

# Optimization of Next-Generation Alcohols and Fishoil Methyl Ester Blends In a Single Cylinder DI-CI Engine Using Response Surface Methodology

Kiran Kumar Billa, G.R.K. Sastry, Madhujit Deb

**Abstract:** *The present investigation delivers a comprehensive viewpoint on the current artificial intelligence (AI) meta-modelling in diesel engine system, particularly in the domains of multi-objective optimization. The relevance to the benefits of AI built modelling stratagems, and the probable Response Surface Methodology has been efficient with the consecutive growth in the current domains of the compression ignition technology. The study establishes the fundamental significance of inspecting certain multi-objective optimization stratagems matching with the accumulating need to deal with emission-performance trade-off trials of the compression ignition technology. To achieve the reliability and versatility of such model centered multi-objective optimization strategies, the current study delivers a unique case-study presenting the creditably accurate model-based standardization in an existing diesel engine. Therefore, n-Octanol produced in renewable ways, methyl esters of fish oil (MEFO) blended with diesel is used as fuel and the experiments were designed by Design of Experiments (DoE) based on response surface methodology (RSM) architecture. The results depicted that the tailor-made fuels proved their ability in terms of both performance and emissions when compared to mineral diesel. The model is further tested on a statistical platform with some special error matrices like Mean Squared Relative Error, MSRE, and Nash–Sutcliffe Coefficient of Efficiency, NCE along with conventional model testing metrics like MSE, RMSE and R which proved that the proposed model is robust and efficient in predicting the input-output paradigm. The ranges of correlation coefficients R, R2 and NCE are 0.99786 - 0.999992, 0.99786-0.999992 and 0.9957 - 0.999984 respectively. And the ranges of the error metrics Theil U2 and MSRE are 0.004048 0.065246 and 6.07E-07 to 0.000158 respectively. Optimization of input parameters was performed using the desirability approach of the response surface methodology for better performance and lower NOx and CO emission at a desirability index of 0.986. Experimental validation suggested a blend of 20% MEFO and 10% n-Octanol with petrodiesel at full loads were found to be optimal values for the test engine.*

**Keywords:** Performance; emission; NOx; CO; MORSM; MEFO;

## I. INTRODUCTION

Energy is a critical foundation in deciding the world's economy. Persistent Industrial development, raise in populace, and enhanced modus vivendi have led the demand and need for energy to increase steadily. Energy is a kernel to accomplish the interrelated objectives of present-day socio-economic goals to meet human needs. The overall

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energy utilization increments at the rate of 1.6% per annum, which will prompt the depletion of fossils assets somewhere in the range of 2050 and 2075 [1]. So, it is obligatory to move the energy supply framework from the non-renewable energy source to the renewable fuel source. Biodiesel is generally utilized as a possible substitute for non-renewable energy source since they are less toxic, natural and furthermore, they have the burning properties like petrodiesel. Extensive research was going in the alternative fuels from decades in these fields and found some alternatives for petrodiesel that can be used in existing engines without any engine modifications [2]. Biodiesel can be extricated from vegetable oils as well as animal fats and transesterified with methyl/ethyl alcohols to frame alkyl esters [3][4]. According to a reliable survey, an exorbitant amount of fish parts is discarded by various fish food processing industries consistently. The Central Institute of Fisheries Technology (CIFT) expressed that over one lakh tonnes of shrimps are generated annually. As per the International Fishmeal and Fishoil Organization (IFFO), the annual fish oil generation is 1.01 million tons worldwide and is anticipated to raise in ten folds in the next five years [5]. Therefore fish oil appears to be excellent feedstock for biodiesel and an alternative to petrodiesel by decreasing the venom due to emissions and guaranteeing energy security. A few analysts investigated the execution and emanation qualities of fish oil biodiesel. The test outcomes demonstrated that the engines worked efficiently with overall efficiency and decrease in emission discharges [6]–[8]. CO and CO<sub>2</sub> emissions are considerably lowered with the blends of fish oil biodiesel [9], [10] and [11] considered the engine performance, ignition and emission attributes of fish oil fuel in a heavy-duty CI engine by differing the blends from 0% to 100% in the interim of 25% and half. The test outcomes demonstrated that the test engine worked normally guaranteeing its appropriateness as a beneficial fuel. Hence, the potential advantages of fish oil biodiesel are utilized in the study. Higher alcohols are less destructive on petrodiesel injection and conveyance courses of action because of their significantly less hygroscopic behaviour than ethanol getting consideration comprehensively. With its incredible miscibility with the petrodiesel, these higher alcohols are promising petrodiesel added chemical substances [12]. Redefining the biodiesel with the aid of higher alcohols like n-octanol is a practical choice to upgrade biodiesel properties all together to enhance the execution in petrodiesel engine applications. Methods for different renewable procedures can create octanol isomers, for example, inversion of beta-oxidation, expanding the 1-butanol conduit, redirecting

the biosynthesis of stretched chain amino acids. Biosynthesis of microorganisms like Clostridium and Escherichia coli species also catching attention. Fuel properties like lower Calorific value, cetane index and lower vapour pressure are better than other lower alcohols, which turned it to be an ideal choice as a biodiesel additive. The lower vapour pressures ensure better storage, road safety and handling.

Subsequently, the utilization of fuel to deliver a similar power yield is trivial. Besides, the oxygen-rich blends of n-Octanol felicitate complete combustions that produce least soot and the oxidation reduces the unburnt hydrocarbon production. The oxygen atoms limited by the fuel region impacts the ignition behaviour; intern decreases the cancer-causing discharges from the CI engine [13]. [14] et al. stated in their report that they utilized three distinct blends in the examinations are n-octanol, di-n-butyl ether (DBE) and n-octane. Each blend is tried on a Compression Ignition Engine, and the emanation results demonstrated that the soot is very low and NOx emanations are inside the satisfactory threshold of Euro 6 standards.

Additionally, the fuel properties are not significantly affecting the start, and the reactivity of the blends is influenced by the blend focuses. The increase in oxygen content by the inclusion of 1-octanol gives improved burning with improved thermal efficiency. [15] examined the impacts of 1-octanol as an additive with petrodiesel fuel in the proportion of 10%, 20%, 30% and 40% on a volume premise. The increase in 1-octanol portion to the petrodiesel fuel moderated the calorific value and increased the viscosity of the blends. The low blend proportion of 1-octanol brought about reduced fuel utilization, and this pattern is switched for the increase of octanol focus in the fuel blend. NOx discharge is lessened to 13.3% and 26.7% on behalf of 10% and 40% part of higher alcohol in petrodiesel. Hydrocarbon (HC) discharges of the 1-octanol combinations are higher than that of petrodiesel because of the joined impact of higher cetane index and heat evaporation. CO discharge is observed to be diminished for the higher alcohol combinations, and the most significant decrease of 23.8% is shown for 40% octanol combination at full loading condition.

Response surface methodology:

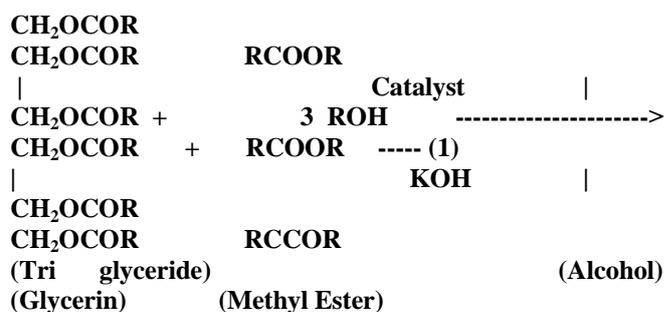
The automobile makers and application engineers believed that it is a tedious, complicated and costly task to run an engine for all possible loading conditions and blends at a time [16]. Demonstrating the engine job employing the artificial neural system and fuzzy logic to anticipate the engine parameters can be a substitute arrangement [17], [18]. Singh et al [19] announced that their model based on a stage is dynamic in enhancing the info parameters for a petrodiesel engine fuelled with biodiesel and petrodiesel combinations. With a low percentage error, the model is a proficient framework recognizable proof device and equipped for foreseeing the actual engine conduct with a praiseworthy exactness. [20] proposed their model using ANN and Fuzzy to predict and optimize engine behaviour with high fidelity. [21] proposed compared two models SVM and ANFIS based on SI engine data with laudable accuracy. Many successful models based on several mathematical models, were successful in predicting the engine behaviour [17], [22], [23]. Hence, Current study deals with performance emission paradigm of a biodiesel

driven engine and statistical analysis is done using Analysis of Variance (ANOVA) and some special metrics like NCE, KGE was optimization using RSM.

