Parametric Optimization in SI Engine Fuelled With Gasoline-Ethanol Blends Using Response Surface Methodology

Kiran Kumar.M, M.C. Math

Abstract: Alcohols are a unit gaining attention everywhere in the world has an alternate to gasolene. Among alcoholic alternative combustible fuels such as Biogas, Hydrogen, Methanol, Biodiesel and Ethanol, Ethanol is the best-listed alternative renewable and neat fuel for Spark Ignition (SI) engines as blends in various fractions boosts the oxygen content, leads to promising minimum emissions as compared to non-blended fossil fuels. Non-oxygenated gasoline-ethanol blends were prepared, with 5% to 35 % ethanol to boost the Octane rating. Iso-octane is also added in to the blends as an additive (3% to 5%). The results from the engine test for the prepared blends at constant loading conditions are analyzed and optimized by RSM and DoE. It was found that at E30 blend with 5% Iso-octane additive found minimum BSFC and higher BTE. The emission characteristics like CO, CO2, HC, and NO2 are quite low for the given maximum constant loading conditions (9kg) with setted Compression Ratio (9) and at rated speed. The perceptions produced using the test that E30 blends and 5% of additive Iso-Octane have come about better engine performance' and least 'emitants' when contrasted with other tested blends.

Keywords : Gasoline, Spark Ignition Engine, Iso-Octane, Ethanol, Response Surface Methodology, Performance, Emissions.

I. INTRODUCTION

Energy could be a key driver for the economic development process of any country. Satisfactory, productive, dependable and reasonable vitality is basic for the feasible advancement and comprehensive development of the general economy of any country on the planet [1]. World transport sector has intensely relied upon import of unrefined petroleum to fulfil its energy need. India has imported 213MMT of unrefined petroleum during 2016-17. India has invested Rs.5349.69 billion amount in order to import crude oil during 2016-17. India has consumed 1.9 million metric tonnes (MMT) (growth of 25.4 percent) of petrol during 2016-17 [2].

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Due to better thermophysical properties, alcoholic fuels are better options with better performance and lower emission characteristics. Ethanol, Methanol, Biogas, Hydrogen, Ethanol, and Biodiesel are better alternative fuels to gasoline [3][4].

The blends of gasoline-ethanol diminish the reliance on import of unrefined petroleum somewhat which lifts the national economy. At the same time the strain on breathing air quality can also be reduced to a larger extent [5][6].The Governments has amended mandatory proposal to increase the ethanol quantity in transport sector from 5 to 10% in gasoline ethanol blends even more in near future,with minor engine modifications percentage of ethanol in gasoline can be increased to have higher performance with lower emissions of Green House Gas (GHG) emissions. Literature study uncovers that no significant modification to the gasoline engine is required if the lower extents of 10% ethanol are blended with fuel. There is a minimal improvement in the presentation and more noteworthy decrease in Carbon monoxide (CO), Corban Dioxide (CO_2), unburnt hydrocarbon (UNHC) discharges from the gasoline engine has been accounted for [7][8]. The most important properties of ethanol are produced from non-conventional energy sources are having high octane rating than gasoline, and also having high laminar flame speed. It is having good anti-knock features, by which engine power increases by increasing the compression ratio. Ethanol (C_2H_5OH) is made up of a set of organic compounds whose molecule is having hydroxyl (OH) group, attached to carbon particle with high latent heat of vaporization. Hence the complete combustion will be recorded and the exhaust emissions will be reduced to a larger extent. Ethanol is broadly utilized in the ongoing years as inexhaustible fuel with up to 10% volume mixing with oil for enduring engines, up to 85% volume mixing for Flex-Fuel vehicles which are intended to keep running at higher convergence of ethanol [8][9]. The results were derived from the trial examination, for the distinctive compression ratios 8:1,8.5:1, 9:1, and 9.5:1 at 2400rpm at given constant speed for three unique fuels at its stoichiometric proportion and wide throttle opening. BSFC, BTE at compression ratio 8.5:1 incremented around 5.25% blended with ethanol and 4.51% with methanol, 58.9% blended with ethanol and 30.22% with methanol, raised around 3.65% with ethanol and 4.51% methanol respectively [10] [11]. Among the prominent methods, DoE is the best and affordable procedure to assess the character and joined impacts of test factors on yield reactions [12].

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RSM is an accumulation of measurable and scientific strategies, it is viably perceived as a useful method to break down designing issues dependent on each displaying and enhancing the reaction surface that is affected by utilizing check variables [12].

This multivariate measurement method at the same time enhances the results of various components and the connection between the factors to increase magnificent framework execution [13]. As the principle advantage, structure of test essentially dependent on RSM requires less tests and less time-ingesting contrasted with the full factorial plan experimentation [14]. RSM results in the most effectual and affordable answers for assessing single and amalgamated elements of exploratory factors that lead to yield reactions [15]. The outcomes gotten by RSM investigation will give the best framework execution to improved datasets [16]. The principle favorable position of this strategy is that less tests are required and is less tedious as opposed to valid test ponder [17]. This methodology is generally utilized and has been connected in numerous analytical investigations particularly in the enhancement of engine yield in both SI and Compression Ignition (CI) engines [18]. Perception for liquor fuel usage apparently augmented ignition proficiency and BSFC. The minimum BSFC for ethanol and methanol mixes augmented by 58% and 84% when contrasted and the fuel case. Acceleration in the estimations of BTE was portrayed with the use of ethanol and methanol as fuel [19] [20]. Using RSM to enhance the exhibition parameters of a SI engine using Ethanol-Gasoline blends in differing extents called E5 to E15 with an augmentation of 2.5%. Using DoE (structure of examinations), the generally utilized factual actualize the analyses were planned and enhancement of engine working parameters were dissected. E10 was found to have the best ideal worth working on the engine speed of 3000 rpm. The test examination yields the outcomes for various parameters, BSFC of 0.25kg/kW-hr, a torque of 103.66Nm, and brake power of 35.26kW individually [21].Present study reveals about the findings of the optimum ethanol-gasoline blends at its 100% fuel conversion and least possible emission characteristics at multiple fuel testing conditions on variety of engine variables. The defined input variable for optimization are Blends Percentage, engine Speeds and compression ratios with additives. An additive in the varying proportions of ethanol-gasoline blends either toluene or Iso-octane. Present work reveals the suitability of RSM for optimization of performance and 'emission' characteristics in the modeling. This modeled study also helps to identify the best blends and additive with optimum values of RSM parameters, here evaluation of performance parameters were extensively carried out.

