Case Studies in Thermal Engineering 25 (2021) 100876

Contents lists available at ScienceDirect

Case Studies in Thermal Engineering

journal homepage: http://www.elsevier.com/locate/csite

An experimental investigation of emission performance of heterogenous catalyst jatropha biodiesel using RSM

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ARTICLE INFO

Keywords:
Diesel engine
Jatropha biodiesel
RSM
Emission

ABSTRACT

Tremendous growth in the number of automobiles in developed and developing global economies has exorbitantly boosted competition for petroleum products. Petroleum products derived from fossil fuels are predominantly responsible for environmental pollution as unburnt hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NO_x) & carbon dioxide (CO_2) emissions are released from the fossil fuel combustion. In the view of increasing environmental pollution and stringent emission norms, the present study is concentrated on using Jatropha biodiesel as an alternate fuel source to run variable compression ratio (VCR) diesel engine. The characteristics of VCR diesel engine emission have been evaluated under different compression ratio (CR), operating conditions of load & pressure of fuel injection. In this research work, Jatropha biodiesel diesel blend B30 (30% biodiesel and 70% diesel) and B0 (100% diesel) have been taken as fuel to run the engine. For conducting experiments, load has been varied from 0 to 12 Kg, CR from 14 to 18 and FIP from 180 to 270 bar as per the model of Response Surface Methodology experiments. The experimental investigation showed that the use of the B30 blend reduces HC & CO emissions by about 16.7% and 24% correspondingly in comparison to diesel. However noteworthy rise in NO_x & CO_2 emissions rate recorded by using the B30 blend as that of diesel. It has been shown that with enhancing in load & CR, HC&CO emissions decreased significantly however increase in CO_2 and NO_x observed. Advancing FIP, significantly decreases HC & CO emissions as well as tends to increase NO_x and CO_2 emissions.

1. Introduction

Sustainable social & economic growth of a country primarily hinge on the accessibility of resources of energy [1]. Shrinking petroleum resources due to Increasing demand, haphazard extraction of fossil fuels and increasing stringent emission norms have presented a major challenge in front of emerging economies of the globe (E.A [2]. Exhaust emissions of carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC) & sulfur oxides (SO_x) are produced from combustion of fossil fuel and are prime cause for environmental pollution [2]. Hence it has become necessity to gradually shift towards renewable alternate fuel to

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https://doi.org/10.1016/j.csite.2021.100876
Received 31 December 2020; Received in revised form 22 January 2021; Accepted 2 February 2021
Available online 5 February 2021

Abbreviations

VCR	Variable compression ratio
CI	Compression ignition
BP	Brake power
BTHE	Brake thermal efficiency
HC	Hydrocarbon
CO	Carbon monoxide
BMEP	Brake mean effective pressure
BSFC	Break specific fuel consumption
ASTM	American society for testing and materials
CR	Compression ratio
FAME	Fatty acid methyl esters
RSM	Response surface methodology
CCFCD	Center composite face centered design
DOE	Design of experiments
S/N ratio	Signal to noise ratio
DAQ	Data acquisition system
ANOVA	Analysis of variance
ANOVA	Analysis of variance

Nomenclature

B0	Diesel
B30	30% biodiesel blending
CO_2	Carbon dioxide
NO_X	Nitrogen oxide
SO_x	Sulfur oxide
CaO	Calcium oxide
P-value	Probability value
F-value	Fisher test value
R2	Coefficient of determination
Kg	Kilogram
ppm	Parts per million
rpm	Revolution per minute
C	Degree Celsius
kJ/mol	Kilo joule per mole
gm	Gram
cSt	Centistokes
kW	Kilowatt
mm	Millimetre

reduce energy dependence on fossil fuels [3]). Substituting the alternate fuels like biodiesel with tralatitious diesel fuel appears to be an available choice to mitigate the energy insecurity and detrimental effects of utilization of fossil fuels [1]. These days biodiesel is acquiring popularity as a auxiliary to diesel fuel as this is a renewable, biodegradable, eco friendly, non toxic, cleaner fuel and it can be combined with diesel in any proportion to get biodiesel blend ([4]). Reduction in exhaust emission is a big challenge for engine manufacturers and biodiesel has shown huge potential to reduce exhaust emissions when used in engine as fuel. Biodiesel blends with diesel fuel have consistently delivered improved performance and lowering HC,CO & particulate matter emissions [5], (Kannan et 2012). Ayatallah et al. evaluated the enactment and emission variables of a single-cylinder E6 Ricardo diesel engine fuelled by blends of biodiesel delivered in the form of diesel waste fish oil. They have mentioned that biodiesel has huge potential to minimize CO & HC emissions in comparative analysis with diesel. From the experiments they have recorded 5.2–27%, 11.6–70% decrease in CO&HC emissions correspondingly as that of diesel. In addition to the above, average increase of 7.2% in CO_2 emissions and 1.9–12.8% increase in NO_x emissions also reported by the usage of biodiesel blends as that of diesel [6]. Biodiesel obtained from waste cooking oil blends with diesel were investigated on diesel engine by ya-fen.lin 2007 Considerable reduction in CO emissions reported, however authors have reported higher NO_x and CO_2 emissions than diesel. G. Labeckas have evaluated the impact of clean blends of rapeseed biodiesel fuel on engine. They have observed lower HC emission using biodiesel blends than diesel [7]. [8] have operated diesel engine using blends of biodiesel formed from oil of soybean &stated almost identical power, slightly greater brake specific fuel consumption than the diesel. They have also stated considerable reduction in HC, CO & NO_x emissions than diesel fuel at higher loading conditions [9]. have examined the emission properties of direct injection diesel engine by consuming blend of Palm &Jatropha biodiesel mixture in different proportion. They have reported that D90 PB5 JB5 (90% diesel, 5% Jatropha biodiesel and 5% Palm biodiesel) has resulted

Table 1
Thermo-Physical Properties of diesel, biodiesel & B30 Blend.

Property	Diesel	Biodiesel	B30 Blend
Chemical Composition	HC(C_{10} to C_{21})	FAME (C_{12}–C_{22})	–
Cetane index	49.53	52	50.32
Density at 15 °C (gm/cm^3)	0.8376	0.8941	0.8541
Kinematic viscosity at 40 °C (cSt)	2.843	6.646	3.667
Flash point (°C)	53	122	85.4
Lower Heating value (kJ/mol)	10927	10716	10848

