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Influence of Biodiesel-Diesel Blend with Ethanol As Additive on Exhaust Gas Emission with Optimization by Combined Response Surface Methodology and Genetic Algorithm

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Abstract: In this study, multi-objective optimization of emission parameters has been conducted with combination of response surface methodology (RSM) and Genetic algorithm (GA) on single cylinder four stroke diesel engine using Karanja biodiesel, ethanol as additive and diesel blend as fuel. The exhaust gas emission or output variables are HC (ppm), CO (% vol.), NOx (ppm) and CO_2 (% vol.). The input variables were biodiesel (10-20% in four level), Ethanol (0-20% in five level) and load (0-5kg in six level) at constant speed of 1500 rpm. Firstly, experiment is performed in three stages i.e. with diesel, biodiesel-diesel blend and then biodiesel-additive-diesel blended fuel. Then analysis of variance (AVOVA) is done by RSM with Design Expert software, where it gives quadratic regression equation which will utilized by GA to obtain optimal solution. GA is performed by using Matlab 2016a software. GA gives Pareto optimal solution containing 18 set. For validation, three values were selected and performed experiment on the same. On comparison, it gives 3-8% error. So, this combination of methods will helpful in reduction of number of experiment effectively. This study gives approach towards utilization of non-edible oil with addition of additive. The developed model and modelling techniques can be used as helpful tool in design and optimization of biodiesel-ethanol-diesel blended fuel with effective emission characteristics.
Keywords: RSM,GA ,AVOVA, Biodiesel, MOGA

I. INTRODUCTION

Energy is important factor in development of mankind. The dependency on petroleum derived product is increasing continuously. Due to continuous increase in demand and price of fuel, researchers are looking for cleaner and renewable alternative fuel, such as biodiesel. Biodiesel has potential to lead forward to address various problems [1-5]. Biodiesel is a fuel which is alkyl (methyl or ethyl or higher) esters of long chain fatty acids derived from vegetable oils, non-edible oil, animal fats, etc. The biodiesel production process, most of the time transesterification is used, typically involves the reaction of an alkyl-alcohol with a long chain ester linkage in the presence of a catalyst to yield mono-alkyl esters (bio-diesel) and glycerol as by product. It has drawbacks as high cost compare to diesel, higher viscosity. So, in place of pure biodiesel, combination of biodiesel and diesel blend as fuel can be used to overcome these drawbacks [5]. Major research conducted on biodiesel for Neem, Karanja, Jatropha, Rubber. Kumar et al. [4] obtained biodiesel from Jatrophacurcas and Karanja as part of national mission in India. Being non-edible oil seed crop, it's oil content ranges from 25-30% and life of plant is nearly 40 years. Vijayakumar et al. [5] reviewed alternative fuel for compression ignition engine. He concluded that straight vegetable oil is not meant for long term engine operation due to free fatty acid. Agarwal et al. [6] carried experimental investigation of Karanja oil and its blend with mineral diesel with and without preheating condition in single cylinder agricultural diesel engine. The result indicated significant improvement performance parameter and emission character tics of engine. So, Karanja biodiesel is selected for analysis based on these. But with addition of biodiesel to diesel fuel, the fuel blend property changes like viscosity, cetane number, high temperature to ignite fuel, etc. Resulting to increase in emission. Korres et al. [8] evaluated the use of ethanol (5-15% volume) with biodiesel (5% by volume) in diesel and jet fuels in stationary diesel engine. With the use of ethanol-diesel fuels, improvement in cold flow properties and reduction in PM. Also, problem brought reduction in flash point, cetane number and NO_X emission with addition of ethanol. So, it gives to indication which can added as additives in blend. Further, Datta et al. [11] evaluated the effect of alcohol (methanol and ethanol) addition to blend of palm sterin biodiesel and diesel on performance, combustion and emission characteristics. The result shows improved characteristics with alcohol addition to blend. The studies carried for analysing effect of ethanol on different biodiesel blend with diesel shows improved emission [13-16].On targeting the optimal characteristics, experimentation work will be increased, due to experimentation at different blend with varying other input parameter simultaneously, which bring cost factor and time factor. To reduce effort of experimentation, artificial intelligence and design of experiment techniques were implemented by researcher [9]. Kiani et al. [17] studied application of artificial neural network (ANN) for prediction of performance parameter and emission characteristics of spark ignition engine. Ganapathy et al. [18] carried optimization of performance parameters with blend of Jatropha biodiesel and diesel by using RSM. Bojan et al. [20] developed RSM model for optimization of biodiesel production from high free fatty acid Jatrophacurcas oil. So, with optimal factors predicted model results matched with experimental yield result i.e. 80.32 +/-0.82%. So, these studies show advantage over experimentation in terms of prediction and optimization of parameters with lesser runs of experiment. Some more studies which utilizes combination of techniques to obtain more accurate result as compared to experiment. Dhingra et al. [23] carried out optimization of Karanja biodiesel yield based on input, namely, molar ratio, reaction time, reaction temperature, catalyst concentration and mixing speed done by using combining RSM and GA. The optimized result is confirmed by re-experimentation on optimized input as of RSM and GA, showing good agreement with developed model. Similar model with combination of RSM and artificial neural network with GA have been developed for optimization [24-25]. Dhingra et al. [26] developed non-dominated sorting genetic algorithm-II for prediction of performance parameter and emission characteristics. With prediction, optimization is carried with specific objective of minimization or maximization of output variable. So, this technique is used to optimize the emission variables. Further, Hiroyasu et al. [27] developed multi-objective genetic algorithm (MOGA) and phenomenological model for reduction of emission and fuel consumption in heavy duty diesel engine. Since, MOGA requires large number of iteration. So, phenomenological model used to simulate engine combustion with reduced calculation cost. In current work, RSM and GA is combined to optimize the exhaust gas emission i.e. HC (ppm), CO (% by volume), NO_X (ppm) and CO_2 (% by volume) with Karanja as biodiesel, ethanol as additive and diesel blend in single cylinder compression ignition diesel engine. This type of study is not previously carried out which involve ternary fuel. So, this study will help in analysis of exhaust gas emission with minimum number of experiments.