II. MATERIALS AND METHODS

A. Engine Test Setup

Fig.1. Actual system of Computerized SI engine Test Rig with Exhaust Gas Analyzer

The testing of performance and emission features was performed on a four-stroke, one-cylinder, computerized SI motor with variable compression ratio. Table.I indicates engine specifications. The engine configuration supplied with gasoline engine, eddy current dynamometer, and multi-fuel tank is shown in Fig.1. It includes a system for data acquisition, a computer, an operating panel and an analyzer for exhaust gas. To measure the pressure of combustion, crank-angle, airflow, fuel flow, temperature and load, the required measurements are provided. The engine operates with programmable Open ECU, Throttle Position Sensor (TPS), fuel pump, ignition spray coil, fuel spray nozzle, trigger sensor, etc. The engine efficiency involves BTE, Mechanical Efficiency, and BSFC measurements. Enginesoft is a software package based on Lab-view, which can serve most of the application testing requirements including surveillance, reporting, data entry and information logging. The computer code is used to evaluate energy, efficiencies, fuel consumption and analysis of combustion. Various graphs are obtained and the results have been tabulated under separate working conditions.

Table I. Engine Specifications

Specifications	Details
Product	Research Engine test setup single cylinder, 4-stroke, Multifuel, VCR.
Engine	Single cylinder, 4-stroke, water cooled, stroke length 110 mm, bore 87.5 mm, 661 cc. Petrol Mode: 4.5 kW@ 1800 rpm, Speed range 1200-1800 rpm, CR range 6-10,
Dynamometer	Type eddy current, water cooled, with loading unit
ECU	PE3 Series ECU, Model PE3-8400P, full build, potted enclosure. Includes
Piezo Sensor	Combustion: Range 350Bar, Diesel line: Range 350 bar,
Crank Angle Sensor	Resolution 1 Deg, Speed 5500 RPM with TDC pulse.
Data Acquisition Device	NI USB-6210, 16 bit, 250kS/s.
Air Flow Transmitter	Pressure transmitter, Range (-) 250 mm WC
Software	"Enginesoft" Engine performance analysis software

B. Experimental Methods

Around seven test fuels were prepared by mixing ethanol with gasoline. Fuel accessible in the market is mixed with ethanol, according to the Supreme Court Directions Government of India made compulsory for the expansion of 5% ethanol into accessible gasoline in the market it is spoken to as E5. Remaining test fills are E10 (10% Ethanol + 90% Gasoline), E15 (15% Ethanol + 85% Gasoline), E-20 (20% Ethanol + 80% Gasoline), E25 (25% Ethanol + 75% Gasoline), E30 (30% Ethanol + 70% Gasoline), and E35 (35% Ethanol + 65% Gasoline). At first, physical properties were evaluated for various mixes utilizing standard testing techniques according to ASTM-D, which were promising as better as unadulterated gasoline fuel. Further, it is additionally seen that exhibition and engine outflows qualities were ideal. To improve the fuel Octane rating it is basic practice to include additives, Toluene and Iso-Octane for better execution of fuel mixes.

The expansion of additives into ethanol - Gasoline mixes are set up in the extent of 3% to 5% and tried on engine till results are promising. Fig. 1 demonstrates the genuine engine arrangement which is given a gasoline engine, swirl current dynamometer, and Multi-fuel tank. In ANOVA examination, an estimation of p-value, which is under 0.05,

demonstrates that the components persevere through important impact at 95% certainty level [23]. High R2 esteem, proximate to 1, is attractive, and a conceivable acquiescence with adj R2 is mandatory [24]. It was withal demonstrated that the worth reactions for an AP more dominant than 4 mean a satisfactory sign implicatively hinting that these models can be habituated to explore the structure space [25]. The relapse measurements decency of fit (R2) and the integrity of foretell for the reactions of brake power were 89.38% and 87.69% separately [26] [27]. The gasoline-ethanol blends were set up in the proportion of 1:0.05(E5), 1:0.11(E10), 1:0.176(E15), 1:0.25(E20), 1:0.33(E25), 1:0.428(E30) and 1:0.538(E35). The second part of tests was set up by including 3%, 4%, and 5% Iso-octane as an added substance to E30 blend. The fuel blends were prepared just before the start of the examination, to ensure that the fuel organization is homogenous and counteract the response of ethyl liquor with H2O vapor. In this piece of investigation Design Expert Software (Version 11) has been utilized to create the estimations of advanced parameters. Three operational factors, for example, Speed, Compression Ratio and Blends likewise greatly affect execution parameters and outflow attributes of SI engine at a steady heap of 12kg; consequently these variables have been chosen as autonomous elements. Factor esteems have been chosen dependent on the detail of the engine. Table II shows the independent factors used in CCD for the optimization technique. Table II shows the independent factors used in central composite design (CCD) for the optimization technique.

Table II. Independent Parameters used in CCD for constant speed

Operating variable	Units	Low	High	-α	+α
Speed	rpm	1000	1500	829.552	1670.45
Compression Ratio		8	10	7.31821	10.6818
Blend	%	15	30	9.88655	35.1134

C. Optimization of Speed, Compression Ratio and Gasoline Ethanol Blends at Constant Load to minimize BSFC and maximize BTE

Experiments were conducted as per Experimental matrix shown in Table III to find minimum BSFC. Twenty experiments were conducted by varying the Speed, Compression Ratio and Blend. It is clear that experimental BSFC has its minimum value of 0.65kg/kW-hr at 1250rpm speed, Compression Ratio of 9 and 22.5% blend. Predicted BSFC has its minimum value of 0.6514kg/kW-hr at optimized operational conditions. There is difference of 0.22% in BSFC has observed between experimental and predicted value. Second performance parameter is Brake Thermal Efficiency (BTE) experimental matrix obtained after the analysis. The experimental matrix of CCD is given in Table III. Examinations were done according to the test matrix in Table

3 to discover improved BTE. From Table III it is clear that experimental BTE has its maximum value of 33.89 % at constant Load, Compression Ratio of 10, Speed of 1670.45rpm (≈1671rpm) and 22.5% blend. Predicted BTE has its maximum value of 33.65 % at optimized operational conditions. There is increase of 0.71% in BTE has observed between experimental and predicted value.