Therefore, to this degree, an express investigation necessarily tending to the level of enhancing performance, emanation trade-off view accomplished by offline alignment practices on existing Direct Injection petrodiesel engines under the skyline of existing outflow guidelines with higher alcohol like n-Octanol and fishoil biodiesel is yet to be addressed. From a thorough literature survey, just a bunch of works have been done, and the present examination shows a potential strategy dependent on demonstrating and streamlining that could analyze various blend structures for a Direct Injection Compression Ignition Engine and prescribe an appropriate blend exposure to no engine adjustments with reasonable accuracy. The present examination additionally conveys a MORSM based optimization using the engine responses of a full factorial structure grid planned by n-octanol per cent, biodiesel per cent, and Load per cent as information factors with the objective to propose an appropriate blend of the information factors by at the same time decreasing the engine responses like BTE, BSFC, NOx and CO has not been investigated yet and an undertaking is organized to stack this void.

## II. MATERIALS AND METHODS

The transformation process of waste fish oil into fish oil methyl ester is done through a specific process called Transesterification. The raw fish oil is heated to 50-60<sup>0</sup>C and maintained steady-state conditions. The essential catalyst KOH is added to the preheated raw oil and whole mixed up. Preheating avoids forming soap and thus allows to form pure methyl esters. The mixture is heated up to 70-80<sup>0</sup>C during which the viscosity reduces drastically. The content which was allowed to settle overnight had a thick layer of glycerol at bottom separated by a mush of biodiesel, catalyst and some calculated measure of alcohol. Water wash with aqueous phosphoric acid (4% v/v) is carried out to get the pure methyl ester. The content is then dried at 80<sup>0</sup>C and observed for chemical stability before analysis and Methyl Ester of Fish Oil (MEFO) is ready. The methyl esters of fish oil, MEFO thus obtained is clear slightly orange-yellow liquid with an intense smell. The methyl esters of Fish oil, MEFO is kept under observation for 72 hours to check the phase separation issues before it is used to blend. The transesterification process [17] is below.



The profile of the fish oil methyl ester was studied. The

chief fatty acids in fish oil biodiesel were palmitic acid (C16:0; 24.53 %), oleic acid (C18:1; 21.77 %) and docosahexaenoic (DHA; C22:6; 17.01 %). The high proportions of saturated fatty acids (33.5%) have improved the cetane number of methyl ester. The greater cetane

numbers of methyl ester have many benefits, such as lower NOX emissions, shorter ignition delay, and less tendency for detonation during the combustion process. The fatty acid profile of fish oil methyl ester of the present study is tabulated in Table 1.

**Table 1: Fatty acid profile of the methyl ester of the fish oil (MEFO) [5], [7], [24]**

Fatty acid	Mo.Wt	Formula	Trivial	Structure	Anchovy[7]	Mix[24]	Salmon[5]	This study
Myristic acid	228	C <sub>14</sub> H <sub>28</sub> O <sub>2</sub>	Tetradecanoic	C 14:0	6.71	4.98	5.08	4.71
Palmitic acid	256	C <sub>16</sub> H <sub>32</sub> O <sub>2</sub>	Hexadecanoic	C 16:0	20.2	19.42	15.39	24.53
Palmitoleic acid	254	C <sub>16</sub> H <sub>30</sub> O <sub>2</sub>	9-Hexadecanoic	C 16:1	6.59	6.43	7.55	5.7
Margaric acid	270	C <sub>17</sub> H <sub>34</sub> O <sub>2</sub>	Heptadecanoic	C 17:0	0.23	1.74	0.16	1.78
Stearic acid	284	C <sub>18</sub> H <sub>36</sub> O <sub>2</sub>	Octadecanoic	C 18:0	4.2	3.8	4	3.76
Oleic acid	282	C <sub>18</sub> H <sub>34</sub> O <sub>2</sub>	9-Octadecenoic	C 18:1 Omega 9	19.71	20.22	20.76	21.53
Linoleic acid	280	C <sub>18</sub> H <sub>32</sub> O <sub>2</sub>	9,12-Octadecadienoic	C 18:2 Omega 6	2.63	3.2	3.78	3.56
Linolenic acid	278	C <sub>18</sub> H <sub>30</sub> O <sub>2</sub>	9,12,15-Octadecadienoic	C 18:3	1.64	1.2	0.99	1.1
Arachidic	312	C <sub>20</sub> H <sub>40</sub> O <sub>2</sub>	Eicosanoic	C 20:0	-	3.56	0.15	4.7
Eicosadienoic acid	308.5	C <sub>20</sub> H <sub>36</sub> O <sub>2</sub>	Eicosadienoic	C 20:2	0.23	0.45	0.3	0.73
Arachidonic acid	304.4	C <sub>20</sub> H <sub>32</sub> O <sub>2</sub>	5,8,11,14-Eicosatetraenoic	C 20:4 Omega 6	0.79	2.2	2.08	2.41
Clupanodonic acid	330.5	C <sub>20</sub> H <sub>30</sub> O <sub>2</sub>	5,8,11,14,17-Eicosapentaenoic	C 20:5 Omega 3	10.41	7.8	9.49	
Behenic acid	340	C <sub>22</sub> H <sub>44</sub> O <sub>2</sub>	Docosanoic	C 22:0	0.82	1.25	5.03	2.22
DHA	339	C <sub>22</sub> H <sub>32</sub> O <sub>2</sub>	4,7,10,13,16,19-Decosahexaenoic	C 22:6 Omega 3	21.58	18.25	13.99	17.01
Saturated fatty acids				C 14–C 18:0	37.93	33.47	32.18	33.5
Unsaturated fatty acids				C 18:1,2,3	23.98	24.62	25.53	24.27
Long carbon-chain fatty acid				C 20–C 22	33.83	36.76	39.52	31.39

**Preparation of test fuels:**

The Fish oil biodiesel is mixed with anhydrous n-Octanol in different proportions as mentioned below. Total nine sample test fuel samples were prepared.

F20: 20% MEFO + 80% Mineral diesel

F20O5: 20% MEFO + 75% Mineral diesel + 5% n-Octanol

F20O10: 20% MEFO + 60% Mineral diesel + 10% n-Octanol

F30: 30% MEFO + 70% Mineral diesel

F30O5: 30% MEFO + 65% Mineral diesel + 5% n-Octanol

F30O10: 30% MEFO + 60% Mineral diesel + 10% n-Octanol

F40: 40% MEFO + 60% Mineral diesel

F40O5: 40% MEFO + 55% Mineral diesel + 5% n-Octanol

F40O10: 40% MEFO + 50% Mineral diesel + 10 % n-Octanol

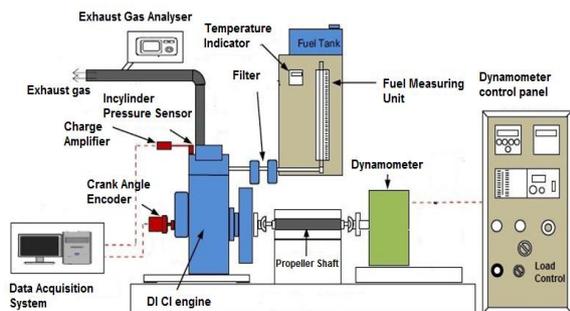
These samples were kept for 18 hours to check the homogeneity and chemical stability.