II. METHODOLOGY

A. Experimental setup

The schematic of experimental setup is shown in Figure 1 which consist of single cylinder four stroke compression ignition diesel engines, eddy current dynamometer, exhaust gas analyser, fuel tank as major component. Table 1 shows technical specification of test engine. For measurement of HC, CO, NO_X, CO_2 emissions, KEG-500 model 5-gas analyser of Sincro company has been used. The eddy current dynamometer used was manufactured by Tecnomech (Model TMEC-10). Maximum power of eddy current dynamometer is 7.5 KW and revolution per minute in range of 1500-1600 rpm. The unmodified diesel engine is initially started by hand cranking with no load. The diesel engine is allowed to run for nearly 15 min to obtain steady condition. While taking readings, all the ests were conducted twice and average of same taken for further analysis to accomplish greater accuracy.

Experiment was performed in three parts with diesel, biodiesel and ethanol blend as fuel. In first part, the test has been conducted with diesel fuel with varying load in range of 0-5 kg. In second part Karanja biodiesel and diesel blend as fuel is used. The biodiesel is blended with diesel in percentage of total volume of fuel i.e. 10%, 15%, 18% and 20%. The tests performed with varying load in range of 0-5kg on different blends as BD10, BD15, BD18 and BD20. In third part, Karanja biodiesel, ethanol as additive and diesel fuel blend was used. Test is performed with BD10+E10, BD15+E15, BD18+E18 and BD20+E20, load is varied in range of 0-5kg on different blend ratio

Figure 1 Experimental setup

Table 1 Technical specification of Test engine

Make	Kirloskar oil engine Ltd.
Constant Speed	1500 rpm
Bore x Stroke	87.5 mm x 110mm
Rated power	5.2 KW @ 1500 rpm
Compression Ratio	17.5:1
Method of Cooling	Water cooled

Table 2 Fuel properties

Test Fuels	Diesel	Karanja BD	Ethanol	K10	K20	K10 + E10	K20 + E20
Flash Point (°C)	78	75.3	14	65.4	62.62	45.5	40.6
Fire Point (°C)	85	80.9	20.3	70.8	68	51	45.2
Pour Ponit (°C)	0	3.53	-2.1	1.23	1.75	2.76	2.4
Density (kg/m³)	840	924.32	789.3	952.36	983.66	980	956.84
Kinematic viscosity (cst)	3.11	40.16	1.23	3.26	4.13	2.38	1.98
Calorific value (KJ/kgK)	42500	36500	26500	39300	37800	28300	27900

B. Fuel used

In the experimentation, base fluid as diesel blended with Karanja biodiesel and ethanol as additive are used. Biodiesel and additive ethanol is purchased from SVM Agro Processor, Nagpur, India. The blended fuel properties were tested in Geo-Chem Laboratories Pvt. Ltd., India, which is presented in Table 2. The density is measured by ASTM D-4052 method. Similarly, Kinematic viscosity, Flash point and Pour point were measured by ASTM D-44, ASTM D-93 and ASTM D-97 method respectively.

C. Design of experiments

The input parameters were Karanja biodiesel, ethanol and load with different levels is shown in Table 3. The number of replicates were three to obtain more accurate outputs. The outcome of experiment was HC (in ppm), CO (% of total volume of exhaust gas), NO_X (in ppm) and CO_2 (% of total volume of exhaust gas). For all reading, speed is kept constant at 1500 rpm. The total number of runs recorded is 54.

