Optimization of Operating Parameters of Diesel Engine Powered with Jatropha Oil Diesel Blend by Employing Response Surface Methodology

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Abstract- Biodiesel is promoted as an appropriate alternative fuel for use in compression ignition (CI) engines as it is non-toxic, biodegradable, and sulphur-free and does not require any change in current engines design. The key objective of this experimental study is to evaluate the best operational parameters of engine referring to performance and emissions of Jatropha biodiesel powered CI engine by employing response surface methodology (RSM). In order to achieve maximum brake power (BP), brake thermal efficiency (BTE) and to reduce nitrogen oxide (NOx) and unburnt hydrocarbon (HC) emissions the optimization model is used. Effects of different factors such as fuel injection pressure (FIP), engine compression ratio (CR), and load on thermal performance have been studied in a single cylinder diesel engine. Experiments design was based on L20 orthogonal array central composite design (CCD) method. RSM was employed to test the suitability of biodiesel in diesel engines and models were developed by using experimental results. Based on the optimization, the optimum engine parameters found were 18 CR, 180 bar FIP and 8.11 kg engine load. Under these settings, the optimum responses were found as 2.21 kW, 28.24%, 25.3 ppm and 174.6 ppm for BP, BTE, HC, and NOx, respectively. Meanwhile, R^2 (coefficient of determination) values were found as 99.96%, 99.93%, 98.5%, 99.14%, and 99.78%, for BP, BTE, net heat release rate (NHRR), HC, and NOx, respectively.

Keywords Jatropha oil, CI engine, RSM, ANOVA

Nomenclature

CI	Compression ignition	JCO	Jatropha curcas oil
VCR	Variable compression ratio	CaO	Calcium oxide
CR	Compression ratio	CCD	Central composite design
FIP	Fuel injection pressure	ANOVA	Analysis of variance
B10	10% biodiesel + 90% diesel	RSM	Response surface methodology
B20	20% biodiesel + 80% diesel	kW	Kilowatt
BP	Brake Power	gm	Gram
BTE	Brake thermal efficiency	ppm	Parts per million
NHRR	Net heat release rate	rpm	Revolution per minute
HC	Hydro carbon	J/deg	Joule/degree
NOx	Nitrous oxide	cm	Centimeter
CO	Carbon mono oxide	Kg	Kilogram

1. Introduction

Over the past few years, biodiesel has gained growing interest as a renewable energy source as the availability of fossil fuel is depleting [1-4]. Crude oil price hikes, volatility in the global economy, and instability in distribution have driven individuals to look for alternative fuels. The emissions arising from combustion of fossil diesel fuel are a significant contributor to the environmental pollution. Diesel engine emissions have a detrimental impact on the biological and human environments. Increasing energy consumption, along with the environmental degradation and rising energy demand, is used as one instrument by humans to identify substitute fuels for replacing fossil fuels. Biodiesel is considered to be one of the best alternatives to petroleum based oils, owing to its considerable ability to minimise emissions and to deliver comparable performance when used in CI engines [4-5]. At present, biodiesel produced form Jatropha, Sunflower, Karanja and Rapseed is considered as a popular substitute for diesel [7-8]. Biodiesel and its blend with diesel are used as a fuel in diesel engine without modifying existing diesel engines configuration [9-11]. In the current CI engine-focused energy scenario, plenty of work is being done to improve thermal performance, accompanied by reduced emissions. Mofijur et al. [12] have investigated the feasibility of Jatropha biodiesel as a potential substitute for diesel. They found that Jatropha biodiesel blend B10 and B20 can be used in diesel engine without any modification in engine design. Authors observed an average 4.67% and 8.86% decrease in brake power than diesel for Jatropha B10 and Jatropha B20 blends, respectively. The average brake specific fuel consumption for B10&B20 was observed to be higher than diesel. The use of B10&B20 contributed to lower HC and carbon monoxide (CO) emissions but slightly increased NOx emissions relative to mineral diesel. Kasaby et al. [13] used Jatropha biodiesel blends to power single cylinder engine under variable compression ratio. The blend B10 achieved the highest peak pressure and highest brake thermal efficiency among the measured blends. B50 to B30 blends yielded lowest CO emissions and higher NOx emissions among other blends. Singh et al. [14] tested various proportions of Jatropha biodiesel under differing load, CR and FIP and observed comparable BP and BTE with mineral diesel. Pandhare et al. [15] reported higher fuel consumption for Jatropha biodiesel than that of diesel fuel. They found marginally higher BTE for biodiesel diesel blends. Patel et al. [16] studied Jatropha biodiesel blends (4%, 8%, 12% and 16%) in VCR engine and operating variables were optimized using RSM. The optimum factors were CR 18, load of 6.7 kg, and 12.2% biodiesel blending for optimum performance. Uslu et al. [17] assessed the performance of palm oil diesel blends by using RSM. Under optimum conditions of 17.88% blend, 780-watt load and injection advance, optimum responses were found to be 30.75%, 0.126%, 189.76 ppm and 196.25 ppm for BTE, CO, HC and NOx respectively. Parida et al. [18] have applied RSM to model and configure selected variables such as load, CR, and fuel blend. The optimum results obtained for BTE, CO, HC and NOx were 26.77%, 0.0059%, 114.84 ppm and 905.6 ppm, respectively. The observations of the RSM models were found to be in accordance with the experimental data, with deviations less than 5%.

