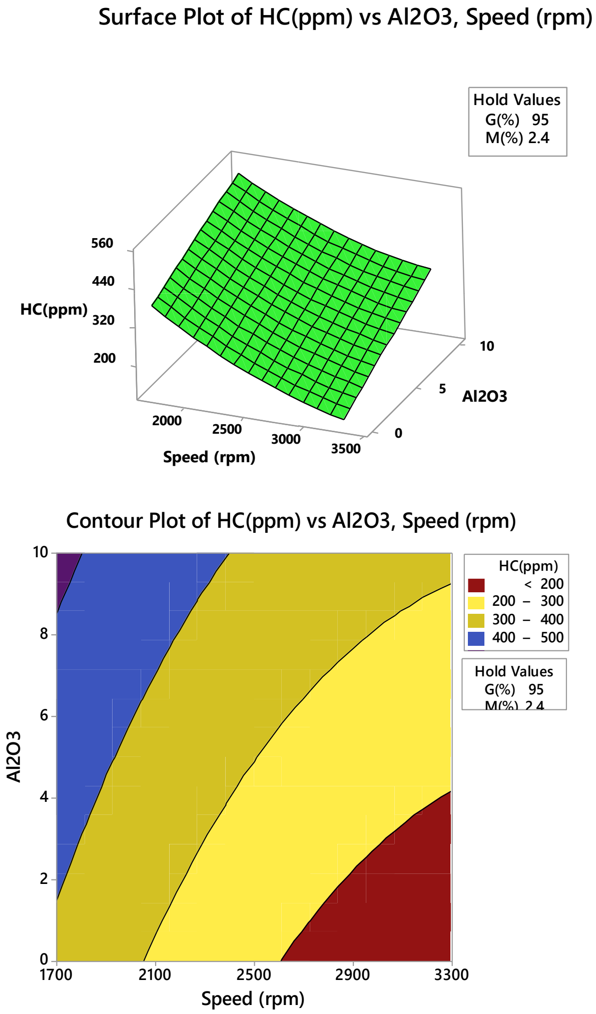


Figure 14: Interactive effect of Speed and Al_2O_3 on HC emissions

The interaction effect of speed and Al2O3 nanoparticle concentration on hydrocarbon emissions is shown in figure 14. From the contour plot, it is noticed that the lowest HC emissions were recorded in the speed range of 2700rpm to 3300 rpm and HC emissions followed a decreasing trend with an increase in speed. HC emissions were lower at higher speeds. The air-fuel mixture homogenizes at high speeds, raising the in-cylinder temperature which improves combustion efficiency [32]. This model is validated as it has the lowest p-value and R2 value is 97.44.

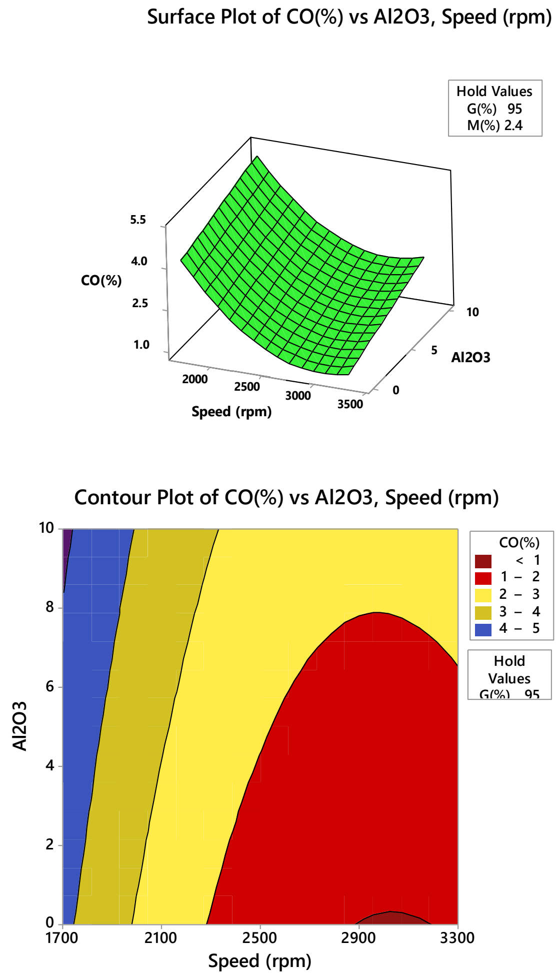


Figure 15: Interactive effect of Speed and Al_2O_3 on CO emissions

The interaction effect of speed and Al_2O_3 concentration on CO emissions is shown in Figure 15. From the contour plots and surface plots of Figure 17, it is observed that the volume of carbon monoxide emissions reduced as speed increased. For all concentrations of alumina, the percentage of CO is lesser at higher speeds.