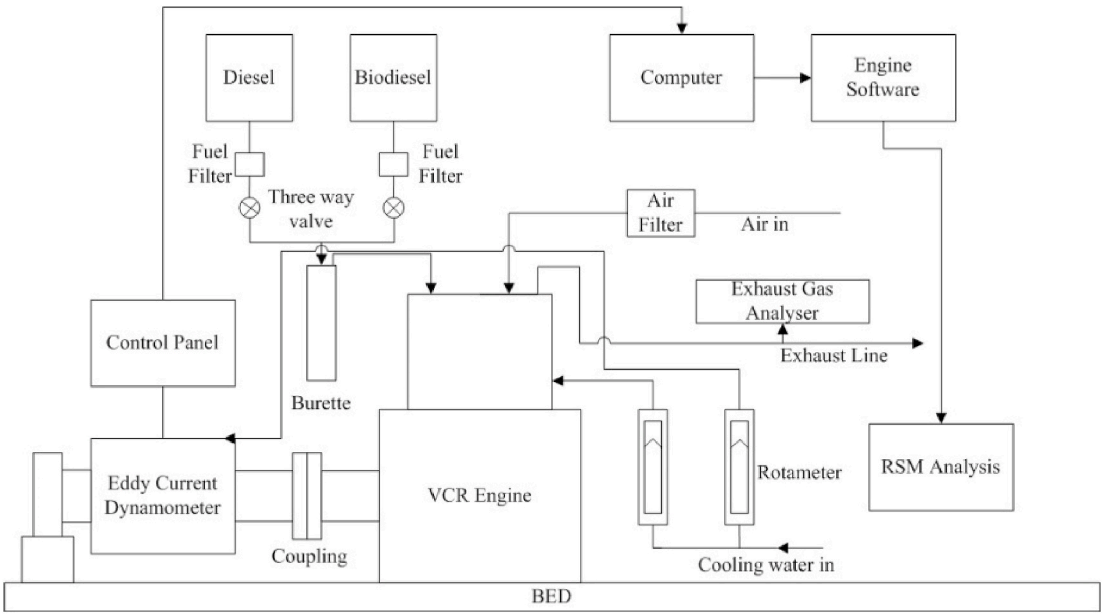

Fig. 1. Layout diagram of test set up.

Table 2
Component wise engine specification.

Manufacturer	Kirloskar
General particulars	Single-cylinder, 4-Stroke
Type of engine	water-cooled, compression ignition variable compression ratio engine
Power rating	3.5 kW at 1500 rpm
Stroke and Bore	110 mm, 87.5 mm
Loading unit	Eddy current dynamometer
Load sensor	Stain gauge load cell
Cubic Capacity	661 cubic centimeter
Compression ratio	12:1 to 18:1
Load Range	0 to 12 Kg

4.65% rise in brake power with compared to diesel. Significant decrease in exhaust gas temperatures observed in instance of all blends. Average decrease in CO emissions for 10%, 20% and 30% biodiesel blends was found to be 7.1%, 17.7% and 14.5% respectively, however average increase in NO_x emissions was observed to be 5.3% and 9% for 5% and 10% biodiesel blends respectively than diesel. (A. K [10]. have studied the consequence of timimng of injection & FIP on single cylinder engine. They have conducted experiments by taking 2 FIPs (1000 & 500 bar) & various start of injection timings at uniform speed of engine at 2500 rpm. Authors have reported significant increase in BTHE, brake mean effective pressure (BMEP) & exhaust gas temperature with increase in FIP. Advancement in IT resulted in increment in BTHE and BMEP while reduction in BSFC & exhaust gas temperature observed. Decrease in CO_2 and HC emissions with increasing FIP observed however increase in NO_x emissions noted. Advanced IT resulted in lower CO_2 and HC emissions however considerable increase in NO_x emissions were recorded [11]) used olive oil methyl ester to operate three cylinder diesel engine and reported constant combustion efficiency, reduction in BSFC in comparison to diesel. [12] studied the mahua oil ethyl ester in four stroke direction injection diesel engine. They have observed considerable increase in BSFC, slight increase in BTHE, reduction in HC

Table 3
Experimental result with input variables for B30 blend.

S. No.	Factors						
	LOAD (Kg)	CR	FIP (bar)	CO (%)	CO_2 (%)	HC (ppm)	NO_x (ppm)
1	6	16	225	0.19	2.4	32	135
2	6	18	225	0.16	2.8	26	156
3	6	16	225	0.19	2.4	31	144
4	12	18	180	0.17	3.7	25	328
5	6	16	180	0.23	2.1	32	120
6	12	14	270	0.15	3.3	33	318
7	6	16	225	0.19	2.4	31	145
8	12	18	270	0.12	4.2	26	346
9	6	16	225	0.19	2.4	31	146
10	0	14	270	0.36	1.5	46	86
11	6	16	270	0.15	2.7	30	139
12	12	16	225	0.16	3.6	29	331
13	0	14	180	0.42	1.6	47	79
14	12	14	180	0.24	2.9	35	313
15	0	18	180	0.31	1.8	33	86
16	0	18	270	0.27	2.1	31	99
17	6	14	225	0.25	2.3	37	127
18	6	16	225	0.19	2.6	30	146
19	0	16	225	0.32	1.6	39	84
20	6	16	225	0.18	2.5	32	144

(63%), CO, NO_x, Smoke (70%) emissions & slight enhance in CO_2 emission in comparison to diesel [13]. analyzed the biofuel developed under various compression ratio from waste cooking oil. They have varied CR from 14 to 18 and reported decreaseof CO emissions by 37.5%, HC emissions by 52% and CO_2 emission increases by 14.28% and NO_x emissions by 36.84% [14]. evaluated enactment & emission variables of Jatropha biodiesel single cylinder diesel engine. The authors have also reported 13–15% decline in CO emissions at full loading condition. (Nagaraja S,Sooryaprakash K 2015) have operated VCR engine using pre heated palm oil & its blends with diesel (5%, 10%, 15% & 20%) under different compression ratios [15]. have examined enactment and emission of VCR engine using biodiesel methanol blends by taking load, CR and fuel blends as input variables and employed RSM technique for conducting experiments and analysis of results. From the analysis they have reported that at 18 CR, 5% fuel blend and 9.03 Kg load, VCR engine delivers optimum performance and emissions. They have also mentioned the values of output responses under optimized input parameters [16]. have carried out experiments in diesel engine fuelled with blends of Karanja biodiesel (10, 20, 30 & 50%) with diesel under different CR (17.5, 17.7, 17.9 & 18.1). They have reported decrease in CO and HC emissions with advancement of CR from 17.5 to 18.1. Lower fuel blend ratio delivered slightly higher BTHE, however BSFC, CO, HC and NO_x emission decreased. They have also reported that RSM technique is a simplest and efficient optimization technique [17]. applied CCFCD-focused RSM to obtain suitable engine variables with bioethanol diesel blend for combustion characteristics efficiency evaluation to get optimum blending. They got 25% of the bioethanol blend can also be castoff in diesel engines. In the current research article authors have investigated CO, NO_x, HC emissions of Jatropha oil, Karanja oil & Putranjiva oil & reported that Jatropha oil as a better fuel in terms of exhaust emissions (Ghosh et al., 2008). The main objective of current investigation is to evaluate consequence of load, CR and FIP on characteristics of emission of CI engine fuelled with Jatropha biodiesel blend B30. The experiments were executed as per design of experiments of RSM. Experimental results have been compared with RSM response. It is evident from the study by the usage of biodiesel blend in diesel engine can greatly minimize HC&CO emissions rate in comparison to diesel fuel.