**Experimental Procedure:**

Experimental tests for performance and emission were conducted on a (Kirloskar make, 5hp 1500 rpm) computerized naturally aspirated petrodiesel engine of DI type. The test engine is fixed with the fuel injection at 27<sup>0</sup> before TDC. "ENGINE SOFT" software was employed for estimating the temperatures of exhaust gas, water inlet & outlet, engine aspiration, fuel consumption, brake power, brake specific fuel consumption, etc. The schematic engine diagram and the details of Test rig are given in fig 1, Table 2.



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**Fig 1. Schematic diagram of Engine setup**

**Table 2: Engine Specifications**

Sl.	Engine Components	Specifications
1	Make	Kirloskar Oil Engine Ltd.
2	Model	TV1
3	No. of Cylinders	1
4	No. of Strokes	4
5	Bore Dia.	87.5 mm
6	Stroke Length	110 mm
7	Compression Ratio	17.5
8	Cylinder Volume	661 cc
9	Cooling System	Water Cooled
10	Fuel Oil	H. S. Diesel
11	Lub. Oil	SAE 30/SAE 40
12	Fuel Injection	Direct Injection
13	Governing	Class "B1"
14	Start	Hand Start
15	Rated Output	3.5 kW
16	Rated Speed	1500 RPM
17	Overloading of Engine	10% of rated output
18	Lub.Oil Sump Capacity	3.7 Lt
19	Injection pressure	205 bar

The properties of base fuels is given in table: 3

**Table 3: Properties of base fuels.**

Property	DIESEL	n-Octanol	MEFO
Density at 15 <sup>o</sup> C	835	827	881
CN	52	39	50.1
KV at 40 <sup>o</sup> C	2.72	7.3	4.02
LCV MJ/kg	42.49	37.53	39.5
Oxygen Content %	<1	12.29	8.1

The properties of test fuels had been measured using different standard testing procedures (ASTM) and are listed in Table 4.

**Table 4: Properties of sample fuels.**

Property	F20	F20O5	F20O10	F30	F30O5	F30O10	F40	F40O5	F40O10
Density at 15 <sup>o</sup> C	0.843	0.842	0.840	0.838	0.843	0.840	0.838	0.841	0.838
CN	51.4	50.75	51.81	50.93	50.41	50.05	49.76	49.26	49.02
KV at 40 <sup>o</sup> C	3.161	3.42	3.34	3.3	3.61	3.57	3.53	3.12	3.07
LCV MJ/kg	41.658	41.415	41.264	41.175	41.168	41.018	40.868	41.51	41.361

## Response Surface Methodology:

RSM is a set of measurable and scientific strategies that are

valuable for demonstrating and examining designing issues. In this technique, the principal objective is to optimize the response surface [25] that is impacted by different input parameters. RSM also evaluated the association between the input information parameters and received reaction surfaces [26]. The design system of RSM is as follows.

1. Designing a progression of examinations for satisfactory and dependable estimation of the response of the engine input parameters.
2. Building up a scientific model for a second-order reaction surface by utilizing the best possible fittings.
3. Finding the ideal arrangement of trial parameters that produce a greatest or least estimation of the reaction.

Representing to the interactive impacts of procedure parameters over 2D, 3D response plots. Reaction surface approach (RSM) includes numerical and measurable strategies that are utilized for demonstrating and dissecting the issues in which a few input factors impact the output paradigm, and the objective of the study is to optimize the parameters based on the responses. For receiving RSM, regulation of contributing parameters, their levels and authentic assessment configuration are necessary steps. RSM comprises of a gathering of procedures employed in building up an exact investigation of the relationships among several responses and a few input factors. The primarily preferred standpoint of employing RSM is to understand and evaluate the impact of various input parametric paradigm and their collaborations with one another in drawing out the desired responses. Therefore, it is considered as a fitting way to deal with advance a procedure with several responses. The connection between the input factors and the engine responses are communicated by a number of equations of multiple regression, which can be employed to assess the normal assessments of the execution of any number of factor levels. If all factors are thought to be assessable, the reaction surface [27] can be communicated as

$$y = f(x_1, x_2, x_3, \dots, x_k) \quad (2)$$

The objective is to improve the reaction variable  $y$ . It is accepted that the free factors are persistent and controllable by trials with least possible errors. More often, a second-order polynomial model  $y$  is used to locate a reasonable prediction for the independent connection between free factors and the reaction surface.

$$y = \beta_0 + \sum_{i=1}^k \beta_i x_i + \sum_{i=1}^k \beta_{ii} x_i^2 + \sum_i \sum_j \beta_{ij} x_i x_j + \varepsilon \quad (3)$$

$\varepsilon$  is a random error.

In matrix form

$$y = \beta x + \varepsilon \quad (4)$$

The solution for the equation (2) is can be obtained by desirability approach.

Second-order polynomial of the response surface for the BTE, BSFC, NO<sub>x</sub> and CO as engine responses corresponding to biodiesel per cent, n-octanol per cent and load per cent as input parameters

#### 2.4.1 The Design of Experiments, DoE:

RSM structures enable us to estimate the connection and even quadratic impacts and in this way gives a thought of the (neighborhood) state of the reaction surface under

scrutiny. Box-Behnken plans and focal composite structures are productive designs to fit a second-order polynomial to reaction surfaces; subsequently they practice a generally modest number of experimental data to gauge the parameters [27]. Rotatability is a practical reason for the regulation of a reaction surface design. The motivation behind RSM is an augmentation, and the area of an ideal is obscure before running the examination, it bodes well to operate a plan that gives a break even with an accuracy of approximation every which way. For such kind of tenacities, Rotary Central Composite Design (RCCD) [23], spherical or face focused and Box – Behnken configuration are the regularly utilized test configuration models for three dimensions of three-factor tests. The present study deals with the full factorial design, FFD. RSM designs enable us to assess cooperation and even quadratic impacts and henceforth give us the possibility of the local state of the reaction surface under examination. The design has the most significant productivity for an RSM problem with three input parameters and three levels. Additionally, the magnitude of runs required is more contrasted with a Box-Behnken design [28], [29] ensuring quality. The proposed FFD required  $3^3=27$  runs to model response surfaces. The details of the FFD is given in table 6.

#### 2.4.2 Analysis of Variance, ANOVA:

ANOVA is a mathematical decision-making parameter utilized for recognizing any deviations in the typical performance of tried parameters. It utilizes the sum of squares and F values to discover the general significance of the scrutinized handling parameters, error estimations and unrestrained parameters. ANOVA [30] was employed to check the adequacy of the model for the engine responses in the experimentation. Process parameters for the current study are based on three levels. The biodiesel percentage, additive percentage and the percentage of loading.