D. Optimization of Speed, Compression Ratio and Gasoline Ethanol Blends at Constant Load to minimize CO, HC, NO_2 and CO_2

The following Table IV represents the optimized values for the emission test for CO, HC, NO_2 and CO_2 at constant load. Experiments were carried out as per Experimental matrix shown in Table IV to find minimum CO. From Table IV it is clear that experimental CO has its minimum value of 0.0298% at 1250rpm speed, Compression Ratio of 9 and 35.1134%(≈35%, E30) blend. Predicted CO has its minimum value of 0.0227% at optimized operational conditions. There is decrease of 23.83% in CO has observed between experimental and predicted value. As per experimental matrix shown in Table IV represents minimum HC, From Table IV it is clear that experimental HC has its minimum value of 59ppm at 1500rpm speed, Compression Ratio of 10 and Blend of 30% percentage. Predicted HC has its minimum value of 59.24ppm at optimized operational conditions. There is decrease of 0.41% in HC has observed between experimental and predicted value. From Table IV it is also clear that experimental NO_2 has its minimum value of 84% at 1250rpm speed, 9 Compression Ratio and blend of 22.5% (E22.5). Predicted NO_2 has its minimum value of 84.5% at above optimized operational conditions. There is decrease of 0.59% in NO_2 has been observed between experimental and predicted value. Experiments were also carried out to find minimum CO_2. From Table IV it is observed that experimental CO2 has its minimum value of 3.92% at 1250rpm Speed, 10%(E10) blend and Compression Ratio of 9.88655(≈10). Predicted CO_2 has its minimum value of 3.96% at above optimized operational conditions. There is decrease of 1.01% in CO_2 has observed between experimental and predicted value.

E. Optimization of speed, Compression Ratio and additive Iso-Octane at Constant Load to minimize BSFC and maximize BTE

In this investigation Design Expert Software (Version 11) has been utilized to create the estimations of improvement parameters. Three operational factors, for example, Speed, Compression Ratio and Additives additionally greatly affect execution parameters and emissions of SI engine at a Constant load of 12kg. Table V shows the independent factors used in CCD for the optimization technique and the independent factors used in central composite design (CCD) for the optimization technique.

Table V. Independent Parameters Used In CCD For Constant Speed

Operating variable	Units	Low	High	-α	+α
Speed	rpm	1000	1500	1000	1670.45
Compression Ratio		8	10	7.31821	10.6818
Additive	%	0.3	0.5	0.231821	0.568179

Experiments were carried out as per Experimental matrix shown in Table VI to find minimum BSFC. Twenty experiments were conducted by

varying the Speed from 1000rpm to 1500rpm, compression ratio from 8 to 10 and additive of 0.3% to 0.5%. From Table VI it is clear that experimental BSFC has its minimum value of 0.39kg/kW-hr at 1250rpm speed, Compression Ratio of 9 and additive of 0.4%. Predicted BSFC has its minimum value of 0.3468kg/kW-hr at above optimized operational conditions. There is difference of 11.08% in BSFC has observed between experimental and predicted value. Second performance parameter is Brake Thermal Efficiency (BTE) experimental matrix obtained after the analysis. Experiments were carried out as per experimental matrix shown in Table VI to find maximum BTE. From Table VI it is clear that experimental BTE has its maximum value of 35.64 % at constant Load, Compression Ratio of 10.6818(≈11), Speed of 1250rpm and 0.4% of Iso-Octane additive. Predicted BTE has its maximum value of 34.49 % at above optimized operational conditions. There is increase of 3.33% in BTE has observed between experimental and predicted value.

F. Optimization of Speed, Compression Ratio and Gasoline Ethanol Blends at Constant speed to minimize CO, HC, NO_2 and CO_2 with additive Iso-octane

As per Experimental matrix shown in Table VII the experiments were carried out to find minimum CO. From Table VII it is clear that experimental CO has its minimum value of 0.0340% at 1250rpm speed, Compression Ratio of 10.6818(≈11) and additive 0.4%. Predicted CO has its minimum value of 0.0335% at optimized operational conditions. There is decrease of 1.47% in CO has observed between experimental and predicted value. From Table VII it is clear that experimental HC has its minimum value of 64ppm at 1250rpm speed, Compression Ratio of 9 and additive of 0.4 percentages. Predicted HC has its minimum value of 63.12ppm at optimized operational conditions. There is decrease of 1.38% in HC has observed between experimental and predicted value. From Table VII it is clear that experimental NO_2 has its minimum value of 30% at 1250rpm speed, 9 Compression Ratio and additive Iso-Octane of 0.4%. Predicted NO2 has its minimum value of 32.17% at optimized operational conditions. There is decrease of 2.56% in NOx has observed between experimental and predicted value. Experiments were carried out as per Experimental matrix shown in Table VII to find minimum CO_2. From Table VII it is clear that experimental CO_2 has its minimum value of 3.12% at 829.552(≈830) rpm Speed, Compression Ratio of 9 and Additive 0.4%. Predicted CO_2 has its minimum value of 2.97% at optimized operational conditions. There is decrease of 4.81% in CO_2 has observed between experimental and predicted value.