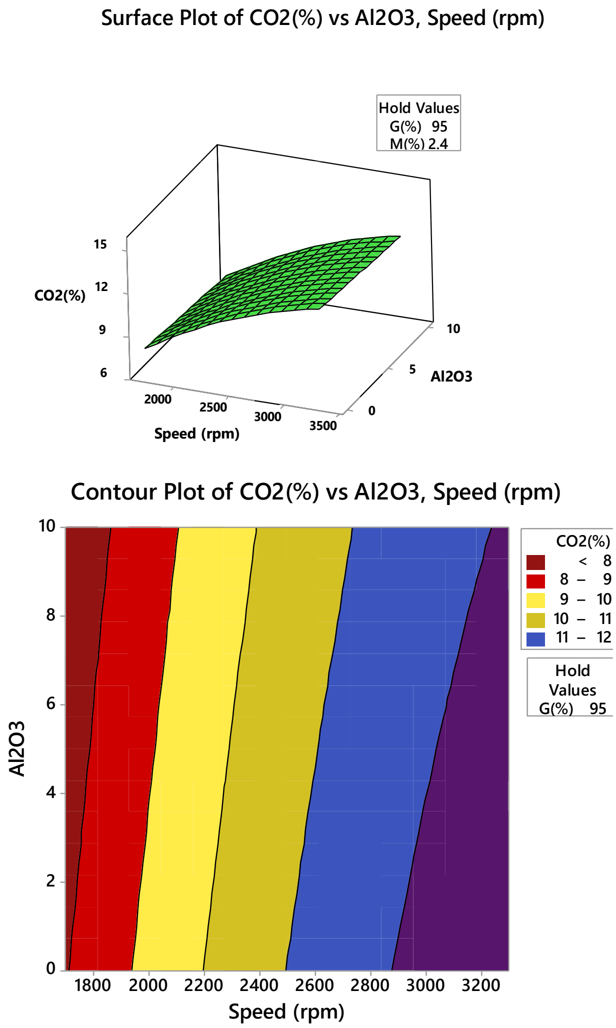


Figure 16: Interactive effect of Speed and Al_2O_3 on CO_2 emissions

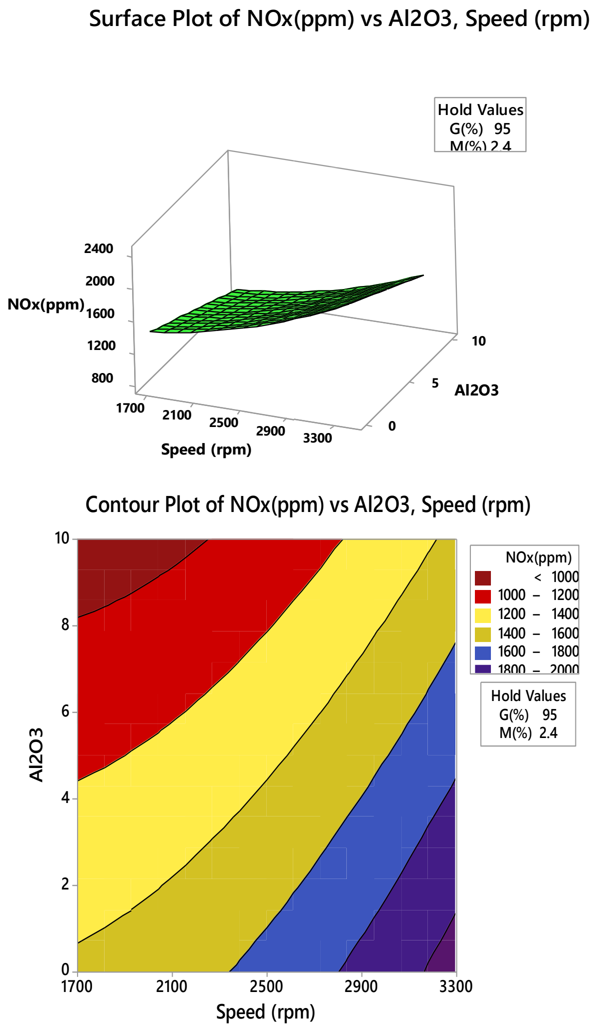


Figure 17: Interactive effect of Speed and Al_2O_3 on NOx emissions

The interaction effect of speed and Al_2O_3 on carbon-dioxide emissions is shown in figure 16. The surface plots and contour plots of fig.16 state the more percentage of carbon dioxide got released at higher speeds of the engine and higher concentrations of alumina. As speed increases the amount of CO_2 also increased due to the presence of more oxygen atoms during the combustion. This is model is supported by the ANOVA as it has a confidence level of 98.11

The interaction effect of speed and Al_2O_3 nanoparticle concentration on nitroxide emissions is shown in figure 17. Speed has a significant impact on the decrease or increase of this gas, from figure 17 NOx emissions increase with the increase in speed, and the lowest values are recorded in the speed range of 1700-2100 rpm and at the concentration levels of 8-10ppm of Alumina nanoparticles. Alumina works as a catalyst by blending nanoparticles with gasoline fuel blends providing oxygen for CO oxidation and absorbing it, resulting in NOx reduction. As a result, using alumina in mixed gasoline reduces NOx emissions [33].