On the basis of the above-mentioned studies, it have been concluded that the following parameters contribute substantially to enhance engine performance, namely compression ratio, fuel injection pressure, biodiesel blends and engine load. According to the study of literature, the most recent work has endeavoured to improve performance of biodiesel powered CI engine by using various optimization techniques to identify the best operating variables of engine. Furthermore, in previous studies, Jatropha shows a better response when used as a biodiesel blend with mineral diesel however studies referring to the application of RSM to optimize performance and emission of heterogeneous Jatropha biodiesel under varying compression ratio, fuel injection pressure and load are scanty. Therefore, the primary objective of this study is to optimize the engine input parameters for optimum performance and emission through response surface methodology technique. Study takes into account three factors, namely compression ratio, fuel injection pressure, and load for optimizing the perf ormance and emission of VCR diesel engine powered with heterogeneous Jatropha biodiesel diesel blend. Three levels of each factor have been chosen in this study. RSM has been applied to obtain optimum setting of input factors to optimize BP, BTE, HC and NOx. Furthermore, study of individual and cumulative effects of engine input factors on output responses is undertaken from experimental results.

2. Material and Methodology

In this analysis, Jatropha biodiesel-diesel blend (B10) was used for experimental investigation as it has shown huge potential to offer comparable performance and reduced emissions in comparison to diesel [12-13]. Heterogeneous catalyst (CaO) and methanol have been used for biodiesel production form Jatropha curcas oil (JCO).

2.1. Biodiesel production

The seeds of the Jatropha plant are rich in oil content which makes it suitable crop for biodiesel production [11]. For obtaining JCO from Jatropha seeds, solvent extraction has been done in Soxhlet extractor using n-hexane [20-21]. Jatropha biodiesel was produced by a chemical transesterification process wherein triglycerides react with methanol to produce fatty acid methyl ester (biodiesel) in presence of catalyst as shown in Eq.1. To catalyze the transesterification process, heterogeneous catalysts (CaO) has been used. In the study authors have obtained biodiesel yield of 81.6% [22].

$$\underset{\text{Triglyceride}}{\begin{array}{l} CH_2OCOR_1 \\ CHOCOR_2 \\ CH_2OCOR_3 \end{array}} + \underset{\text{Methanol}}{3CH_3OH} \xleftrightarrow[\text{60-70°C}]{\text{Catalyst}} \underset{\text{Fatty acid methyl ester}}{\begin{array}{c} R_1COOCH_3 \\ R_2COOCH_3 \\ R_3COOCH_3 \end{array}} + \underset{\text{Glycerol}}{\begin{array}{l} CH_2OH \\ CHOH \\ CH_2OH \end{array}} \quad (1)$$

2.2. Experimental setup

The CI engine test rig featured a four stroke, VCR single cylinder engine with an eddy current dynamometer. Engine configuration included necessary instrumentation. Software package "Enginesoft LV" was integrated with the rig for data analysis. The characteristics of the test engine and a block diagram of a test rig are shown in the Table 1 and Fig. 1. Engine performance analysis included BP, BTE and NHRR. AVL Digas 444 exhaust analyzer was employed for HC and NOx measurement. The experiments were performed at varying injection pressures (180, 225, and 270 bar), compression ratios (14, 16, and 18), and engine loads (0, 6, and 12 kg). The speed of the engine was set at 1500 rpm during experimentation. The engine was operated on clean diesel for around 30 minutes before it was switched to a biodiesel blend to ensure a stable temperature of the lubricant.