III. RESULTS AND DISCUSSION

A. Interactive Effect of Ethanol-Gasoline Blends at constant Load

Statistical method RSM is used for modelling and analyzing the resulting responses to evaluate the characteristics of SI engine running on gasoline-ethanol blends with variable speed at constant loading conditions. The interactive effect of this methodology of engine testing is under taken as follows, initially the input parameters are identified which influences the performance and emission characteristics. To evaluate above characteristics, seven (E5 to E35) ethanol-gasoline blends with different additives (3 to 5%) were selected for a given compression ratio 10, maximum constant load of 9kg at variable speed from 1200 to 1800rpm. The limits of the input parameters were selected with the permissible limits in CCD matrix as independent parameters with modifications on the basis of engine setup. Most of the investigation begins with DoE, contains 20 trials in the examination on the engine over the whole scope of information parameters with least tests. Aftereffects of engine testing were broke down utilizing a second-request polynomial condition utilizing DoE. Utilizing Design Expert programming rendition 11 is utilized for coefficients and conditions to assess the reactions. At that point, the streamlined qualities for the given info parameters were acquired by the RSM's allure approach which is recorded in the last part.

▪ **Brake Specific Fuel Consumption (BSFC)**

Fig.2 shows the 3D plot for the effect of the engine speed and Compression Ratio (CR) on BSFC at constant Load. With increase in load, BSFC decreases and reaches minimum value at CR of 9 and then increases for a given compression ratio. At the same time with the increase in compression ratio, BSFC decreases, reaching minimum value at compression ratio of 9 for a given speed 1250rpm. In the meantime with the further rise in compression ratio, BSFC increases, reaching maximum value at compression ratio of 10 for a given Speed. The model equation based on coded values for minimum BSFC is shown in Equation (1).

$$BSFC = (0.6514+0.0120X_1 - 0.0066X_2 - 0.05X_3 + 0.01X_1X_2 - 0.0125 X_1X_3 - 0.00250X_2X_3 + 0.1093X_1^2 + 0.0739X_2^2 + 0.0616X_3^2)$$
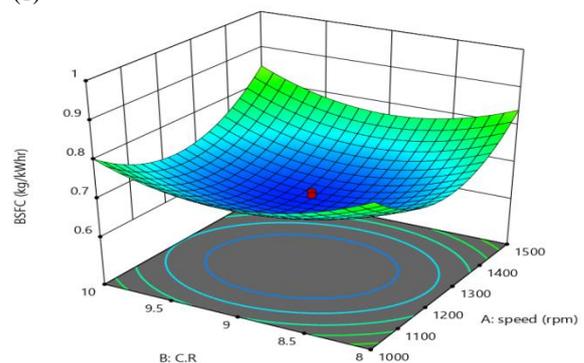(1)

Fig. 2 3D Plot for the effect of BSFC to the Speed and Compression Ratio (CR) at constant Load.
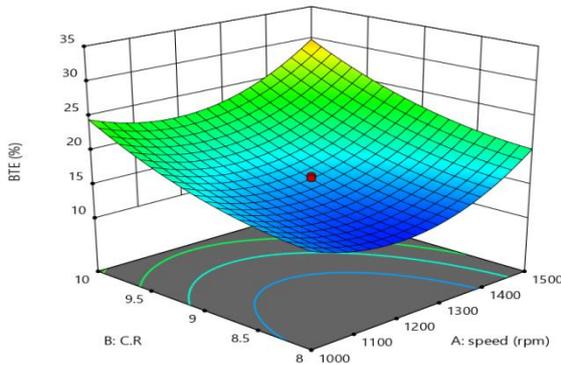
▪ **Brake Thermal Efficiency(BTE)**

Fig. 3 3D Plot for the effect of BTE to the Speed and compression ratio (CR) at constant Load.

Fig.3 shows the 3D plot for the effect of the engine Speed and compression ratio (CR) on BTE at constant Load. With increase in Speed, BTE increases and reaches maximum value at 1500rpm speed and then decreases for a given compression ratio. At the same time with the rise in Compression Ratio, increases value of BTE, reaching highest value at Compression Ratio of 10 for a given speed. The model Equation (2) based on coded values for minimum BTE equation is as shown below,

$$BTE = (15.88 + 2.57 X_1 + 4.72 X_2 - 3.07 X_3 + 0.0687 X_1 X_2 - 2.38 X_1 X_3 + 3.12 X_2 X_3 + 4.75 X_1^2 + 1.87 X_2^2 + 0.7230 X_3^2) \quad (2)$$

- **Carbon Monoxide (CO)**

Fig.4 shows the 3D plot for the effect of the engine speed and compression ratio (CR) on CO at constant load. With increase in Speed, CO increases and reaches maximum value at 1500rpm speed and then decreases for a given compression ratio. At the same time with the increase in compression ratio, CO decreases, reaching minimum value 0.0298% at compression ratio of 9 for a given Speed 1250rpm. The model equation based on coded values for minimum CO is shown in Equation (3),

$$CO = (0.1234 + 0.0124 X_1 - 0.0113 X_2 - 0.0259 X_3 + 0.0009 X_1 X_2 + 0.0019 X_1 X_3 + 0.0104 X_2 X_3 - 0.0052 X_1^2 + 0.0104 X_2^2 - 0.0202 X_3^2) \quad (3)$$
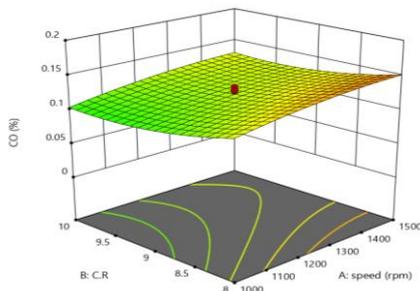

Fig. 4 3D Plot for the effect of CO to the Speed and compression ratio (CR) at constant Load.
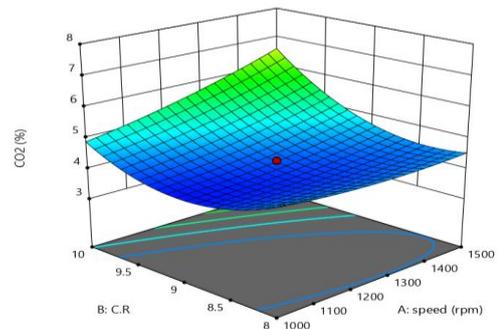
- **Corbon Dioxide (CO₂)**

Fig. 5 3D Plot for the effect of CO₂ to the Speed and Compression Ratio (CR) at constant Load.