The model has good validity, as seen in Figure17. Notably, the experimental results and the model's outcomes are extremely similar. The software's results help to corroborate the model that has been used. Furthermore, these findings revealed that the model has a 95.39 high consistency. The derived model's p-value for nitrogen oxides is 0.000, indicating that it is correct.

Table 5: Validation of the optimized parameters and experimental results

Fuel blend	Speed (RPM)	Responses	BTE (%)	BSFC	CO (%)	HC (ppm)	NOx (ppm)
G91.2M4.8A10	2900	Predicted	32.584	0.24	0.96	85.42	1498
		Experimental	32.64	0.2466	0.7	91	1534
		Difference	0.056	0.0066	-0.26	5.58	36

RSM Optimizer

RSM optimizer used to find optimum input process parameters at which best possible output responses available are shown by Figure 18. The multi-objective optimization was carried with different inputs for various output factors. In this work, the objective is to minimize emissions such as HC, CO, NOx and BSFC were obtained from the Minitab RSM optimizer module, where each answer is described by unit less desirability values (d) and magnitude counters ranging from 0 to 1. The composite desirability is 0.7625. The optimum values of all the responses are observed at 92.523% of gasoline, 4.80 % of methanol, and 10ppm of Al_2O_3. From Figure 18, the optimum values are 1304 ppm, 0.7%, 163 ppm for NOx, CO, HC respectively.

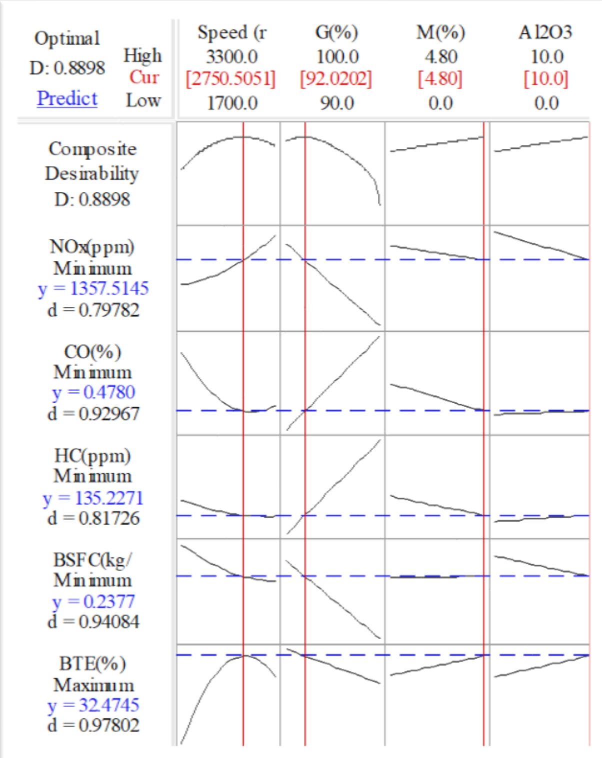


Figure 18: RSM Optimizer

Conclusion:

In the present study, efforts have been made to study the influence of aluminum oxide nanoparticles in gasoline, ethanol, methanol-based fuel blends to improve the performance and emission characteristics of SI engines. A series of experiments were performed by considering the optimized input parameters predicted by the RSM model and the results were compared with neat gasoline (G100).

1. Presence of Alumina in fuel blends E10A10 and E10B3A10 led to the increase of brake thermal efficiency by 20 and 26% respectively compared to Gasoline
2. Though there isn't much increase in brake-specific fuel consumption, it didn't show any negative effect compared to gasoline. BSFC decreased by 5% for the fuel blend E10B3A10.
3. HC emissions were diminished by 69% on average due to improved combustion
4. Availability of more oxygen atoms led to the formation of more moles of CO2 while reducing CO and NOx emissions by 78.5% and 39.2% respectively for the blend EBA compared to gasoline
5. The optimized results conclude that the addition of nanoparticle additives in fuel blends improves the performance and emission characteristics. In the present study, the highest engine performance and minimum emissions are obtained at a speed of 2700 rpm with 10 ppm alumina and 4.8% of methanol.

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