D. Response surface method (RSM)

RSM is an aggregation of mathematical and statistical techniques which are used for the modelling and analysis of problems. Here, the response of interest or output is influenced by several variables and the aim is to optimize this response. In RSM, approximation between response variable and input parameters is sated firstly. For this, model second order quadratic polynomial equation is formed, can be seen in [18], to fit response using input variables. After fitting developed model is directed to testing such as, significance test with ANOVA (validation). The same model equation is, also, used to calculate precision index values such as coefficient of determination (R^2), adjusted R^2, predicated R^2. The Fisher's test (*F-value*) for ANOVA was conducted on experimental data to determine the statistical significance of the model, while *p-value* is probability of getting results equal to actually observer value [31].

With reference to various studies conducted which reveals that RSM requires minimum number of experiment to generate accurate model for analysis. In current work, RSM is developed by using Design Expert 7.0.0 software. RSM part is used to develop regression equation which will be utilized by GA model. In RSM, quadratic order model is selected to study detailed interaction of variables with polynomial mode. No transformation is selected, since ratio of maximum to minimum value of parameters were less than 10.

E. Genetic Algorithm (GA)

GA is algorithm that simulate heredity and evolution of living organisms. GAs were invented by John Holland and developed by him and his students and colleagues. GA is multi-point search method and probabilistic. It can be applied to both continuous and discrete function. While designing diesel engine, it is difficult to perform parameter search with conventional method like response surface method, gradient method, etc. So, GA can be applied in this situation [27]. This algorithm starts with a set of solutions as population. Solutions from one population are taken and utilize to form a new population. This is with assumption that the new population will be better than the old one. Solutions which are to be selected to form new solutions are selected based on their fitness function. This process is repeated until the best solution is obtained [30]. The steps involved during optimization are starting solution with random population, defining fitness function, selection of new population based on selection function, crossover function and mutation, replace the old population and test new one against fitness function. It has been performed by using optimization tool of Matlab 2016a software.

Table 3 Detailing of input variables

Variable	Levels	Detailing
Karanja Biodiesel (%vol.)	4	10, 15, 18, 20.
Ethanol (%vol.)	5	0, 10, 15, 18, 20.
Load (kg)	6	0, 1, 2, 3, 4, 5.

Table 4 Sequential Model of Sum of Squares

Parameter	Source term	Sum of Squares	Mean Square	F-value	p-value
HC	Two-way interaction	7381.14	2460.38	18.28	<0.0001
CO	Linear	0.085	0.028	101.75	<0.0001
NOx	Two-way interaction	7723.67	2574.56	10.48	<0.0001
CO_2	Two-way interaction	0.92	0.31	4.37	0.0085

Table 5 Model Summary Statistics

Parameter	Source term	R^2	Adjusted R^2	Predicated R^2	Adequate Precision
HC	2FI	0.8533	0.8346	0.7974	8738.00
CO	Linear	0.8593	0.8508	0.8402	0.016
NOx	2FI	0.9887	0.9873	0.9852	15230.77
CO_2	2FI	0.8252	0.8028	0.7670	4.38

Table 6 ANOVA for Response Surface 2FI Model of HC emission

Source	Sum of Squares	Mean Square	F-value	p-value	
Model	36801.74	6133.62	45.57	<0.0001	Significant
A-BD	3603.12	3603.12	26.77	<0.0001	
B-Ethanol	13740.42	13740.42	102.09	<0.0001	
C-Load	76.94	76.94	0.57	0.4534	
AB	2402.12	2402.12	17.85	0.0001	
AC	1433.52	1433.52	10.65	0.0021	

BC	4807.42	4807.42	35.72	<0.0001	
Residual	6325.59	134.59			
Cor. Total	43127.33				

Table 7 GA parameters

Parameter	Value
Solver	gamultiobj
Population size	200
Crossover Fraction	0.8
Mutation function	Constraint dependent
Crossover Function	Intermediate
Crossover ratio	1.0
Migration Fraction	0.2

Table 8 Pareto optimal solution

Index	BD	Ethanol	Load	HC	CO	NOX	CO_2
1	10.01	19.85	0.00	58.89	0.050	170.04	1.372
2	10.02	19.62	0.18	58.50	0.051	183.11	1.387
3	10.01	20.00	4.79	28.42	0.031	499.09	1.336
4	10.04	19.96	0.27	57.07	0.048	188.27	1.365
5	10.01	19.83	3.06	40.17	0.038	380.09	1.360
6	10.03	19.87	2.74	42.00	0.039	358.31	1.359
7	10.02	19.97	1.27	50.71	0.044	256.73	1.358
8	10.02	19.99	4.58	29.89	0.032	484.16	1.338
9	10.00	20.00	5.00	27.11	0.030	513.06	1.334
10	10.00	20.00	5.00	27.11	0.030	513.06	1.334
11	10.02	19.95	1.01	52.38	0.046	239.29	1.361
12	10.01	19.85	3.74	35.79	0.036	427.22	1.355
13	10.03	19.93	2.32	44.37	0.041	329.16	1.356
14	10.01	19.98	3.51	36.58	0.036	410.68	1.344
15	10.01	19.84	0.53	55.67	0.048	206.44	1.370
16	10.00	20.00	4.02	33.29	0.034	445.49	1.340
17	10.04	19.45	1.86	49.13	0.045	299.64	1.396
18	10.00	20.00	4.33	31.35	0.032	466.77	1.338