2.3. Response surface methodology

The RSM includes a series of mathematical and computational attempts in which the outcomes are based on some key parameters, and the objective of the methodology is to model and optimise these results. By RSM, fewer tests allow greater precision, saving time and resources. This method analyses the responses as per the selected variables by establishing the relationship between input and output parameters. For this purposes, the first step in implementing the RSM is to use the approximation function between input variables and output responses [23]. In this study optimization of variables that influence engine performance has been analysed by using RSM. For designing the experiments Central Composite Design (CCD) consisting of twenty experiments has been used which included six fractional points and six axial points. The influencing engine variables included CR (x_1), load (x_2, kg) and FIP (x_3, bar), while output response parameters were BP (y_1, kW), BTE (y_2, %), NHRR (y_3, J/deg), HC (y_4, ppm), NOx (y_5, ppm). Taking into consideration of operational and combined limitations of experimental setup, the ranges of engine input variables were selected to optimization. To interpret and analyze the experimental results, design expert software has been used. The test results were fitted to a quadratic regression model (Eq. 2).

Where, β_0, β_i, β_{ij}, and β_{ii} are the regression coefficients, and x_i and x_j denotes independent factors that influence output responses (Y). By using equations of RSM models, the optimal conditions for CR, load, and FIP were obtained and engine performance and emissions were estimated on optimal setting. Central Composite Design (CCD) is used in this analysis, which produces comparatively precise results [24]. Table 2 displays the input factors. Table 3 displays the experimental design containing the data for 20 experiments.

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

Table 1. Specifications of test rig

Make & Model	Kirloskar
Type	Single cylinder, Four stroke, Water cooled, Diesel
Bore diameter and Stroke length	87.5 mm and 110 mm
Power rating	3.5 kW
Cubic capacity	661cm^3
CR	12 to 18
Loading range	0-12 Kg
Peak cylinder pressure	77.5 kg/cm^2
Speed	1500 rpm (constant)

Table 2. Operating variables and their levels

Operating variable	Unit	Symbol	Coded levels		
			-1	0	1
Load		x_1	0	6	12
CR	kg	x_2	14	16	18
FIP	bar	x_3	180	225	270