2. Materials and methods

Jatropha curcas seeds were procured from Biotech Park, Lucknow India. Crude Jatropha oil was obtained by crushing the seeds and subsequent filtration. Crude Jatropha oil has been chemically reacted with methanol (purity 99.9%), in the presence of a heterogeneous catalyst calcium oxide (CaO, purity 99%) to produce methyl ester which is known as biodiesel. Conversion yield of 81.3% was achieved in transesterification process. Commercially available diesel has been used to prepare blends of biodiesel for investigation purposes.

2.1. Fuel characterization

In the present study biodiesel, diesel blend B30 (30% biodiesel and 70% diesel) has been used to perform the experiments. Pilot experiments and various studies have confirmed that biodiesel blend B30 shows better potential to reduce emission characteristics [7]. The biodiesel blend B30 was just prepared before beginning the experiments to make sure the mixture to be homogeneous. The testing of blend B30 and diesel have been done as per the ASTM norms at lab of IOCL (Indian Oil Corporation Ltd.) Bhopal, India & it is listed in Table 1.

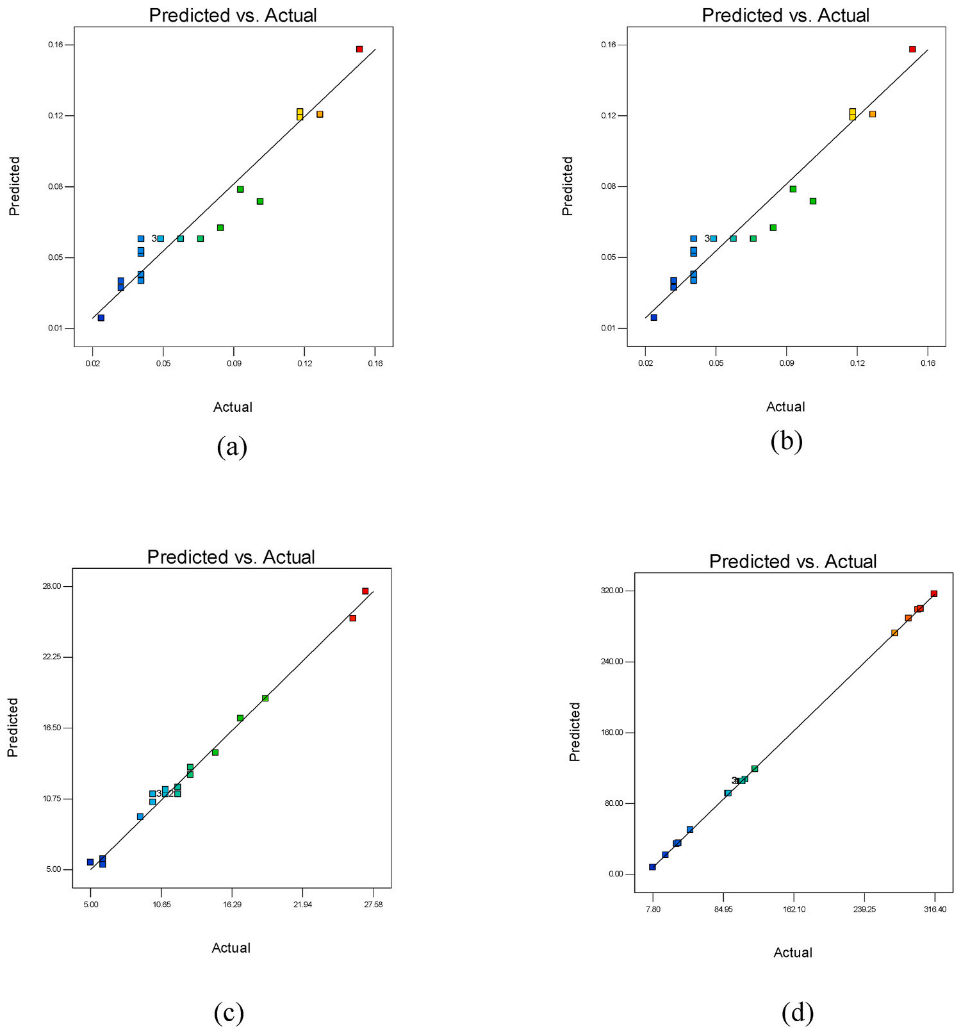

Fig. 2. Predicted Vs actual plot for (a) CO, (b) CO_2, (c) HC, and (d) NO_x.

2.2. Engine specification and test procedure

The layout of the experimental test bench has been shown in Fig. 1. The main components of the test bench are VCR diesel engine, eddy current dynamometer, control panel for applying load along with digital display, rotameter based water cooling system for engine and dynamometer, fuel storage tanks for biodiesel blend and diesel, data acquisition system, exhaust gas analyzer and various sensors for combustion and performance measurement. Component wise specifications are mentioned in Table 2. The caliberation of VCR engine fuel injector pump has performed at calibration diesel injection centre which is located in Bhopal, India. For recording and analyzing the input data from different sensors with DAQ system. The research engine was powered using the B30 blend and diesel at a steady speed of 1500 rpm. Twenty experiments have been carried out as per DOE of RSM and emission parameters namely CO, HC, NO_x and CO_2 were recorded for analysis. Recorded emission data has been used for establishing analysis of variance (ANOVA). In the field of research of input variables such as CR (18, 16 & 14), load (12, 6 & 0 Kg), & FIP (270, 225 & 180 bar) have been selected.

2.3. Response Surface Methodology

This methodology RSM is a set of statistical based mathematical procedures that is mainly used for development of prediction model for the analysis of desired output parameters. RSM provides objective function for correlating output responses with number of selected input parameters. In the present study, a quadratic equation given in equation (1) has been used to predict output responses like CO_2, CO, NO_x & HC emissions for biodiesel blend B30 & diesel. According to DOE, Input variables Load, CR and FIP have been taken and denoted as X_1, X_2 and X_3 and β_0, β_i, β_{ij}, β_{ii} represents regression coefficients [7]. The experimental results for blend B30 been mentioned in Table 3. The statistical evaluation and ANOVA has been carried out.