Fig.5 shows the 3D plot for the effect of the engine speed and compression ratio (CR) on CO_2 at constant Load. With increase in Load, CO_2 decreases and reaches minimum value 3.92% at given load and then increases for a given compression ratio. At the same time with the increase in compression ratio, CO_2 increases, reaching maximum value at compression ratio of 9 for a given Load. The model equation based on coded values for minimum CO_2 is shown in Equation (4),

$$CO_2 = (4.24 + 0.38666 X_1 + 0.5678 X_2 + 0.3939 X_3 + 0.4650 X_1 X_2 + 0.2325 X_1 X_3 + 0.3250 X_2 X_3 + 0.1453 X_1^2 + 0.7923 X_2^2 + 0.135 X_3^2) \quad (4)$$

- **Hydrocarbon(HC)**

Fig.6 shows the 3D plot for the effect of the engine Speed and compression ratio (CR) on HC at constant Load. With increase in Speed, HC increases and reaches maximum value at 1500rpm Speed and then increases for a given compression ratio. At the same time with the increase in compression ratio, HC increases, reaching maximum value at compression ratio of 9 for a given Speed. The model equation based on coded values for minimum HC is shown in Equation (5),

$$HC = (95.48 + 18.11 X_1 - 0.8820 X_2 - 16.78 X_3 - 1.88 X_1 X_2 - 26.38 X_1 X_3 - 16.13 X_2 X_3 + 9.12 X_1^2 - 9.44 X_2^2 + 7 X_3^2) \quad (5)$$

Fig. 6 3D Plot for the effect of HC to the Speed and compression ratio (CR) at constant Load.

- **Nitrogen Dioxide (NO₂)**

Fig.7 shows the 3D plot for the effect of the engine speed and compression ratio (CR) on NO_2 at constant Load. With increase in Speed, NOx decreases and reaches minimum value of 84% at 1250rpm speed and then increases for a given compression ratio. At the same time with the increase in compression ratio, NO_2 increases, reaching maximum value at compression ratio of 10 for a given load. The model equation based on coded values for minimum NO_2 is shown in Equation (6),

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$$NO_2 = (85.5 + 2.65\, X_1 -- 0.1964\, X_2 - 7.69 X_3 + 5.38\, X_1\, X_2 - 0.8750 X_1 X_3 + 1.38 X_2\, X_3 + 2.86\, X_1{}^2 + 1.09\, X_2{}^2 + 13.11\, X_3{}^2)$$
$$(6)$$

Fig. 7 3D Plot for the effect of NO$_2$ to the Speed and Compression Ratio (CR) at constant Load.

B. Interactive Effect of Ethanol-Gasoline Blend with Additive at constant Load
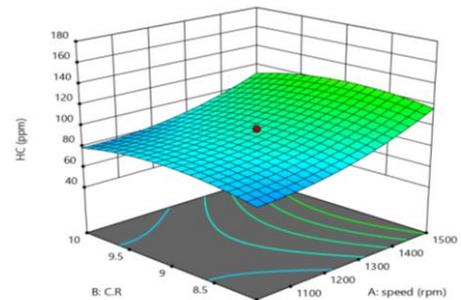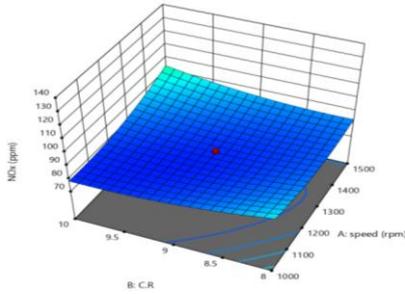
- **Brake specific Fuel consumption(BSFC)**

Fig. 8 3D Plot for the effect of BSFC to the Speed and compression ratio (CR) at constant Load.

Fig.8 shows the 3D plot for the effect of the engine speed and Compression Ratio (CR) on BSFC at constant Load. With increase in Speed, BSFC decreases and reaches minimum value at 9 CR and then increases for a given compression ratio. At the same time with the increase in compression ratio, BSFC decreases, reaching minimum value at compression ratio of 9 for a given speed 1250rpm. At the same time with the further increase in compression ratio, BSFC increases, reaching maximum value at compression ratio of 10 for a given Speed. The model equation based on coded values for minimum BSFC is shown in Equation (7),

$$BSFC = (0.4168 - 0.0292 X_1 - 0.0568 X_2 - 0.0142 X_3 - 0.0513 X_1 X_2 - 0.0288 X_1 X_3 - 0.0133 X_2 X_3 + 0.0676 X_1{}^2 + 0.1118 X_2{}^2 + 0.0765 X_3{}^2)$$
$$(7)$$

- **Brake Thermal Efficiency (BTE)**

Fig.9 shows the 3D -plot for the effect of the engine Speed and compression ratio (CR) on BTE at constant Load. With increase in Speed, BTE increases and reaches maximum value at 1500rpm speed and then decreases for a given compression ratio. At the same time with the increase in compression ratio, BTE increases, reaching maximum value 35.64% at compression ratio of 10.6818 (≈11) for a given speed 1250rpmThe model equation based on coded values for minimum BTE is as shown in Equation (8),

$$BTE = (23.82 + 0.2973 X_1 + 0.4179 X_2 + 0.7845\ X_3 - 1.1 X_1\ X_2 - 0.3538 X_1 X_3 + 2.05 X_2 X_3\ + 3.74 X_1{}^2 - 2.74 X_2{}^2 + 0.8482 X_3{}^2)$$
$$(8)$$

Fig. 9 3D Plot For The Effect Of BTE To The Speed And Compression Ratio (CR) At Constant Load.
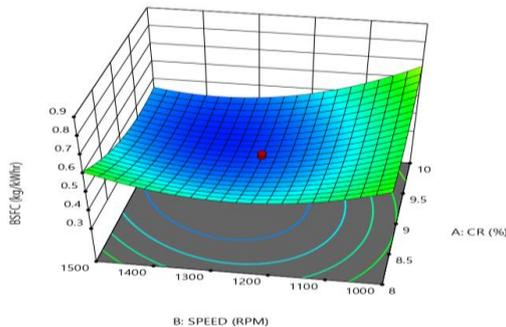
- **Carbon monoxide (CO)**

Fig. 10 3D Plot for the effect of CO to the speed and compression ratio (CR) at constant Load.