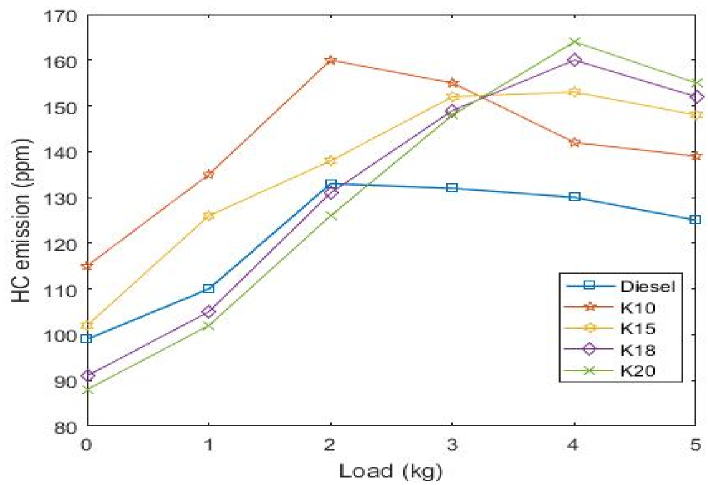

Figure 2 Comparison of HC emission of biodiesel-diesel blend with pure diesel.

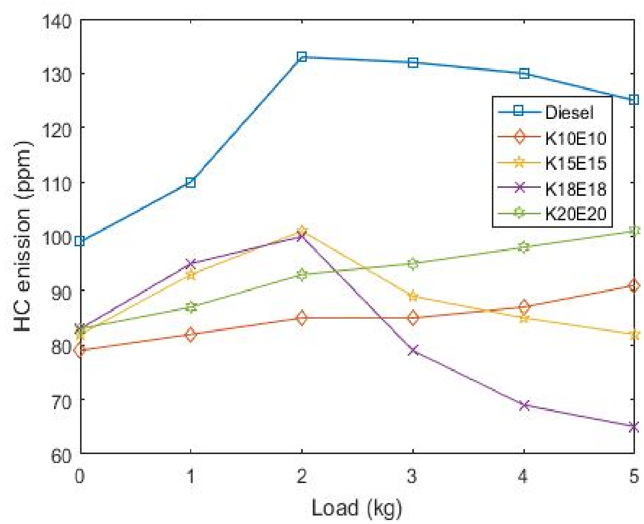

Figure 3 Comparison of HC emission of biodiesel-additive-diesel blend with pure diesel.