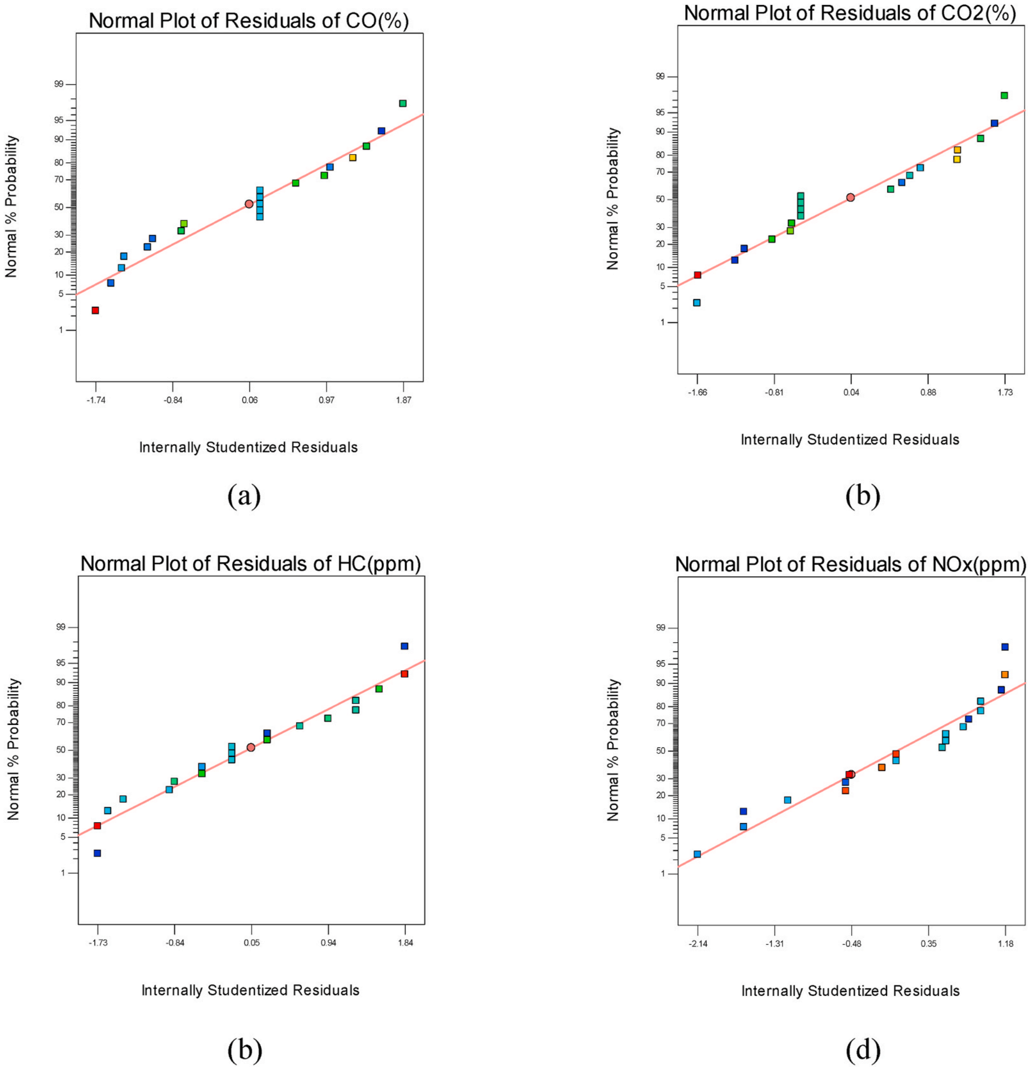

Fig. 3. Normal plots of residuals for (a) CO, (b) CO_2, (c) HC, and (d) NO_x.

Table 4
ANOVA model analysis (p value and F value).

	CO		CO_2		HC		NO_x	
Source	p value	F value	p value	F value	p value	F value	p value	F value
Model	<0.0001	302.81	<0.0001	94.96	<0.0001	127.64	<0.0001	590.26
A-load	<0.0001	1647.90	<0.0001	719.66	<0.0001	420.30	<0.0001	4559.74
B-CR	<0.0001	355.22	<0.0001	78.21	<0.0001	592.69	0.0004	26.71
C-FIP	<0.0001	239.15	0.0005	25.12	0.0282	6.57	0.0059	12.13
AB	0.0003	29.19	0.0141	8.80	0.0002	32.84	0.1792	2.09
AC	0.0560	4.67	0.0437	5.32	0.3621	0.91	0.8543	0.04
BC	0.0088	10.51	0.1304	2.72	0.3621	0.91	0.2603	1.42
A^2	<0.0001	163.50	0.0483	5.06	<0.0001	43.79	<0.0001	420.86
B^2	0.0029	15.34	0.1708	2.18	0.3326	1.04	0.3092	1.15
C^2	0.9106	0.01	0.4188	0.71	0.9209	0.01	0.0335	6.07
Lack of Fit	0.0726	4.14	0.1924	2.29	0.5286	0.93	0.1562	2.63

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \sum_{j=1}^{2} \beta_{ij} X_i X_j + \sum_{i=1}^{3} \beta_{ii} X_i^2 \quad (1)$$

Table 5
ANOVA models evaluation.

	Std. Dev.	Mean	R^2	Adj. R^2	Pred. R^2	Adeq. Precision
CO	0.00654	0.2220	0.99634	0.99305	0.96971	66.99811
CO_2	0.10727	2.5450	0.98843	0.97803	0.91537	36.38702
HC	0.74039	32.80	0.99137	0.98360	0.91300	42.40389
NO_x	5.62904	173.60	0.99812	0.99643	0.99030	68.13497