Table 5: Levels

Factors	Name	Unit	Type	Levels		
				1	2	3
A	MEFO	%	Numeric	20	30	40
B	n-Octanol	%	Numeric	0	5	10
C	Load	%	Numeric	0.1	0.55	1

Table 6: Full Factorial Design, FFD of input factors

Run Number	MEFO%	n-Octanol %	Load %
1	20	0	0.1
2	20	0	0.55
3	20	0	1
4	20	5	0.1
5	20	5	0.55
6	20	5	1
7	20	10	0.1
8	20	10	0.55
9	20	10	1
10	30	0	0.1
11	30	0	0.55
12	30	0	1
13	30	5	0.1
14	30	5	0.55
15	30	5	1

16	30	10	0.1
17	30	10	0.55
18	30	10	1
19	40	0	0.1
20	40	0	0.55
21	40	0	1
22	40	5	0.1
23	40	5	0.55
24	40	5	1
25	40	10	0.1
26	40	10	0.55
27	40	10	1

The mathematical relations for the indices mentioned above were as follows.

$$MSRE_k = \left[ \frac{1}{n} \times \frac{\sum_{i=1}^n (e_i - p_i)^2}{\sum_{i=1}^n e_i^2} \right] \quad k \quad (6)$$

$$NCE_k = \left[ 1 - \frac{\sum_{i=1}^n (p_i - e_i)^2}{\sum_{i=1}^n (e_i - e_m)^2} \right] \quad k \quad (7)$$

**Model Uncertainty:**

In the present study, Theil uncertainty familiar as "Theil U2"[31] method has been adopted in the interest of approval and assessment of prediction quality of proposed AI-based models. The following equation gives the mathematical equation of uncertainty.

$$[U2_{Theil}]_k = \frac{\sqrt{\sum_{i=1}^n (o_i - t_i)^2}}{\sqrt{\sum_{i=1}^n (t_i)^2}} \quad (5)$$

The above equation is developed with the least-square methodology, which is an of multiple regression techniques. The model is robust as the TheilU2 values range is. The performance and emission profiles of the proposed DI petrodiesel engine were evaluated with the help of an artificial intelligent regression model MORSM. The input parameters biodiesel per cent, n-Octanol per cent and load are optimized by the model by taking BTE, BSFC, NOx and CO as engine responses. The response BTE is maximized, and the rest of the responses were minimized simultaneously

**2 Results and Discussion**

**3.1. Model analysis**

Evaluation is acknowledged with the authentic design matrix prepared with the factors and the engine responses. The model predicted responses were compared with the experimental paradigm on a mathematical platform and several mathematical terms like R restrained the performance of the model, R<sup>2</sup>(Adj.), R<sup>2</sup>(Pred.), Mean Squared Relative Error (MSRE) and Nash-Sutcliffe Coefficient of Efficiency (NCE) [18] that are detailed in the table 10 which were found commendable. Finally, the desirability approach is implemented to assess the optimum blend composition for the engine, and the best one is taken grounded on the desirability methodology on various factor variance. The ANOVA of each engine response which quantifies the homogeneity invariance and the quadratic equation model for each of the response is given in the separate response session below. The power of the developed model is tested on a statistical sordid in the next phase. Normal probability residual graphs are drawn to authenticate the fitness of normality conventions with measured records. These diagnostic graphs were employed to authenticate the residual distribution with in the data. Fig 3a, b, c and d consider over the validation of ANOVA of BTE, BSFC, NOx, and CO response residuals as they track the normal distribution. The homogeneity of the ANOVA is confirmed and are illustrated in fig 4a, b, c and d.

Where **ei**, **em**, **pi** and **n** are measured data, mean of the measured data, the model predicted data and total data respectively. k is the model type. Table 7 demonstrates the additional diagnostic indices that are utilized to evaluate the model. The values of the error matrices seemed to be very good as the MSRE range is 0.000005 – 0.000158 and NCE range being 0.9957 – 0.999984.

**Table 7: Model analysis**

Parameter	BTE	BSFC	NOx	CO
MSRE	5.46927E-06	6.07E-07	3.9E-05	0.000158
NCE	0.99985233	0.999984	0.998947	0.995743
Theil U2	0.012151961	0.004048	0.032455	0.065246
R	0.999926151	0.999992	0.999473	0.99786
R <sup>2</sup> Adj	0.994914901	0.999581	0.996029	0.986144
R <sup>2</sup> Pred	0.991934639	0.99919	0.993066	0.983416
AdjR <sup>2</sup> - Pred.R <sup>2</sup>	0.002980262	0.000391	0.002963	0.002728
Adeq. Precision	61.48247298	209.6831	67.61407	47.6682

Normal probability graphs were made to verify normality assumption for the measured data graphically. It has been one of the diagnostic graphs which are employed to analyze the distribution of residuals. Fig.2 designates that the residual plots for BTE, BSFC, NOx, and CO tracking a normal distribution that it is one of the elementary circumstances to validate ANOVA. The homogeneity of the variance is another prerequisite to validate ANOVA, and that has been evaluated by predicted vs actual response graphs in fig3. Probability values or p-values were utilized to verify the impact of each factor on the engine responses. The lesser the p-value, the higher will be the significance of the corresponding factor. Mathematical models have been modelled by fitting a second-order polynomial equation for each engine response as specified by following equations

$$BTE = 16.04 - 0.0297 * MEFO + 0.562 * n - Octanol + 27.956 * Load - 2.0e-3 * MEFO * n - Octanol - 0.027 * MEFO * Load - 0.022 * n - Octanol * Load + 8.33e-4 * MEFO^2 - 0.038 * n - Octanol^2 - 10.37 * Load^2 \quad (8)$$

$$BSFC = 0.54276 + 2.647e-3 * MEFO + 1.407e-004 * n - Octanol - 0.511 * Load + 3.83e-5 * MEFO * n - Octanol - 4.44e-4 * MEFO * Load + 4.81 * n - Octanol * Load - 2.27e-5 * MEFO^2 - 1.51E-4 * n - Octanol^2 + 0.224 * Load^2 \quad (9)$$

$$NOx = 16.36 - 0.062 * MEFO + 0.494 * n - Octanol + 10.1 * Load - 0.166 * MEFO * Load - 2.33 * n - Octanol * Load + 0.026 * MEFO^2 + 0.31 * n - Octanol^2 + 484.8 * Load^2 \quad (10)$$



$$CO = 0.277 - 4.507e-3 * MEFO - 7.38 * n\text{-Octanol} - 0.179 * Load - 1.25e-4 * MEFO * n\text{-Octanol} - 2.03e-4 * MEFO * Load - 1.59 * n\text{-Octanol} * Load + 1.433e-$$

$$4 * MEFO^2 + 6.2E-4 * n\text{-Octanol}^2 + 0.0518 * Load^2 + \dots \quad (11)$$