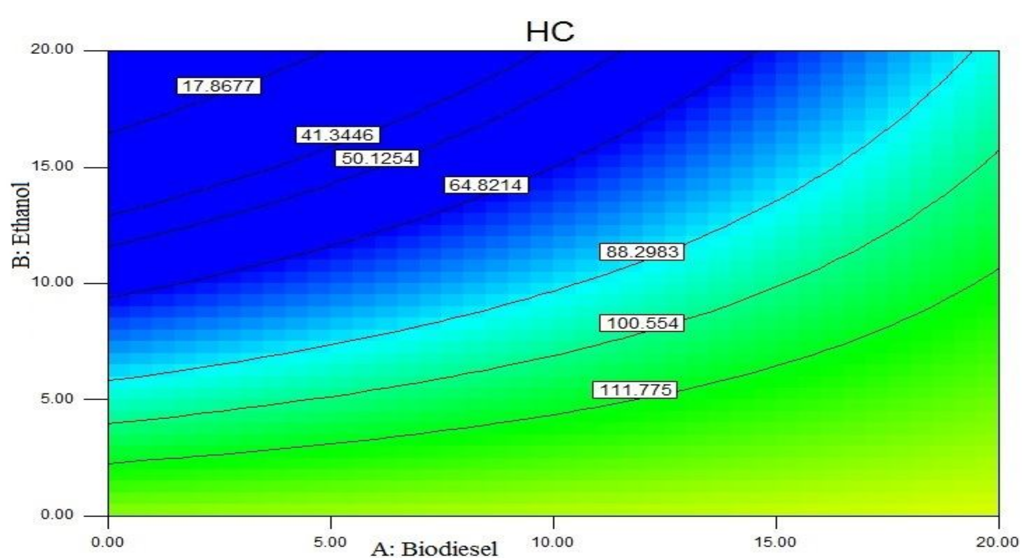

Figure 4 Contour plot of HC emission vs Biodiesel, Ethanol

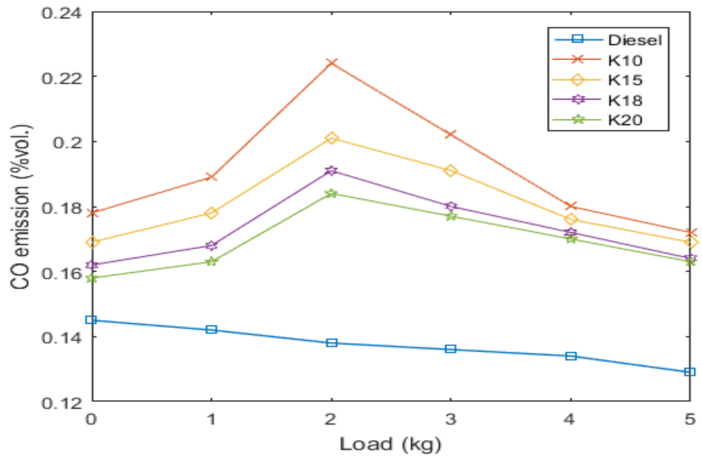

Figure 5 Comparison of CO emission of biodiesel-diesel blend with pure diesel.

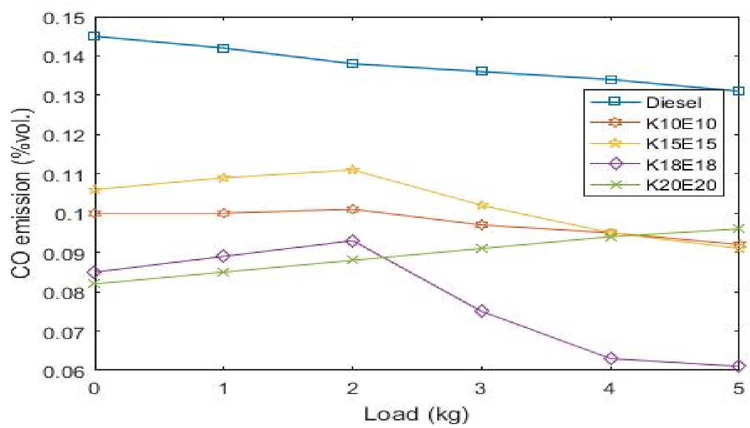

Figure 6 Comparison of CO emission of biodiesel-additive-diesel blend with pure diesel.

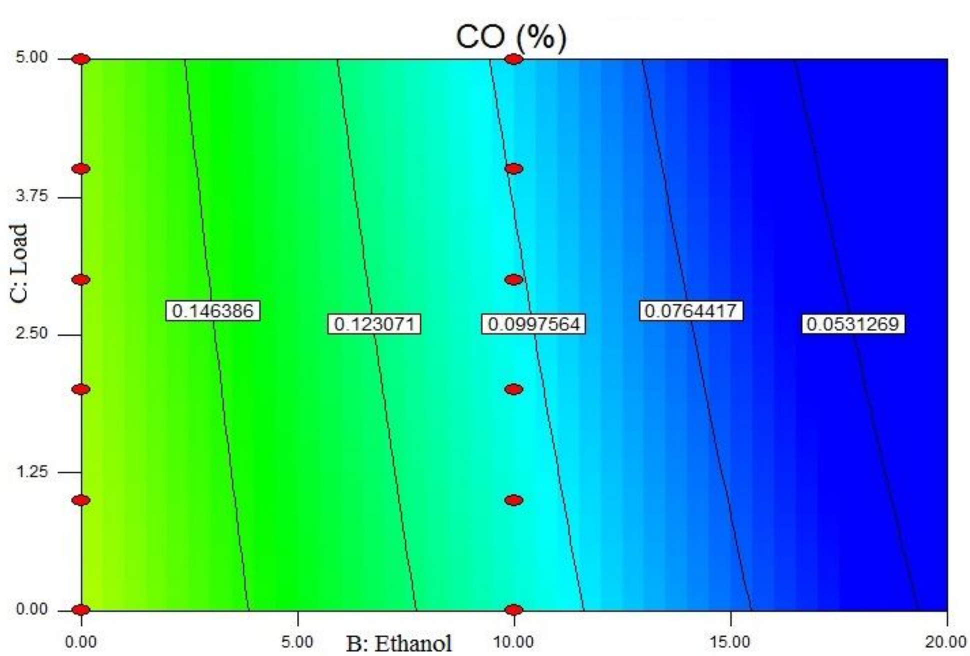

Figure 7 Contour plot of CO v/s Ethanol, Load

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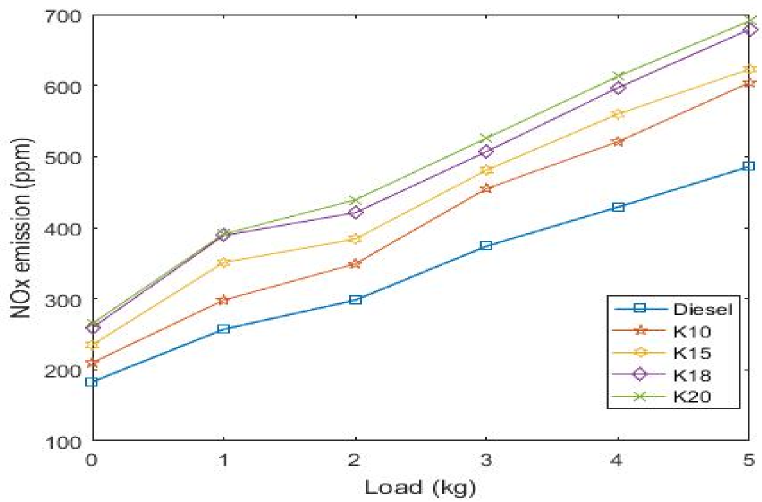

Figure 8 Comparison of NOx emission of biodiesel-diesel blend with pure diesel.