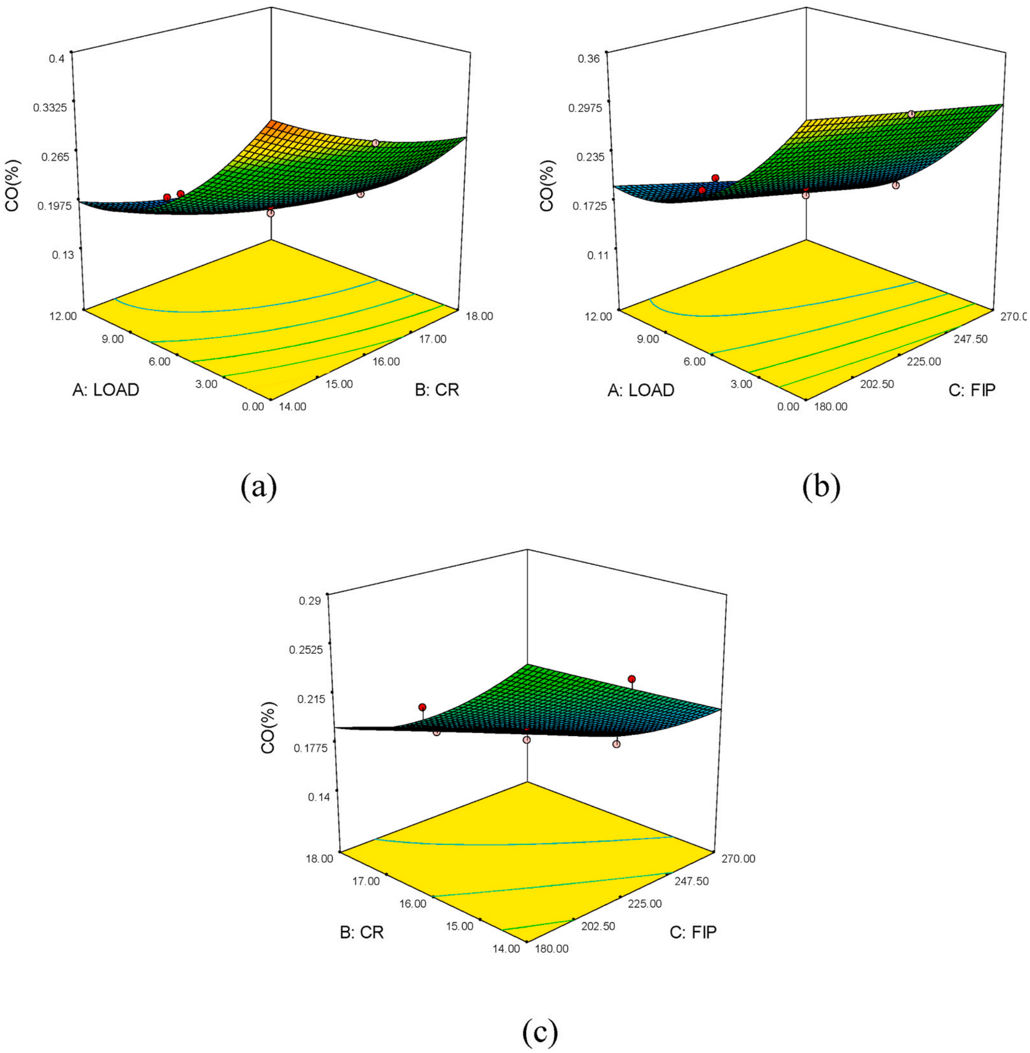

Fig. 4. CO variation surface plots with engine input parameters for B30 blend.

3. Result and discussion

3.1. Model analysis

The model analysis and evaluation were primarily based on analysis of variance (ANOVA) which helped in computing the numerical data for the p-value and validation of model stability. Fig. 2 presents plot between real responses versus RSM response (Predicted) values. The graphical plot also show that input statistics points are fragmented uniformly by 45° line which specify that all modelsare well fitted.

Fig. 3 represents a normal probability plot for CO, CO_2, HC and NO_x. The population normality can be verified with a normal residual probability plot. If the distribution of residuals is normal, a straight line would resemble in the plot. In the normal probability plots of output responses, the residuals are following the straight line, hence it can be confirmed that residuals are normally

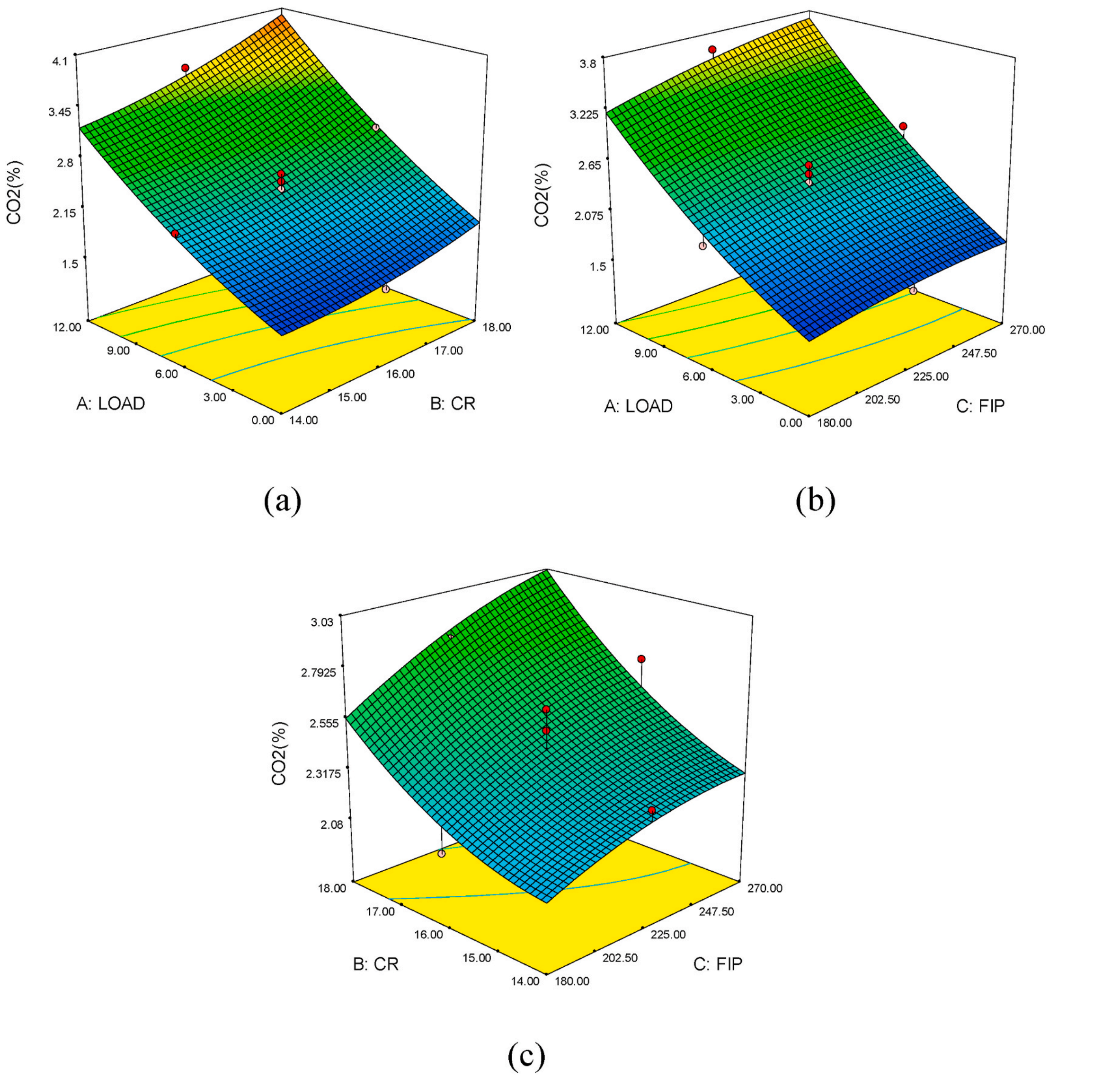

Fig. 5. CO_2 variation surface plots with engine input parameters for B30 blend.

distributed. In the present study, the p values of the model have been observed to be less than 0.0001, which implies that the selected models are significant [8]. ANOVA model analysis for F value and p value has been presented in Table 4. The goodness of fit (i.e. R^2) & the Adjusted R^2 data for various output responses for B30 blend has been shown in Table 5. The various models for the output response have been established in terms of input variables are shown in equations (2)–(5).

$$CO = 2.170727273 - 0.002034343xFIP - 0.168136364xCR - 0.043318182xLOAD - 0.000083xFIPxCR - 0.000018xFIPxLOAD + 0.00104xCRxLOAD - 0.0000022x\,(FIP)^2 + 0.003863x(CR)^2 + 0.00140x(LOAD)^2 \quad (2)$$

$$CO_2 = 7.020227 + 0.00284xFIP - 0.82614xCR - 0.11973xLOAD - 0.00069xFIPxCR + 0.00032xFIPxLOAD + 0.00937xCRxLOAD - 0.000027x\,(FIP)^2 + 0.02386x(CR)^2 + 0.0040x(LOAD) \quad (3)$$

$$HC = 138.6773 - 0.05323xFIP - 7.861xCR - 3.9932xLOAD + 0.00278xFIPxCR + 0.00093xFIPxLOAD + 0.125xCRxLOAD - 0.00002x\,(FIP)^2 + 0.1136x(CR)^2 + 0.08207x(LOAD)^2 \quad (4)$$

$$NO_x = 129.4932 + 1.565xFIP - 31.865xCR - 7.3246xLOAD + 0.00263xFIPxCR + 0.00138xFIPxLOAD + 0.23958xCRxLOAD - 0.00413x\,(FIP)^2 + 0.9090x(CR)^2 + 1.9343x(LOAD)^2 \quad (5)$$