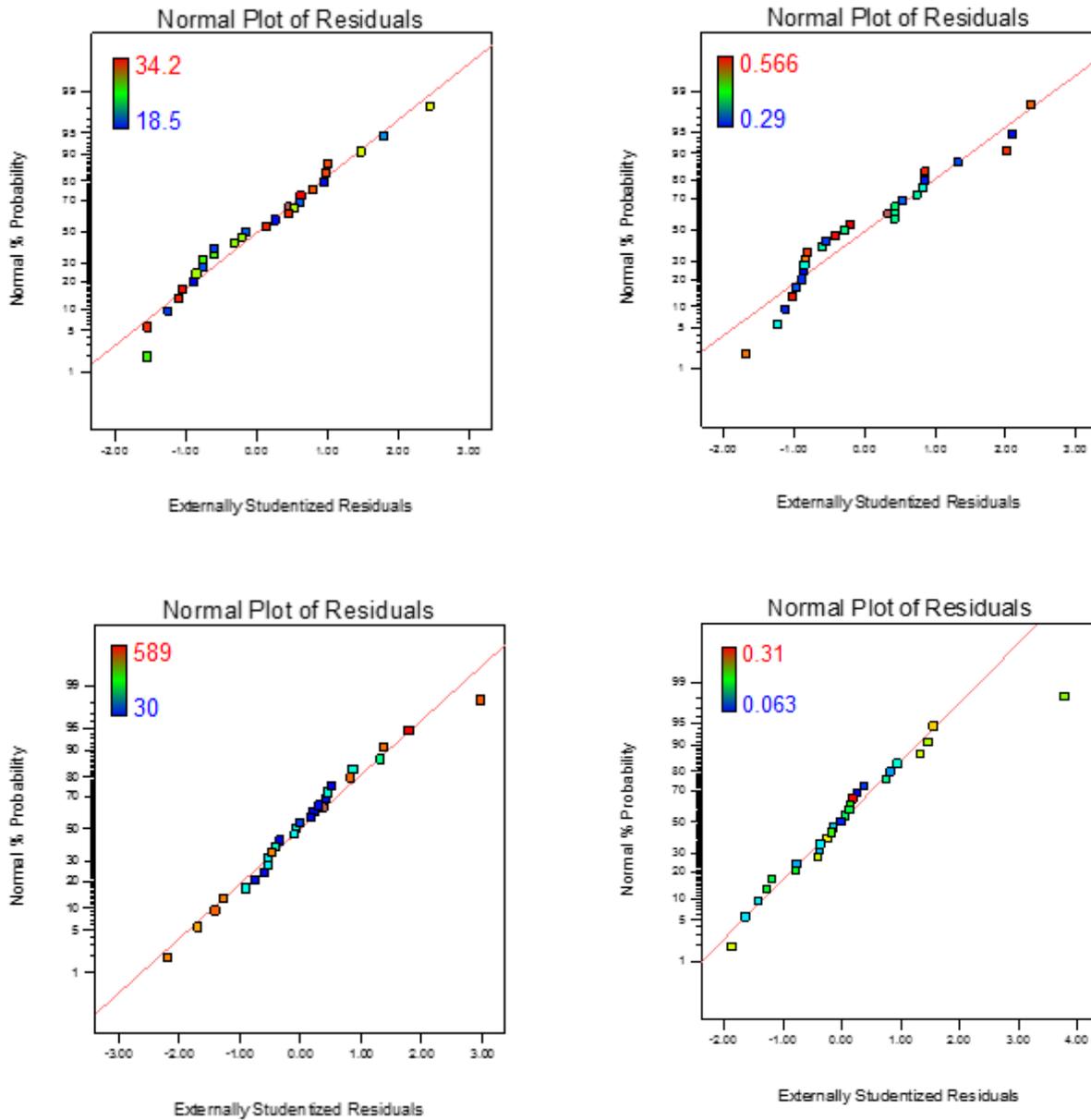


Fig.2 Normal Probability of a) BTE, b) BSFC, c) NOx, d) CO

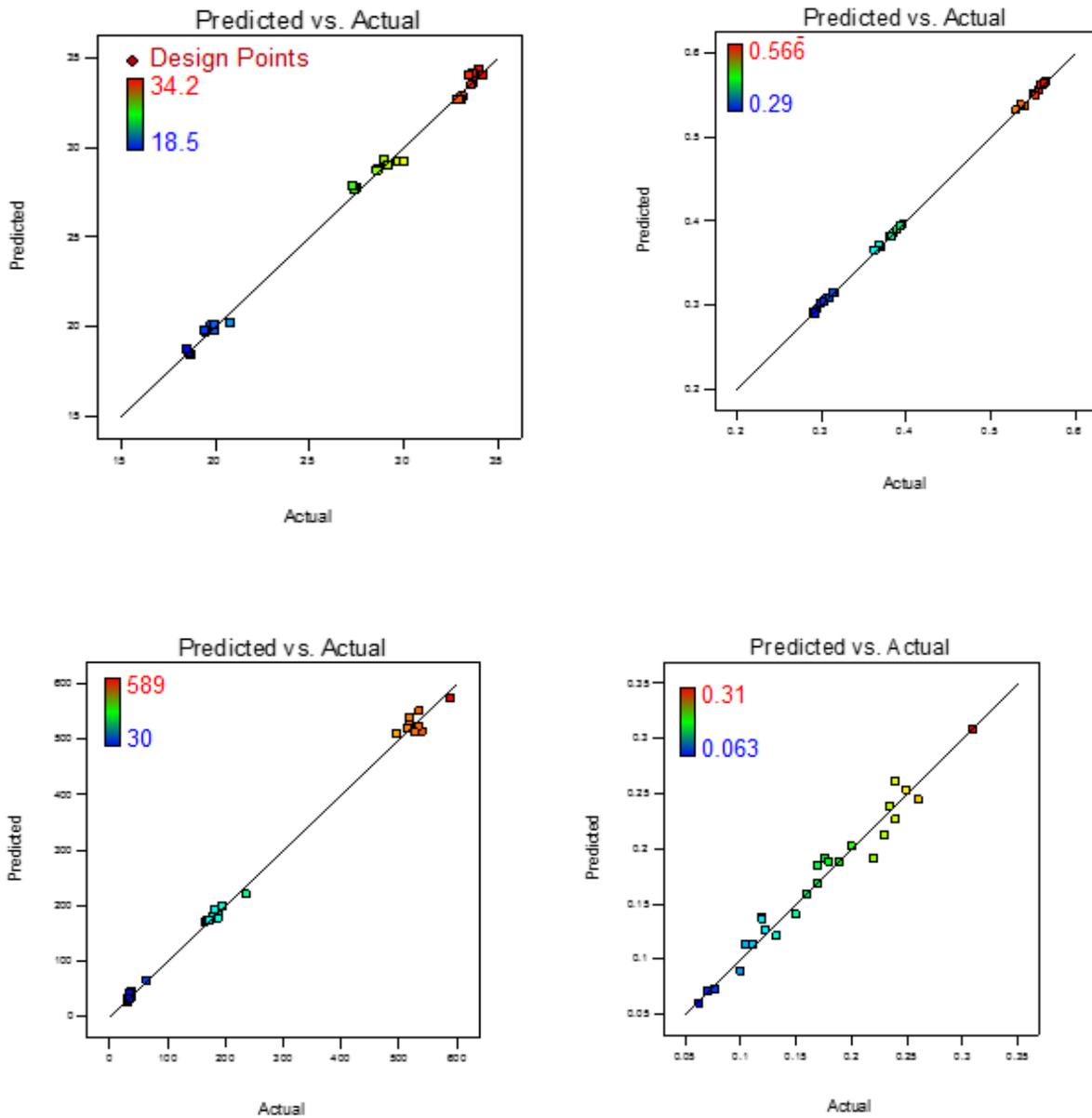


Fig.3 Actual Vs Predicted data plots of a) BTE, b) BSFC, c) NOx, d) CO

Table 8: ANOVA a) BTE, b) BSFC, c) NOx, d) CO

Source	BTE	Table 8a	Source	BSFC	Table8b		
Model	SS	F-Value	p-value	Model	SS	F-Value	p-value
Model	925.35	566.22	< 0.0001	Model	0.29	6890.18	< 0.0001
A-MEFO	0.045	0.25	0.625	A-MEFO	2.71E-03	578.87	< 0.0001
B-n-Octanl	5.44	29.99	< 0.0001	B-n-Octanl	8.89E-07	0.19	0.6687
C-Load	887.61	4888.12	< 0.0001	C-Load	0.28	58728.5	< 0.0001
AB	0.12	0.66	0.4275	AB	4.41E-05	9.4	0.007
AC	0.19	1.03	0.3238	AC	4.80E-05	10.24	0.0052

BC	0.03	0.17	0.6895	BC	1.41E-05	3	0.1011
A <sup>2</sup>	0.042	0.23	0.638	A <sup>2</sup>	3.11E-05	6.64	0.0196
B <sup>2</sup>	5.41	29.82	< 0.0001	B <sup>2</sup>	8.56E-05	18.27	0.0005
C <sup>2</sup>	26.46	145.72	< 0.0001	C <sup>2</sup>	0.012	2656.47	< 0.0001
Residual	3.09			Residual	7.97E-05		
Total	928.44			Total	0.29		

Source	NOx	Table 8c		Source	CO	Table 8d	
Model	SS	F-Value	p-value	Model	SS	F-Val	p-value
Model	1.16E+06	725.56	< 0.0001	Model	0.11	54.92	< 0.0001
A-MEFO	1850.35	10.43	0.0049	A-MEFO	0.02	93.6	< 0.0001
B-n-Octanol	3226.72	18.19	0.0005	B-n-Octanol	0.015	70.18	< 0.0001
C-Load	1.09E+06	6166.06	< 0.0001	C-Load	0.068	312.14	< 0.0001
AB	833.33	4.7	0.0447	AB	4.69E-04	2.16	0.1595
AC	69.12	0.39	0.5407	AC	1.01E-05	0.047	0.8317
BC	330.75	1.86	0.1899	BC	1.54E-04	0.71	0.4106
A <sup>2</sup>	43.56	0.25	0.6265	A <sup>2</sup>	1.23E-03	5.69	0.0289
B <sup>2</sup>	362.96	2.05	0.1707	B <sup>2</sup>	1.44E-03	6.66	0.0195
C <sup>2</sup>	57833.26	326.08	< 0.0001	C <sup>2</sup>	6.62E-04	3.05	0.0985
Residual	3015.15			Residual	3.68E-03		
Total	1.16E+06			Total	0.11		

The validation of the equations 8-11 has been carried out by ANOVA tables for the responses generated by the model. The factual importance of the models was controlled by utilizing the F-value. Additionally, the factual significance of the elements and their levels on the reactions were assessed from the estimations of p, F-values. F-values above 4 is an acceptable situation and p-values less than 0.0001 ensures the impact of the factor on the response with a 99% confidence level [32].