Fig.10 shows the 3D plot for the effect of the engine speed and compression ratio (CR) on CO at constant Load. With increase in Speed, CO increases and reaches maximum value at 1500rpm speed and then decreases for a given compression ratio. At the same time with the increase in compression ratio, CO decreases, reaching minimum value of 0.0340% at compression ratio of 10.6818(≈11) for a given Speed. The model equation based on coded values for minimum CO is shown in Equation (9),

$$CO = (0.1234 + 0.0124\, X_1 - 0.0113\, X_2 - 0.0259\, X_3 + 0.0009\, X_1\, X_2 + 0.0019\, X_1\, X_3 + 0.0104\, X_2\, X_3 - 0.0052\, X_1{}^2 + 0.0104\, X_2{}^2 - 0.0202\, X_3{}^2)$$
$$(9)$$

- **Hydro carbon (HC)**

Fig. 11 3D Plot for the effect of HC to the speed and compression ratio (CR) at constant Load.

Fig.11 shows the 3D plot for the effect of the engine speed and compression ratio (CR) on HC at constant Load. With increase in Speed, HC increases and reaches maximum value at 1500rpm speed and then increases for a given compression ratio. At the same time with the increase in compression ratio, HC increases, reaching maximum value at compression ratio of 9 for a given Speed. The model equation based on coded values for minimum HC is shown in Equation (10),

$$HC = (68.84 + 2.11\,X_1 + 2.620X_2 + 3.06\,X_3 - 0.875\,X_1\,X_2 - 3.13\,X_1X_3 + 4.62X_2\,X_3 + 5.86\,X_1^2 + 10.98\,X_2^2 + 4.27X_3^2)$$
(10)

- **Carbon Dioxide (CO$_2$)**

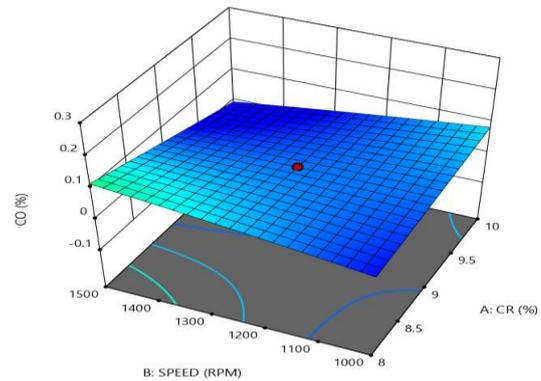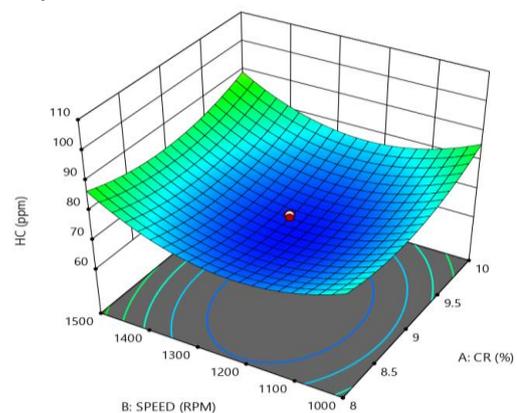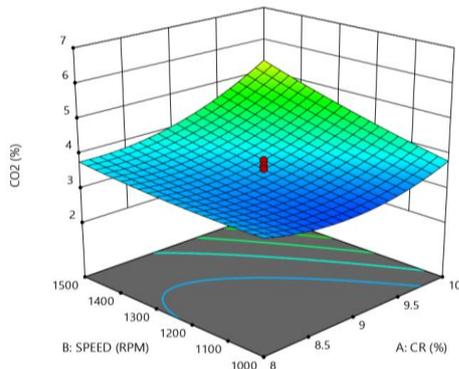**Fig.12 3D Plot for the effect of CO$_2$ to the speed and Compression Ratio (CR) at constant Load.**

Fig.12 shows the 3D -plot for the effect of the engine speed and compression ratio (CR) on CO$_2$ at constant Load. With increase in speed, CO$_2$ decreases and reaches minimum value 3.12% at speed 830rpm and then increases for a given compression ratio. At the same time with the increase in compression ratio, CO$_2$ increases, reaching maximum value at compression ratio of 10 for a given speed. The model equation based on coded values for minimum CO$_2$ is shown in Equation (11),

$$CO_2 = (3.57 + 0.4628X_1 + 0.4515\,X_2 + 0.2325X_3 + 0.3287X_1\,X_2 - 0.0237X_1X_3 + 0.2138\,X_2\,X_3 + 0.4656\,X_1^2 + 0.0890X_2^2 + 0.5663X_3^2)$$
(11)

- **Nitrogen Dioxide (NO$_2$)**

Fig.13 shows the 3D plot for the effect of the engine speed and compression ratio (CR) on NO$_2$ at constant Load. With increase in Speed, NO$_2$ decreases and reaches minimum value of 30ppm at 1250rpm speed and then increases for a given compression ratio. At the same time with the increase in compression ratio, NO$_2$ increases, reaching maximum value at compression ratio of 10 for a given Speed. The model equation based on coded values for minimum NO$_2$ is shown in Equation (12),

$$NO_2 = (32.17 + 8.65\,X_1 + 3.29X_2 - 1.57X_3 - 3.38\,X_1\,X_2 + 4.12X_1X_3 - 6.88X_2\,X_3 + 11.94X_1^2 + 6.10X_2^2 + 14.47X_3^2)$$
(12)

Fig. 13 3D Plot for the effect of NO$_2$ to the speed and Compression Ratio (CR) at constant Load.