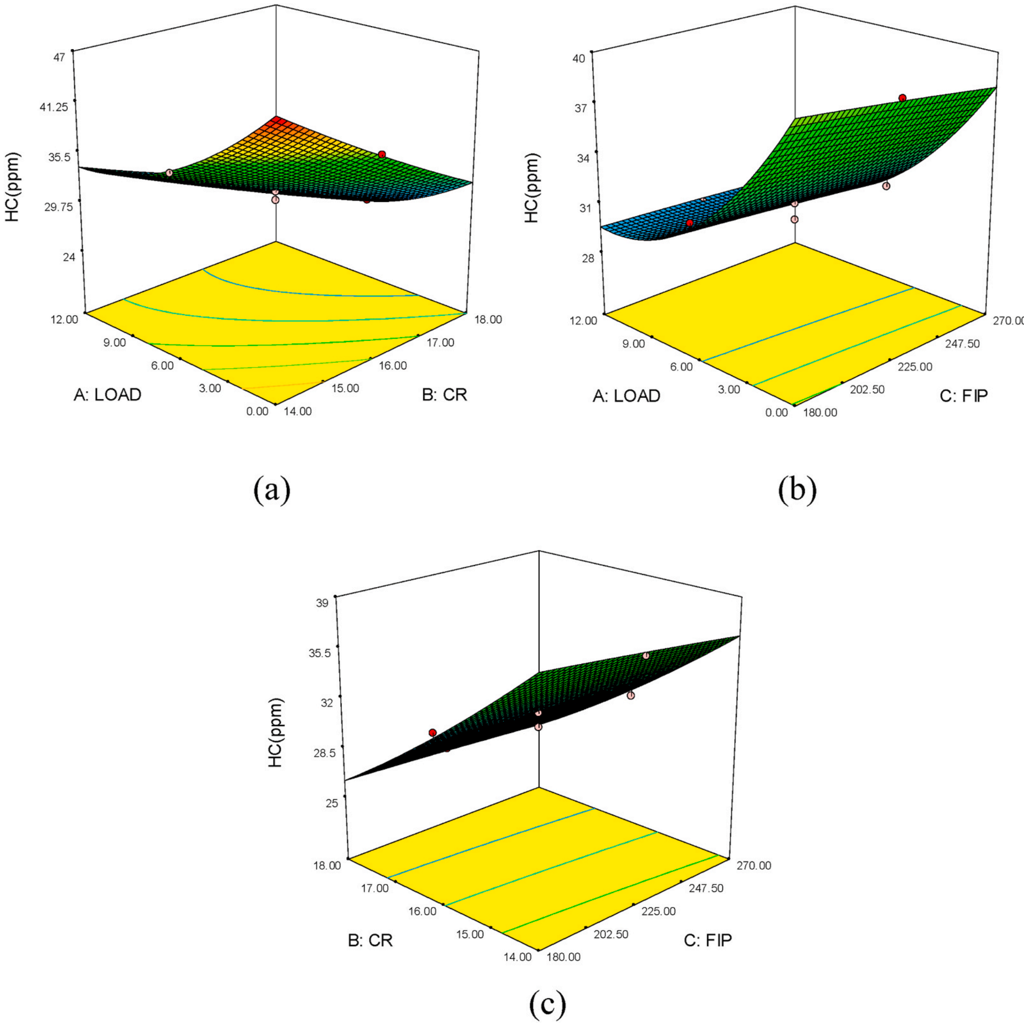

Fig. 6. HC variation Surface plots with engine input parameters for B30 blend.

3.2. CO emission

ANOVA Table 4 shows that load (F value 1647.9) is having highest impact on CO generation. The influence of CR, load & FIP on CO production when engine was operating at 1500 rpm is depicted in Fig. 4. CO emission with CR &load at 225 bar pressure of fuel injection is presented in Fig. 4(a). It has been perceived that CO emission decreases with increase in engine load and CR. Experimental results show that CO emission varies from 0.4% to 0.13% as load increases from 0 to 12 Kg and CR advances from 14 to 18 at constant FIP of 225 bar. Load and FIP effect of CO emission has been portrayed in Fig. 4(b). From the analysis it has been noted that CO emission varies from 0.36% to 0.11% under the influence of load and FIP variation from their lower to higher values at constant CR at 16. Increased FIP felicitates proper atomization of mixture of air-fuel that leads to decrease in CO emission [11]). The Impact of FIP & CR on CO emission has been represented in Fig. 4(c). Similar declining trend in CO emission from 0.29% to 0.14% observed with the increase in CR and FIP at constant load of 6 Kg. This is due to the fact that increased engine load and CR, increases combustible mixture temperature, provides sufficient oxidation temperature and shorter ignition results in more complete combustion producing lower CO emissions [13].

3.3. CO_2 emission

From the ANOVA analysis of CO_2 emission as shown in Table 4, it has been observed that CO_2 generation is strongly affected by load (F value 719.66) followed by CR and FIP. The consequence of CR, load, &pressure of fuel injection on CO_2 emission has been explained by plotting three dimensional surface plots as shown in Fig. 5. Increase in load and advancement in CR at constant FIP at 225 bar, increases CO_2 emission from 1.5% to 4.1% as shown in Fig. 5(a). The load and FIP impact on CO_2 emissions at 16 CR were depicted in Fig. 5(b). As load varies from 0 to 12 Kg and FIP advances from 180 to 270 bar, CO_2 emission increases from 1.5% to 3.8%. Fig. 5(c)