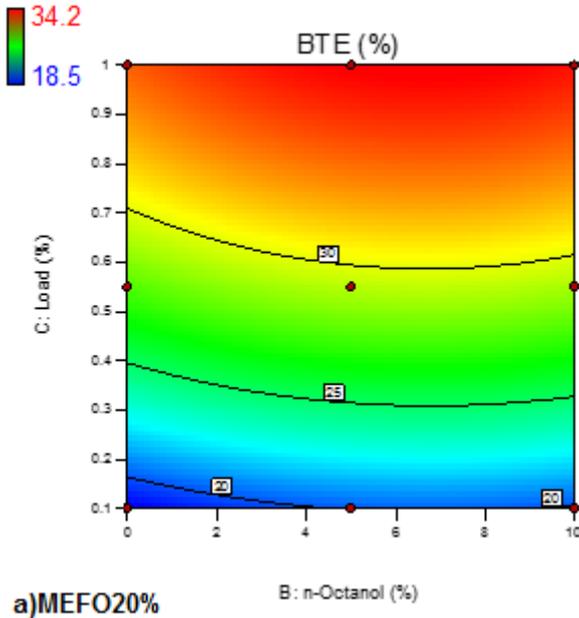
**Performance Analysis**

**Brake Thermal Efficiency:**

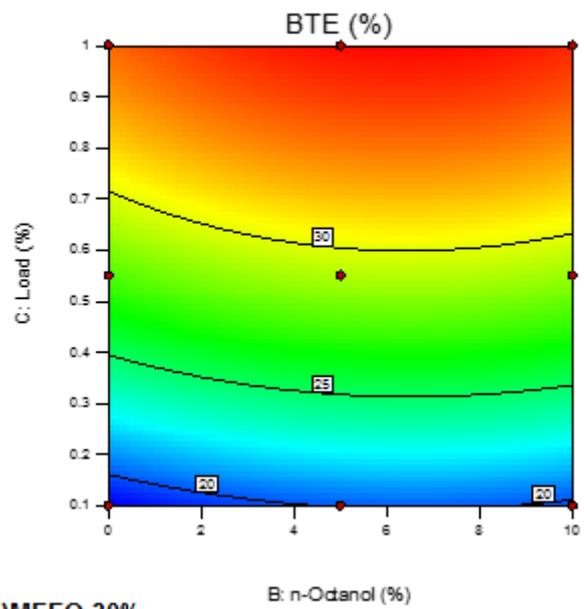
BTHE is directly representing the efficiency, which utilizes the chemical energy of a particular form of fuel converted into convenient work. It is also the ratio of brake power with respect to the input fuel energy [17]. The red colour and blue colour zones in the response surfaces demonstrate the maximum and minimal conceivable BTE's separately with n-octanol/biodiesel blends. The mutual effect of Load and n-Octanol share is depicted in fig 4a, b, and c for different

Biodiesel percentages in the blend standpoints. From the response surfaces created by the model for BTE, it is seen that the colour changes in the response surfaces shows the increasing trend in the response behaviour and found maximum at higher loads. In consonance with the ANOVA table of the response created by the statistical model, the load variations are found to be more productive on the response followed by the n-Octanol share in the blend. The biodiesel with 20 % methyl esters in the samples has slightly favored the response as more percentage of red colored zones are visible suggesting to operate at higher loads. The explanation behind the improvement in warm brake proficiency is the optimum oxygen content in the pilot fuel having n-octanol and MEFO, enhanced the combustion. However, the scores were negligibly low when compared to petrodiesel as the heating values are low for the pilot fuels.

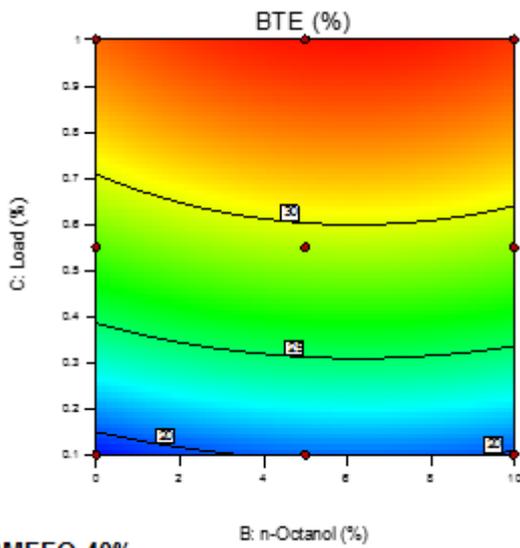




a)MEFO20%



b)MEFO 30%

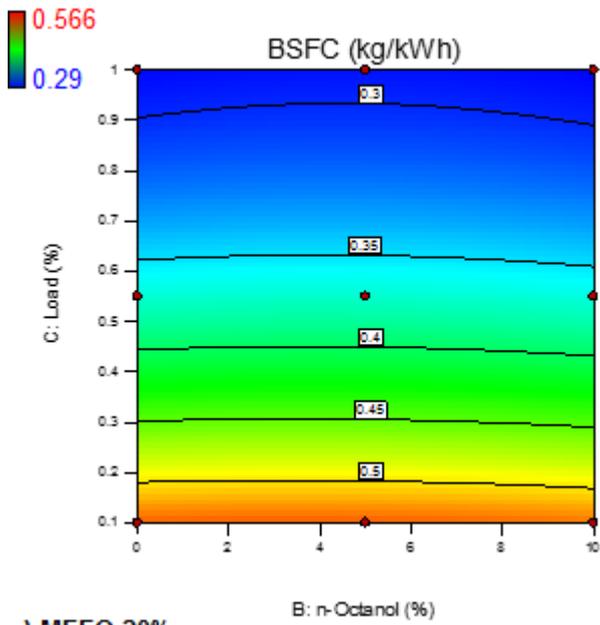


c)MEFO 40%

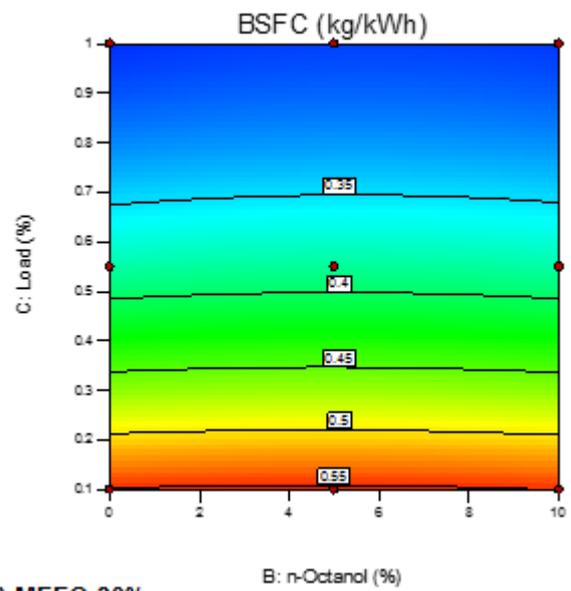
**Fig 4 Effect of n-Octanol Vs Load on BTE for pilot fuels at different proportions of MEFO addition**  
a) 20% b) 30% c) 40%