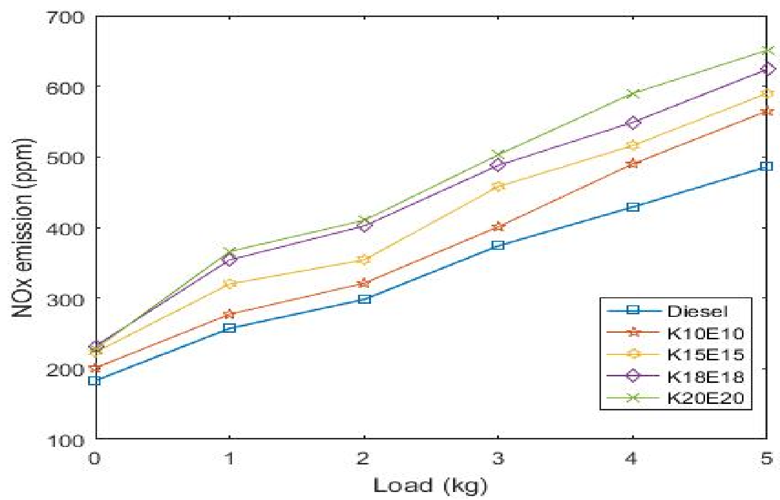

Figure 9 Comparison of NOx emission of biodiesel-additive-diesel blend with pure diesel.

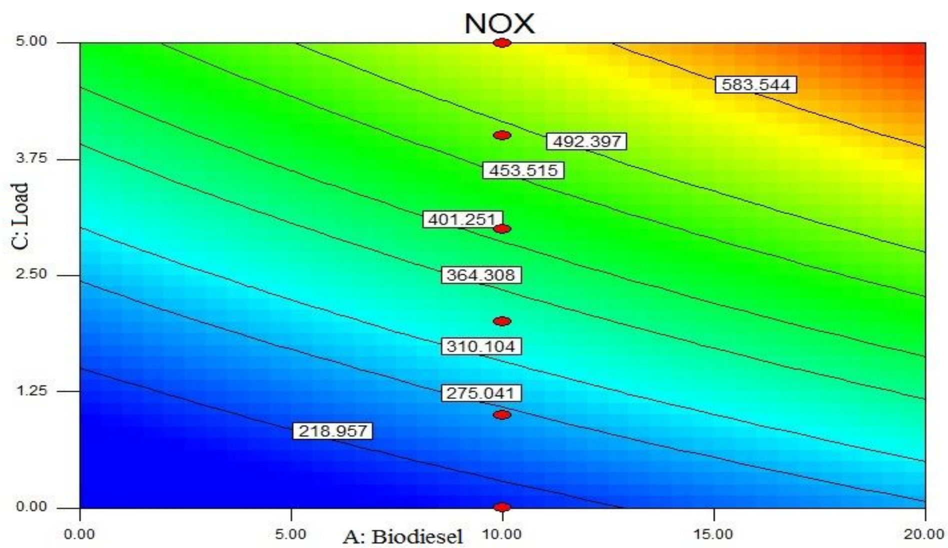

Figure 10 Contour plot of NOx v/s Biodiesel, Load

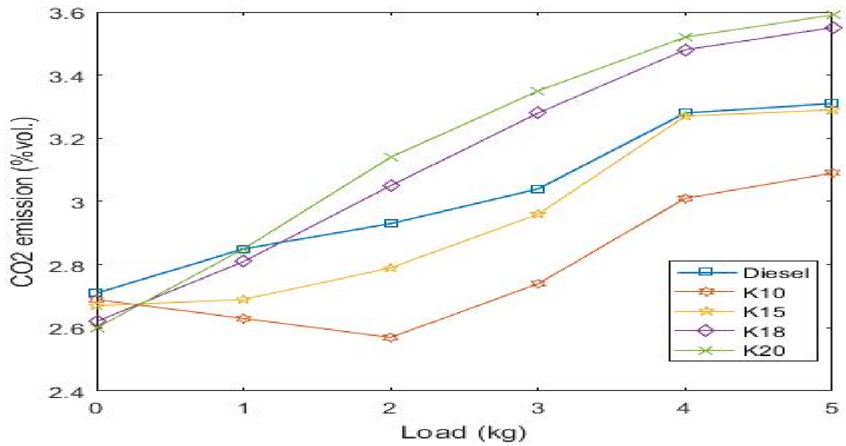

Figure 11 Comparison of CO_2 emission of biodiesel-diesel blend with pure diesel.