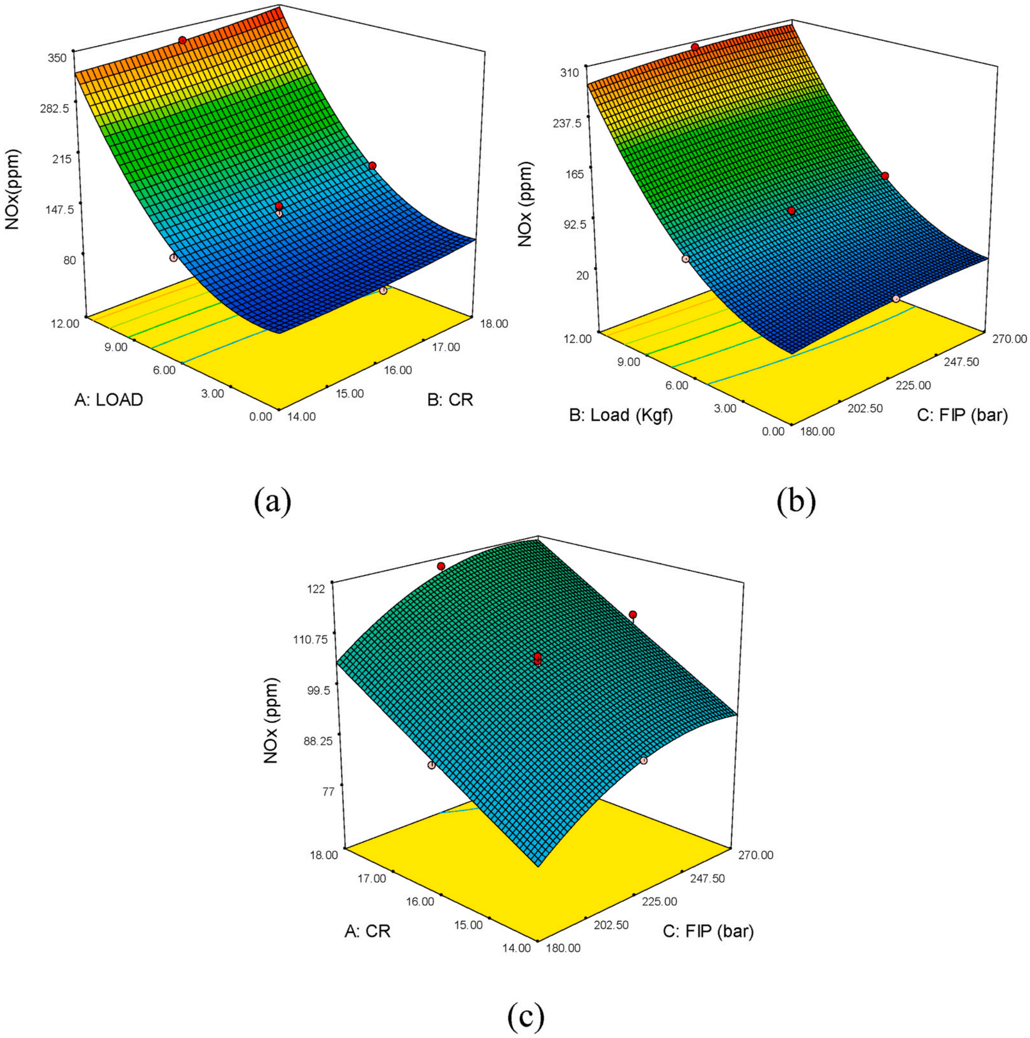

Fig. 7. NO_x variation surface plots with engine input parameters for B30 blend.

shows the cumulative impact of CR and FIP on CO_2 emissions. Similar behaviour in CO_2 emission observed with the increase in CR and FIP and varies from 2.0% to 3.1%.

3.4. HC emissions

The consequence of engine input variables on HC emissions is shown by three dimensional surface plots (Fig. 6). From the F values as mentioned in ANOVA Table 4, it can be observed that effect of CR is having highest effect on HC emission followed by load and FIP. Higher the F value more will be the effect of input parameter on output response. Surface plot between HC emission and load, CR havebeen plotted at 225 bar FIP as revealed in Fig. 6(a). It can also be perceived that HC emission decreases from 47 ppm to 24 ppm at elevated load and CR conditions. HC emission with load and FIP at 16 CR has been depicted in Fig. 6(b). From Fig. 6(b), it can also be perceived that HC emission reduced from 40 ppm to 28 ppm with the increase in load and FIP in the experiment range. Fig. 6(c) shows the combined effect of CR and FIP in HC emission generation at 6 Kg load. Decrement in HC emission observed with advancement in CR and FIP. From the graphical plot, it can be observed that HC emission reduces to 25 ppm from a higher value of 39 ppm.

3.5. NO_x emission

NO_x is mainly generated because of higher temperature inside the combustion chamber. Fig. 7 exhibits the NO_x variation surface plots at various engine input parameters. NO_x emissions are influenced by various parameters, such as: combustion temperature, amount of oxygen, equivalence ratio and combustion time period [18].The uncontrolled stage of combustion is based on the high temperature where NO_x is produced. From the F values as shown in ANOVA Table 4, it can be observed that CR is having highest effect

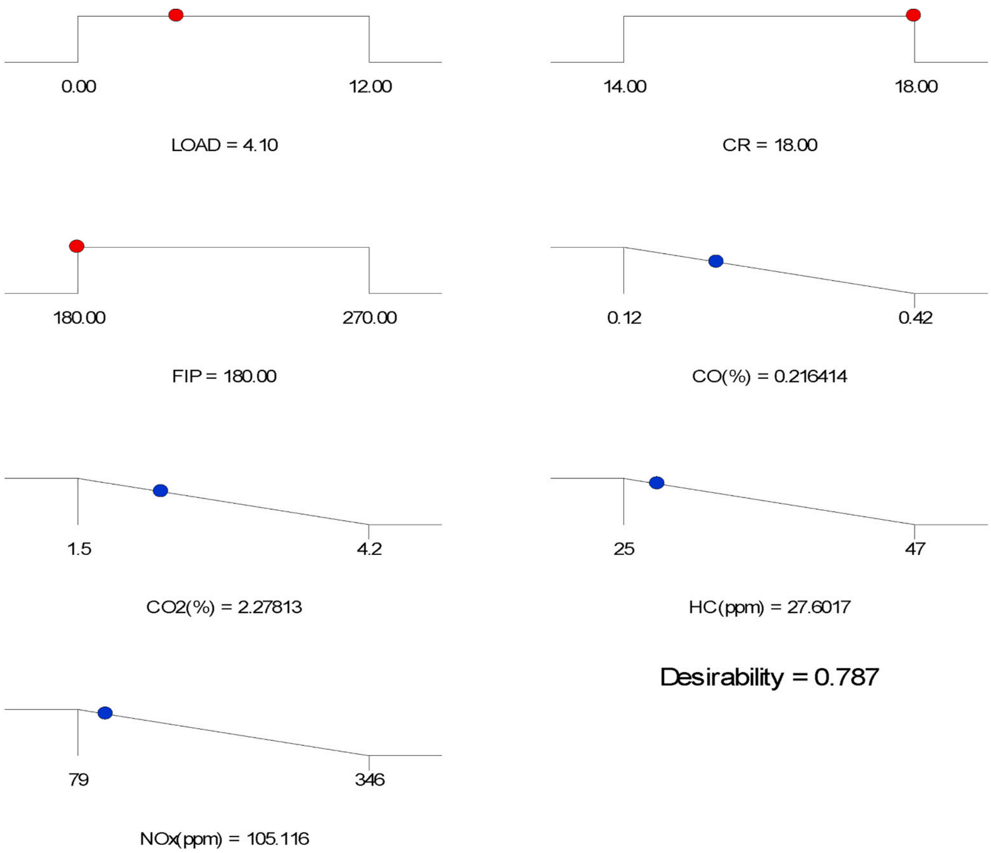

Fig. 8. Numerical optimization ramp plots.

Table 6
Validation test results.