**Brake Specific Fuel Consumption:**

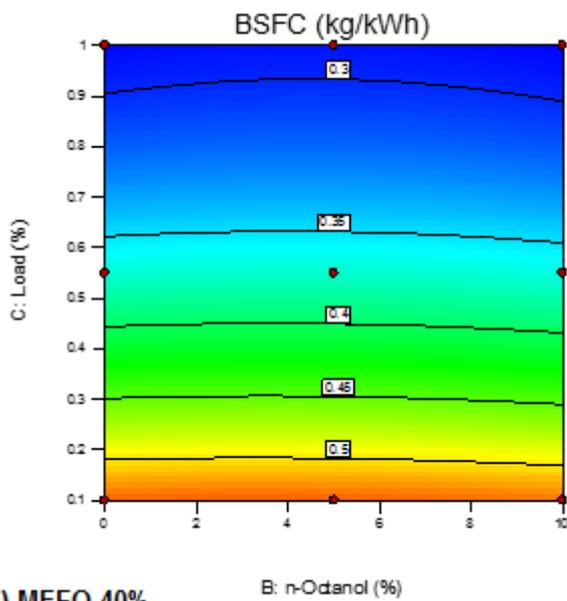
BSFC demonstrates the measure of fuel to be expended per unit power yield [33]. It can be seen that the red colored zones at the lower loads and went on decreasing with increment in load percentage for all pilot fuels. At peak loads, minimum heat losses with efficient combustion takes place could be the prime cause for the minimum in BSFC. The red colour and blue colour zones in the response surfaces demonstrates the maximum and minimal conceivable BSFCs separately with n-octanol/biodiesel blends. The mutual effect of Load and n-Octanol share is depicted in fig 5a, b, and c for different Biodiesel percentages in the blend standpoints. As per ANOVA of BSFC response created by the statistical model, the load variations are found to be more effective on the response followed by the n-Octanol share in the blend. The effect of n-Octanol addition is visible clearly in 20 % biodiesel blend as the blue colored areas are more likely and attained quickly. However, slopes of the colors are diminishing with the n-octanol percentage of all the percentages.



a) MEFO 20%



b) MEFO 30%



c) MEFO 40%

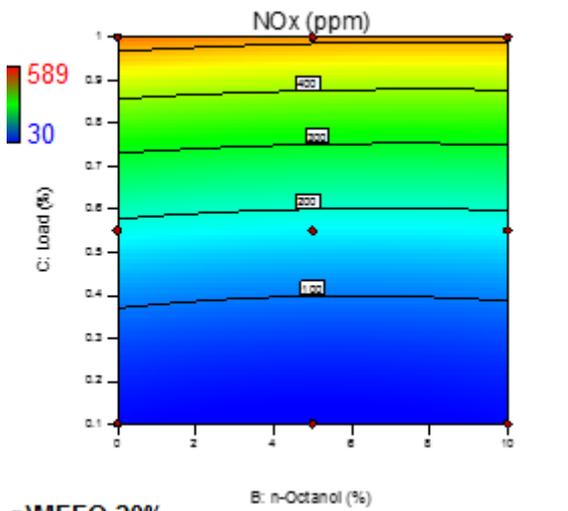
**Fig 5 Effect of n-Octanol Vs Load on BSFC for pilot fuels at different proportions of MEFO addition**  
a) 20% b) 30% c) 40%

**Emission Analysis**

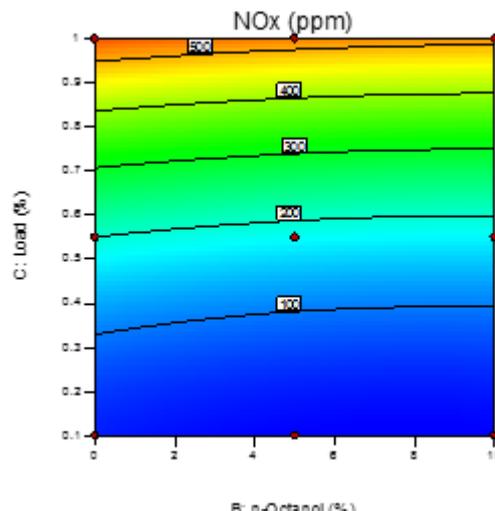
**Nitrogen emissions, NOx:**

The key variable in the study is the NOx, which is directly linked to environmental issues. NOx is responsible for several health problems. The variables like in-cylinder

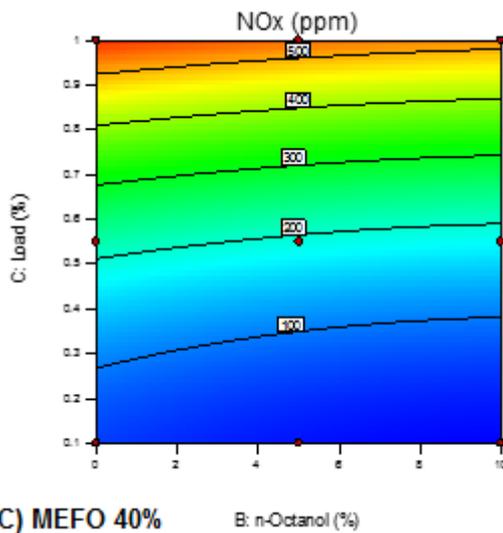
temperature, the oxygen share in the pilot fuel and equivalence ratio influence the NOx emissions of an engine. The red colour and blue colour zones in the response surfaces demonstrates the maximum and minimal conceivable NOx separately with n-octanol/biodiesel blends. The joint effect of Load and n-Octanol share is depicted in fig 6a, b, and c for different Biodiesel percentages in the blend standpoints. As per ANOVA of NOx response fashioned by the statistical model, the load variations are instituted to be more effective on the response followed by the n-Octanol share in the blend. The effect of n-Octanol addition is visible clearly in 20 % biodiesel blend as the blue colored zones are retained up too much loading conditions and are more likely. However, slopes of the colors are diminishing with the increase in the n-octanol percentages. The increasing slopes of the colors as we move from left to right indicate the diminishing of red zones indicating that the response scored less when we increase in n-Octanol share. The portions were less likely in biodiesel 20%. The fundamental reason for this increment in NOx paradigm for all biodiesel combination conditions is, because of greater ignition temperature in the engine chamber the particles like O2 and N2 separate into their previous nuclear state NO [16], [34].