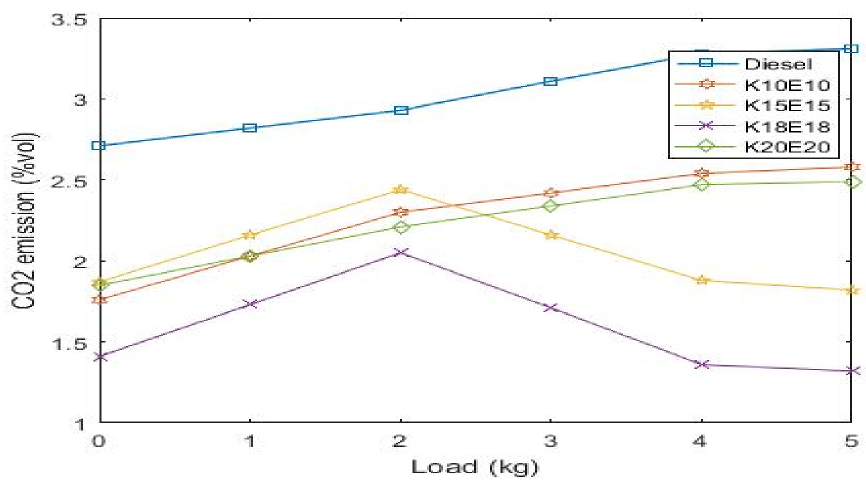

Figure 12 Comparison of CO_2 emission of biodiesel-additive-diesel blend with pure diesel.

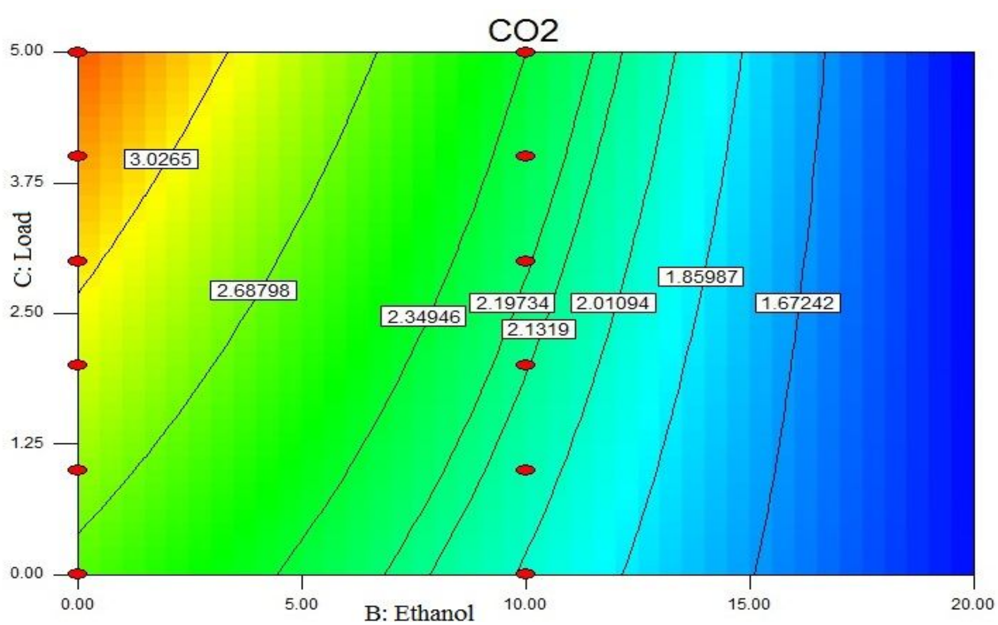

Figure 13 Contour plot of CO_2 v/s Ethanol, Load

III. RESULTS AND DISCUSSION

A. HC emission

The variation of HC emission with blend biodiesel-diesel and biodiesel-ethanol-diesel as fuel is shown in Figure 3 and Figure 4 respectively. So, with biodiesel HC emission is increased. For blend K15, K18, K20, it increases with increasing load. For blend with biodiesel-ethanol, the HC emission is decreased with all blend. Exception K18+E18 blend, which increased with load initially and then decreased. The main reason for HC emission is unburned fuel blend due to insufficient combustion so with addition of ethanol this emission can be reduced effectively. From result of sum of squares, as shown in Table 4, it can be seen that among the effect of linear, interaction, quadratic, cubic factors; interaction variables are effective. It can be decided based on *p-value* and *F-value* which is provided from analysis of variance (ANOVA). The *p-value* less than 0.001 is significant in most of the cases. The contour plot of HC emission with biodiesel and ethanol is shown in Figure 5. For evaluation of model, deciding criteria are R^2, Adjusted R^2, which is shown in Table 5. So, interaction model is suggested by software. ANOVA for response surface model is shown in Table 6, since interaction variables effect are significant, so quadratic and cubic effect have been aliased. As it can be seen from Table 6 developed model is significant. The Quadratic Regression equation obtained for HC emission is given as

$$HC = 119.63473 - 0.90943 \times BD - 4.81021 \times Ethanol + 2.85834 \times Load + 0.22081 \times BD \times Ethanol + 0.53320 \times BD \times Load - 0.72371 \times Ethanol \times Load \quad (1)$$