Table- III: Experimental matrix of CCD for BSFC and BTE

Std	Run	Speed (rpm)	CR	Blend	BSFC*, kg/kW-hr	BSFC#, kg/kW-hr	BTE*, %	BTE#, %
2	1	1250	8	15	0.9100	0.9095	23.36	23.08
20	2	1500	9	22.5	0.9800	0.9765	32.86	32.92
3	3	1670.45	10	15	0.9800	0.9807	33.89	33.65
12	4	1500	10.6818	22.5	0.9600	0.9648	29.23	29.58
7	5	1250	10	30	0.6700	0.6514	15.63	15.88
13	6	1250	9	9.88655	0.6600	0.6514	15.96	15.88
6	7	1250	8	30	0.6600	0.6514	15.87	15.88
8	8	1500	10	30	0.8500	0.8465	28.23	28.25
17	9	1250	9	22.5	0.8700	0.8716	13.56	13.24
1	10	1250	8	15	0.8400	0.8493	28.99	29.10
10	11	1250	9	22.5	0.6500	0.6514	16.34	15.88
15	12	1000	9	22.5	0.8700	0.8658	12.12	12.21
9	13	1250	9	22.5	0.6600	0.6514	15.87	15.81
19	14	1250	9	22.5	0.6500	0.6514	15.87	15.81
18	15	1250	9	22.5	0.7500	0.7414	12.89	12.76
4	16	1000	10	15	0.8400	0.8275	27.94	27.73
14	17	1500	9	35.1134	0.8500	0.8448	12.36	12.45
11	18	1000	7.31821	22.5	0.9100	0.9075	22.82	22.87
5	19	829.552	8	30	0.9400	0.9403	25.96	25.00
16	20	1000	9	22.5	0.9400	0.9357	19.69	19.81

Note: * Experimental value, **#** Predicted value

Table- IV: Experimental matrix of CCD for emission parameters

Std	Run	Speed (rpm)	CR	Blend (%)	CO*, %	CO#, %	HC*, ppm	HC#, ppm	NO$_2$*, %	NO$_2$#, %	CO$_2$*, %	CO$_2$#, %
2	1	1250	9	9.88655	0.1140	0.1097	144.00	144.51	135.00	135.52	3.92	3.96

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20	2	1500	10	15	0.1210	0.1240	178.00	177.80	118.00	117.58	5.80	5.78
3	3	1670.45	9	22.5	0.1320	0.1295	153.00	152.74	98.00	98.04	5.24	5.30
12	4	1500	8	15	0.1630	0.1655	151.00	151.07	110.00	109.97	4.41	4.36
7	5	1250	9	22.5	0.1340	0.1234	97.00	96.48	85.00	85.50	4.30	4.24
13	6	1250	9	22.5	0.1280	0.1234	96.00	96.48	87.00	85.50	4.10	4.24
6	7	1250	9	22.5	0.1290	0.1234	96.00	96.48	86.00	85.50	4.27	4.24
8	8	1500	10	30	0.0960	0.0967	59.00	59.24	103.00	103.20	7.76	7.68
17	9	1250	7.31821	22.5	0.1710	0.1717	71.00	71.27	89.00	88.92	5.52	5.52
1	10	1250	10.6818	22.5	0.1360	0.1338	68.00	68.31	88.00	88.26	7.36	7.43
10	11	1250	9	22.5	0.1290	0.1234	98.00	96.48	86.00	85.50	4.25	4.24
15	12	1000	8	30	0.0720	0.0700	110.00	109.79	97.00	97.30	4.69	4.66
9	13	1250	9	22.5	0.1080	0.1234	96.00	96.48	84.00	84.50	4.25	4.24
19	14	1250	9	22.5	0.1320	0.1234	96.00	96.48	86.00	85.50	4.27	4.24
18	15	1250	9	35.1134	0.0298	0.0227	88.00	88.07	110.00	109.65	5.24	5.28
4	16	1000	10	30	0.0680	0.0665	80.00	79.53	89.00	88.90	5.52	5.51
14	17	1500	8	30	0.0980	0.0968	97.00	97.00	90.00	90.09	4.96	4.97
11	18	1000	10	15	0.0990	0.1013	93.00	92.59	100.00	99.79	4.60	4.54
5	19	829.552	9	22.5	0.0870	0.0880	91.00	91.84	89.00	89.14	3.98	4.00
16	20	1000	8	15	0.1460	0.1463	144.00	144.51	114.00	113.68	4.96	4.98

Note: * Experimental value, # Predicted value

Table.VI: Experimental matrix of CCD for BSFC and BTE with additive Iso-octane

Std	Run	CR	Speed (rpm)	Additive (%)	$BSFC^*$, kg/kW-hr	$BSFC^\#$, kg/kW-hr	BTE^*, %	$BTE^\#$, %
2	1	10	1000	0.3	0.7900	0.7833	28.57	28.27
18	2	9	1250	0.4	0.4100	0.4168	23.89	23.82
3	3	8	1500	0.3	*0.6900*	*0.6930*	*23.97*	*23.70*
11	4	9	829.552	0.4	0.8200	0.8286	15.43	15.38
9	5	7.31821	1250	0.4	0.6600	0.6571	33.98	33.89
12	6	9	1670.45	0.4	0.6500	0.6375	16.57	16.78
4	7	10	1500	0.3	0.5800	0.5896	22.96	22.80
16	8	9	1250	0.4	0.4200	0.4168	23.89	23.82
17	9	9	1250	0.4	*0.4100*	*0.4168*	*23.49*	*23.82*
10	10	10.6818	1250	0.4	0.5600	0.5590	35.64	34.49
20	11	9	1250	0.4	0.4400	0.4168	23.89	23.82
7	12	8	1500	0.5	0.6900	0.6995	29.89	30.08
8	13	10	1500	0.5	*0.4800*	*0.4812*	*27.97*	*27.76*
19	14	9	1250	0.4	0.4300	0.4168	23.89	23.82
5	15	8	1000	0.5	*0.7400*	*0.7332*	*22.89*	*22.94*
15	16	9	1250	0.4	0.3900	0.3468	23.92	23.82
6	17	10	1000	0.5	0.7200	0.7198	24.87	25.03
14	18	9	1250	0.568179	0.6100	0.6091	27.71	27.54
13	19	9	1250	0.231821	0.6600	0.6569	28.57	28.27
1	20	8	1000	0.3	0.7900	0.7833	23.89	23.82