a) MEFO 20%



b) MEFO 30%



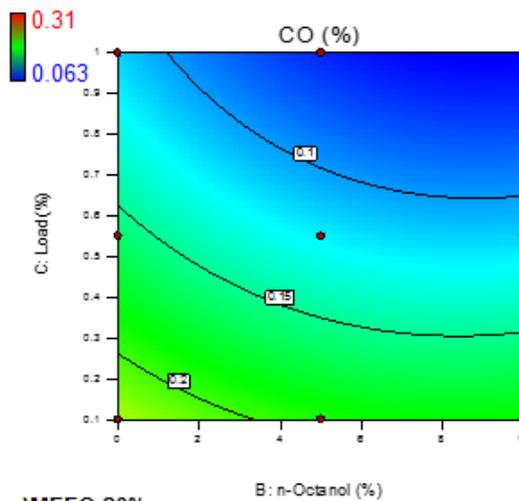
c) MEFO 40%

**Fig 6 Effect of n-Octanol Vs Load on BTE for pilot fuels at different proportions of MEFO addition**

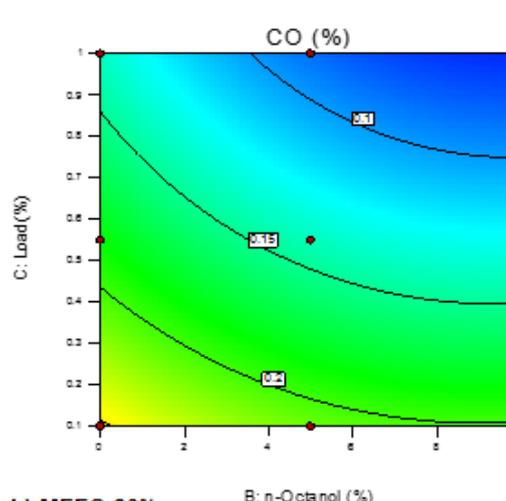
a) 20% b) 30% c) 40%

**Carbon monoxide emissions, CO:**

The CO emissions is a function of blend strength, the oxygen portion of the pilot test fuel [35] [36]. The red-colored and blue colored regions in the response surfaces reveal the maximum and minimal conceivable CO separately with n-octanol/biodiesel blends. The joint effect of Load and n-Octanol share is depicted in fig 7a, b, and c for different Biodiesel percentages in the blend standpoints. The ANOVA of the CO response, Table 8d validates the effect of Load per cent seemed to be highest on the response followed by n-Octanol percentage and biodiesel share which suggests that, even minor fluctuations in load shares result in a notable effect in the response behaviour. It can be seen from the graphs that the higher percentages of alcohol and peak loads were favored. The figures depict that B20 is producing least CO indices as favored blue-colored areas in fig 7 a. totally from figures, as the percentage of n-Octanol is increasing, there is a significant decrease in CO observed in different biodiesel participations.



a) MEFO 20%



b) MEFO 30%

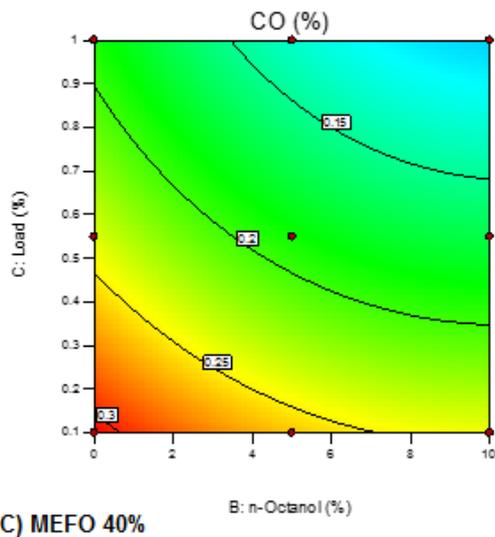


Fig 7 Effect of n-Octanol Vs Load on CO for pilot fuels at different proportions of MEFO addition

Table 9: Optimized results

	n- MEFO %	Octanol %	Load %	BTE %	BSFC kJ/kwh	NOx ppm	CO %	Desirability
Predicted	20	10	98.3	33.213	0.291	494.579	0.062	0.986
Actual	20	10	100	33.896	0.293	496	0.063	
% Error				0.88%	0.68%	0.28%	1.58%	

Experimental validation is demonstrated in the below table 10. The model recommends an optimum blend of 20% MEFO, 10 % n-Octanol with petrodiesel to run at almost full loads by considering the optimum engine responses. The

Table 10: Comparison of model proposed blend and petro diesel

MEFO %	n-Octanol %	Load %	BTE %	BSFC kJ/kwh	NOx ppm	CO %
20	10	100	33.213	0.291	494.579	0.062
Diesel		100	34.2 (2.88%▼)	0.28 (3.92%▲)	513 (3.59%▼)	0.089 (30.33%▼)

Experimental engine responses of the prepared blend, which was recommended by the model are confirmed with the baseline petrodiesel and given in table 10. There is a negligible reduction of 2.88%, in BTE due to the lower heating values of the suggested blend, and raise in fuel consumption (BSFC) of 3.92 % due to the higher viscosity and density. But, a reduction of 3.59% NOx and 30.33% CO engine responses were noticed with the current study when compared to petrodiesel operation.

### III. CONCLUSION:

The performance and emission characteristics of a single-cylinder, four-stroke, water-cooled, DI-CI engine fueled with MEFO based biodiesel with alcohol were analyzed using a full factorial approach where percentages composition of MEFO based biodiesel with alcohol were

a) 20% b) 30% c) 40%

### Optimization:

The tradeoff amongst BTE, BSFC, NOx and other emissions demands the optimizing the input governing factors; the percentage of biodiesel, percentage of n-Octanol and the Load share. The MORSM of Design Expert 10.0.7 contributed a range of solutions constructed on the desirability conditions based on the individual importance of the responses. The desirability is minimizing the BSFC, NOx, CO and maximizing BTE responses simultaneously. The model has drawn the best result concerning the response desirability measures. Optimization results revealed that 20 % MEFO, 10 % n-Octanol with 70% diesel is optimum for the existing DIC I engine. Model predicted results were compared with the actual engine responses and found minimum error of 0.28% and a maximum error of 1.58% which was deliberated in table 9.

recommended blend has been prepared by 20 % MEFO biodiesel, 10% n-Octanol with petrodiesel and validation tests were accompanied at full load conditions, and results are portrayed in table 9.

varied with respect to variation in load which were considered as input parameters. Experiments were performed, the engine responses were logged, and models were developed employing RSM. Optimization of the input parameters was brought out by the desirability approach. The conclusions drawn for the current study is as follows. The quadratic models developed and unfolded using MORSM from the experimental data for BTE, BSFC, NOx, and CO was observed to be most significant at 99% confidence levels.

1. The Full Factorial Design was extremely helpful in identifying the significance of parameters which have the most influence on the performance and emission profiles. Desirability concept of the response surface methodology gave an impression of being

the simplest and proficient optimization practice. The desirability of 0.986 was attained at the optimum blending parameters viz. 10% n-Octanol, 20 % of MEFO and 100 % loading, with the response scores of the BTE, BSFC, NO<sub>x</sub>, and CO emissions observed to be 33.896%, 0.291kg/kWh, 494 ppm and 0.062 % v/v respectively. ANOVA tables of BSEC, NO<sub>x</sub>, and CO responses revealed the effect of load's share seemed to be highest on the response followed by MEFO share and n-Octanol percentage indicating the changes in load shares resulted in noteworthy effect in the response behavior.

2. The ANOVA of unburnt hydro carbon's response showed that the effect of DEE share is seemed to be highest on the response followed by n-Octanol percentage and load percent. The model fetched blend is giving 3.92 % higher consumption in terms of BSFC response when compared with baseline fuel diesel consumption of 0.28kg/kWh at full load. The entire oxygenated pilot fuel blends consumed a little more fuel to produce the same power output.

3. The critical response NO<sub>x</sub> emission production by the model suggested blend is 3.92% lesser than diesel emissions (494 ppm) at full loads. The lower vapor pressures of n-Octanol proved worthy in terms of reducing the response behavior.

4. The increase in the addition of MEFO on the CO response is very low which was depicted in the ANOVA table. The model suggested blend is producing 30.33 % less CO emissions when compared to baseline petro diesel's production of 0.062 v/v of CO. The oxygen-rich pilot fuels increased the oxidation processes during the combustion process that lead to least production.

5. The model is tested further with the special error matrices like MSRE, NCE and Theil U2. The ranges of correlation coefficients R, R<sup>2</sup>(Adj) and NCE are 0.99786 - 0.999992, 0.99786-0.999992 and 0.9957 - 0.999984 respectively. And the ranges of the error metrics Theil U2 and MSRE are 0.004048 0.065246 and 6.07E-07 to 0.000158 respectively.

6. Optimization results revealed that 20 % MEFO, 10 % n-Octanol with 70% diesel is optimum for the existing DICl engine. Model predicted results were compared with the actual engine responses and found minimum error of 0.28% and a maximum error of 1.58%. The optimized blend that is predicted by the model was experimentally validated with the baseline mineral diesel and found a negligible decrease of 2.88 % in BTE, 3.92 % increase in BSFC but it reduced the NO<sub>x</sub> by 3.59 % and CO by 30.33 %.

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