B. CO emission

CO emission is toxic in nature and has to be controlled. CO emissions are results from incomplete combustion i.e. due to deficiency of oxygen in blended fuel. The variation of HC emission with blend biodiesel-diesel and biodiesel-ethanol-diesel as fuel is shown in Figure 6 and Figure 7 respectively. In first case blend with biodiesel, CO emission increases with compare to pure diesel case. Also, with increasing blend volume, there is decrease in CO emission. In second case with biodiesel-ethanol, CO emission decreased with compare to diesel as fuel. For K18+E18 blend, observed the lowest possible emission in range of 3-5kg.From results of sequential model of sum of squares and model summary parameters in Table 4 and Table 5 respectively, it is clear that linear model is significant over quadratic and interaction model. ANOVA model developed for CO emission, is similar to HC emission as shown in Table 6 with linear model is significant a compare to quadratic, interaction and cubic term. The contour plot of CO emission versus ethanol and load is shown in Figure 8, which gives same interpretation. The quadratic regreesion equation obtained from RSM for CO emission is

$$CO = 0.15955 + 1.01489E\text{-}003 \times BD - 7.60932E\text{-}003 \times Ethanol - 3.71995E\text{-}003 \times Load + 1.57767E\text{-}004 \times BD \times Ethanol + 2.21993E\text{-}004 \times BD \times Load - 1.17554E\text{-}004 \times Ethanol \times Load \quad (2)$$

C. NOx emission

uring combustion of fuel in diesel engine, it requires highly compressed air which is mainly consists of oxygen and nitrogen. Since nitrogen do not react with oxygen at temperature below 1600°C in the cylinder resulting NO_X emission (NO and NO_2 emission).With experimental data shown for biodiesel and biodiesel-ethanol blend with diesel in Figure 9 and Figure 10 respectively, NOx emission have been increased as compare to pure diesel for both cases. With results observed from sequential model of sum of squares and model summary statistics results in Table 4 and Table 5 respectively, the interation model is significant over other. The overall model is significant. The contour plot of NO_X emission versus biodiesel and load is shown in Figure 11. The quadratic regression equation obtained from RSM for NO_X emission is given as

$$NO_X = 178.47765 + 4.92102 \times BD - 5.06672 \times Ethanol + 62.45842 \times Load + 0.21467 \times BD \times Ethanol + 1.03307 \times BD \times Load - 0.20147 \times Ethanol \times Load \quad (3)$$

D. CO_2 emission

As shown in Figure 12 and Figure 13 shows CO_2 emission for biodiesel and biodiesel-ethanol blend with diesel as fuel respectively. In first case with biodiesel blend, for K10 and K15 blend, CO_2 emission is decreasing as compare to diesel. For K18 and K20 blend, it is increasing with load. In second case with biodiesel-ethanol blend, for all blend CO_2 emission is reduced as compare to diesel fuel. Lowest value of CO_2 emission is observed with K18+E18 and also decreasing nature with increasing load.

With results from sum of squares and model summary statistics results in Table 4 and Table 5 respectively, interaction effect is predominant to linear, quadratic and cubic effect in the model. The overall model of CO_2 emission is significant which can be seen with reference to *F-value and p-value* of AVOVA table. The contour plot of CO_2 emission versus ethanol andload is shown in Figure 14, which shows same interaction model. The quadratic regression equation by RSM for CO_2 emission is given as,

CO_2 = 2.64541 - 1.49320E-003 × BD - 0.091328 × Ethanol + 0.11163 × Load + 2.78926E-003 × BD × Ethanol + 3.52806E-003 × BD × Load - 7.62413E-003 × Ethanol × Load…………(4)

E. Multi-objective Optimization by GA

The objective is to minimize emission,namely HC, CO, NO_X and CO_2 emission, from exhaust gas in single cylinder CI engine with Karanja biodiesel and ethanol additive blend with diesel as fuel. The parameters used to perform is shown in Table 16. Among these emission, NO_x emission have selected for importance as compare to other. The Pareto optimal soilution ontained by GA is shown in Table 17. Also, Distance plot and spread plot is shown in Figure respectively obtained by software.For validation, three rows selected from Pareto optimal solution as highlited in Table 17. The input variable were adjusted to these values and average of five times reading noted. It shows 3-8 % error. So, it shows good agreement with these input variables. So, best solution obatined ad 10.02 % of biodiesel, 19.97 % of ethanol and 1.27 kg of load at constant speed of 1500 rpm. The response were 50.71 ppm, 0.044 % vol., 256.7 ppm and 1.358 % for HC, CO, NO_X and CO_2 emission respectively.

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