Note: * Experimental value, # Predicted value

Table.VII: Experimental matrix of CCD for CO, HC, NO2 and CO₂ with additive Iso-octane

Std	Run	CR	Speed (rpm)	Additive (%)	CO^*, %	$CO^\#$, %	HC^*, ppm	$HC^\#$, ppm	NO_2^*, %	$NO_2^\#$, %	CO_2^*, %	$CO_2^\#$, %
2	1	10	1000	0.3	0.0890	0.0895	95.00	94.99	62.00	61.98	4.82	4.38
18	2	9	1250	0.4	0.0590	0.0604	69.00	68.84	33.00	32.17	3.87	3.57
3	3	8	1500	0.3	*0.1830*	*0.1828*	*80.00*	*80.52*	*72.00*	*73.26*	*3.96*	*3.88*
11	**4**	**9**	**829.552**	**0.4**	0.0560	0.0551	95.00	95.49	43.00	43.91	**3.12**	**2.97**
9	5	7.31821	1250	0.4	0.0940	0.0939	82.00	81.86	52.00	51.39	4.49	4.11
12	6	9	1670.45	0.4	0.0480	0.0483	105.00	104.31	56.00	54.95	4.68	4.28
4	7	10	1500	0.3	0.0410	0.0419	89.00	89.24	76.00	75.55	5.87	5.51
16	8	9	1250	0.4	0.0620	0.0604	69.00	68.84	34.00	32.17	3.68	3.57
17	9	9	1250	0.4	*0.0610*	*0.0604*	*70.00*	*68.84*	*33.00*	*32.17*	*3.87*	*3.57*
10	**10**	**10.6818**	**1250**	**0.4**	**0.0340**	**0.0335**	89.00	88.95	80.00	80.47	5.69	5.60
20	11	9	1250	0.4	0.0620	0.0604	69.00	68.84	33.00	32.17	3.58	3.17
7	12	8	1500	0.5	0.1660	0.1659	102.00	102.15	48.00	48.12	4.87	4.12
8	13	10	1500	0.5	*0.0650*	*0.0641*	*98.00*	*98.36*	*66.00*	*66.91*	*6.69*	*6.36*
19	**14**	**9**	**1250**	**0.4**	0.0590	0.0604	**64.00**	**63.12**	34.00	32.17	3.87	3.57
5	15	8	1000	0.5	*0.1270*	*0.1265*	*86.00*	*85.90*	*48.00*	*48.55*	*4.18*	*4.11*
15	16	9	1250	0.4	0.0590	0.0604	68.00	68.84	**30.00**	**32.17**	3.84	3.57

6	17	10	1000	0.5	0.1950	0.1956	86.00	85.61	82.00	80.84	4.48	4.37
14	18	9	1250	0.56817	0.2590	0.2597	86.00	86.05	65.00	64.79	5.48	5.16
13	19	9	1250	0.23182	0.1860	0.1847	76.00	75.75	70.00	70.07	4.87	4.28
1	20	8	1000	0.3	0.0580	0.0593	83.00	82.78	47.00	46.19	4.12	4.06

Note: * Experimental value, **#** Predicted value

IV. OPTIMIZATION

From the statistical tool RSM using Design Expert software for optimization of responses governed by desirability parameters approach, several optimal solutions were obtained between the objective function seen between 0 and 1[26]. The prominent responses will vary from 1 to 5 that indicate the minimum to maximum significant responses. In the event that the estimation of importance is indistinguishably equivalent for the majority of the reactions, the estimation of the target capacity will be diminished to the standard conditions for desirability. The point anticipation predicated on the criteria to decide ideal execution and discharges attributes. In the present analysis the desirability value is 0.88 which results to the model developed satisfies the model criteria [27]. The approval of results assigned that the models created was very exact as the level of blunder in the forecast was in a decent acquiescence. These results confirmation trials are not mandatory as the predicted error found to be 5% or even less [28]. Just one best arrangement has arrived from the collateral desirability approach. At a speed of 1229rpm, compression ratio 8.667 and constant loading 12kg, additive of 4% in E30 blend, the independent parameters for all combined responses desirability value is 81.5%. The performance characteristic BSFC is 0.439 kg/kW-hr and BTE is 24.82%. The emission parameters like CO of 6.4%, 68.359ppm of HC, 30.54ppm of NO_2 and 3.424% of CO_2 are the desirable emission parameters. For non-additive analysis at a speed of 1030rpm, compression ratio of 9.759 and ethanol blend of 30% the independent parameters for all combined responses desirability value is 72.8%. The performance characteristic BSFC is 0.778 kg/kW-hr and BTE is 24.03%. The desirable emission parameters are 6.59% of CO, 84.12ppm of HC, 89.51ppm of NO_2 and 5.153% of CO_2 are recorded.

V. CONCLUSION

In the current investigations the ethanol-gasoline blends with additive were tested and the results are analyzed for optimum engine performance and emissions for single cylinder, 4-stroke SI engine. Depending on the multiple experiments conducted by varying speed, compression ratio and at constant load. The experimental results were optimized using statistical tools with Design of Experiments from RSM technique. The prominent summary of the findings were drawn as following;

1. Experimental result analysis from ANOVA represents all designed models were found to be significant
2. Optimal blends of ethanol-gasoline were determined from statistical models of RSM, as 30% ethanol, 4% Iso-Octane additive found to be optimum at varied compression ratio, engine speed and constant engine loading.
3. Statistical methods of RSM in its mathematical models used enables to predict the non-experimental value using multiple regressions with the desirability approach.
4. The BSFC found to be low comparatively to pure Gasoline but BTE found nominal increase at optimum blending conditions.
5. In RSM we are chosen desirability approach which resulted as a promising technique, around 0.873 average desirability was obtained from statistically optimized performance and emission characteristics.

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