Load	CR	FIP		CO	CO_2	HC	NO_x
(Kg)		(bar)		(%)	(%)	(ppm)	(ppm)
4.1	18	180	Predicted	0.216	2.28	27.60	105.12
			Actual	0.22	2.3	28	102
			% Error	2.46	3.07	1.44	3.16

on NO_x emission followed by load and FIP. Higher the F value more will be the effect of input parameter on output response. Surface plot between NO_x emission and load, CR has been plotted at 225 bar FIP as depicted in Fig. 7(a). At high load and CR conditions, NO_x increases from 14 ppm to 80 ppm. The emission of NO_x with load and FIP at 16 CR has been depicted in Fig. 7(b). It can be seen from Fig. 7(b) that NO_x emission increases from 70 ppm to 340 ppm with the increase in load and FIP in the experiment range. Fig. 7(c) shows the combined effect of CR and FIP in NO_x emission generation at 6 Kg load. Increment in NO_x emission observed with advancement in CR and FIP. From the plot, it can be seen that NO_x emission increases to 157 ppm from a lower value of 120 ppm.

4. Optimization and validation

Numerical optimization technique has been used for optimization of engine process variables and RSM responses. Using Design expert software engine parameters optimization was done, and optimized output responses suggested by RSM models are shown by Fig. 8. The key objectives of present analysis are to minimize the engine emissions. The desirability method has been applied for generating the optimal solutions as per the optimization criteria. The results showed that the optimal values of CO, CO_2, HC and NO_x are 0.216%, 2.28%, 27.6 ppm, and 105.12 ppm respectively at optimal level of load at 4.1 Kg, compression ratio of 18 and 180 bar fuel injection pressure. A validation test on the optimal expected range of engine input variables was performed as results are shown in Table 6. The prediction errors for output responses are below 5%, which are perceived to be significant for acceptance [19]. The overlap plot has been represented in Fig. 9. The Flag presents the optimal data of output response. The factors of input engine can be fixed in yellow section to get optimal data of all four responses. The region which is shaded not meeting the criteria of optimization.

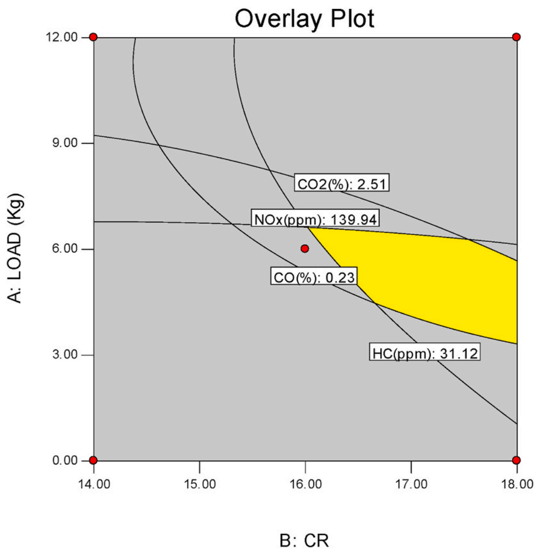

Fig. 9. Overlay plot.

Table 7
Comparison of optimized blend responses with mineral diesel.

Fuel	CO (%)	CO_2 (%)	HC (ppm)	NO_x (ppm)
B30 blend	0.18	2.7	24	104
Diesel	0.22	2.3	28	102
	(24%↓)	(13.3%↑)	(16.7%↓)	(2.12%↑)

At optimized conditions of load at 4.1 Kg, CR at 18 and 180 bar FIP

Therefore, RSM can be used to forecast and optimize engine operating factors. Hence, the experimental work is significantly reduced, in which effort and costs are saved.

5. Comparative analysis of B30 blend emissions with mineral diesel

A comparative study was also conducted to compare the emissions generated by using biodiesel blend B30 with baseline mineral diesel. Experiment was performed in engine fuelled with mineral diesel at optimum engine input control factors setting at 4.1 Kg load, 18CR and 180 bar FIP. From Table 7, it can be inferred that Jatropha biodiesel blend B30 generates 16.7% lower unburnt HC emissions, 24% lower CO emissions as compared to mineral diesel. Moreover, the study reported rise of 13.3% in CO_2 emissions and 2.12% in NO_x emissions. The incomplete combustion of fuel inside combustion chamber causes CO and HC formation. Conventional diesel fuel do not have oxygen molecule in their chemical structure. However, biodiesel is an oxygenated fuel which contains 10–15% oxygen, leads to proper combustion resulting in lower CO emission [9]. Reduction in CO emission using the B30 blend can also be explained as some quantity of CO produced at the time of combustion could have converted into higher oxides of carbon due to existence of surplus oxygen in biodiesel (A. K [10]. Reduction in unburnt HC emissions can also be attributed to greater Cetane No. of biodiesel which shows shorter ignition delay and leads to proper combustion [20]. Rise in CO_2 emission (13.3%) is observed which is mainly due to conversion of CO (reduction in 24%) and HC (reduction in 16.7%). Biodiesel blend B30 is more oxygenated fuel than mineral diesel resulting in proper combustion which reduced CO and HC emissions and increase in CO_2 emission observed due to conversion of CO and HC into CO_2. CO and HC emissions are toxic in nature and have adverse effect on human life and environment. On the contrary CO_2 is a non toxic gas, so it has no such impact on the health of living beings but it is a significant contributor for the phenomenon called Greenhouse effect. Effect of an Increase in CO_2 emissions will be neutralized by growing biodiesel plants and will not be an immense concern for the environment and green house effect [12]. Increment in NO_x emission can be due to increased exhaust temperatures and the amount of oxygen in biodiesel [14]. Oxygenated nature of biodiesel helps for proper combustion of biodiesel consequently higher NO_x formation. Higher density, presence of oxygen content and a small quantity of Nitrogen in biodiesel is also responsible for increase in NO_x emission.

6. Conclusion

In this study, experimental investigation has been performed to investigate the characteristics of emission of VCR diesel engine fuelled with biodiesel blend B30 with varying load, CR and FIP. The subsequent conclusions can be made from the results of experimentation & RSM analysis.

- The emission characteristics found from the RSM model are in close proximity to experimental results.
- Biodiesel blend B30 has shown huge potential to reduce CO and HC emission as compared to diesel. In Present work, about 24% reduction in CO emissions and 16.7% reduction in HC emissions observed using B30 blend as that of diesel.
- Use of biodiesel blend B30 diesel engine has significantly increased NO_x and CO_2 emissions by 2.12% and 13.3% as compared to mineral diesel. Effect of an Increase in CO_2 emissions will be neutralized by growing biodiesel plants and will not be a concern for the environment.
- From the study, it can be concluded that Jatropha biodiesel blend B30 could replace diesel in CI engine and will help to reduce the environmental pollution.

Author statement

Conceptualization, Manuscript prepared and experimented by Aparna Singh, Shailendra Sinha.
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Declaration of competing interest

All authors have no conflict of interest.

Acknowledgments

This work was carried by the NPRP grant # NPRP11S-1221-170116 from the Qatar National Research Fund (a member of Qatar Foundation). The statements made herein are solely the responsibility of the authors".

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