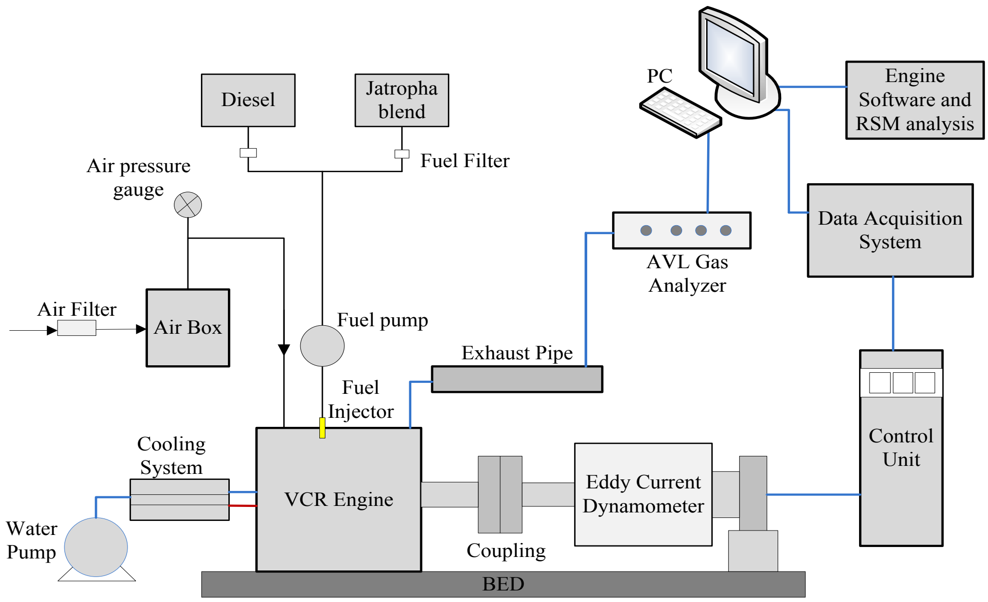


Fig. 1. Block diagram of a test rig

Table 3. Experimental results

Run	Load kg	CR	FIP bar	BP kW	BTE (%)	NHRR (J/deg)	HC (ppm)	NOx ppm
1	6	16	225	1.61	23.41	25.36	32	121
2	6	18	225	1.65	25.06	28.89	26	143
3	6	16	225	1.64	23.89	24.49	31	129
4	12	18	180	3.19	30.52	40.21	25	314
5	6	16	180	1.61	23.07	19.5	32	105
6	12	14	270	3.22	29.79	35.37	33	304
7	6	16	225	1.60	23.35	23.49	31	132
8	12	18	270	3.23	31.79	48.97	26	331
9	6	16	225	1.59	24.43	23.49	31	130
10	0	14	270	0.09	2.38	15.29	46	70
11	6	16	270	1.69	24.59	29.76	30	126
12	12	16	225	3.05	29.60	34.66	29	317
13	0	14	180	0.06	2.04	13.26	47	64
14	12	14	180	3.09	28.89	27.37	35	298
15	0	18	180	0.08	2.18	21.89	33	73
16	0	18	270	0.09	2.59	24.26	31	85
17	6	14	225	1.61	23.09	17.73	37	111
18	6	16	225	1.62	23.43	23.49	30	132
19	0	16	225	0.07	2.12	18.89	39	71
20	6	16	225	1.65	23.39	25.27	32	131

3. Result and Discussion

3.1. Analysis and evaluation of the model

The ANOVA of output responses are described in Table 4 and Table 5. For statistical analysis, Design expert software determined R^2 values, regression coefficients, p-values, and F-values so that significant parameters can be interpreted. The significance of predicted models can be described by p-values and the interpretation of the R^2. The larger F and smaller p-values reflect a greater degree of significance for the corresponding term, while a p-value less than 0.05 is perceived as significant. After analysing and evaluating the models, magnitude of p-values for all the predicted model were determined to be smaller than 0.05 which suggests all models were significant [25]. The R^2 indicates how well the predicted models are fitting the experimental data. The R^2 for BP, BTE, NHRR, HC, and NOx are 99.96%, 99.93%, 98.5%, 99.14%, and 99.78%, respectively. R^2 values are very close to 1, this shows a high level of precision of predicted models compared to experimental findings. Adeq. Precision measures signal to noise ratio and a ration greater than 4 is desired. In the predicted models Adeq. Precision value ranges from 35 to 144 indicating higher signal to noise ratio. Second-order equations developed from RSM to predict output parameters are given in Eqs. (3) – (7) respectively [26].

$$BP = 1.82 + 0.244EL - 0.138CR - 0.00659FIP + 0.000938EL*CR + 0.0000602EL*FIP - 0.000153CR*FIP - 0.00134EL*EL + 0.00547CR*CR + 0.0000207FIP*FIP \quad (3)$$

$$BTE = 26.75 + 4.247EL - 2.885CR - 0.0283FIP + 0.0342EL*CR + 0.00066EL*FIP + 0.00061CR*FIP - 0.2183EL*EL + 0.08875CR*CR + 0.000054FIP*FIP \quad (4)$$

$$NHRR = - 2.52 - 2.307EL + 3.271CR - 0.2432FIP + 0.092EL*CR + 0.00572EL*FIP + 0.0015CR*FIP + 0.09136EL*EL - 0.0439CR*CR + 0.00056FIP*FIP \quad (5)$$

$$HC = 138.68 - 3.9932EL - 7.8614CR - 0.0532FIP + 0.125EL*CR + 0.000926EL*FIP + 0.0028CR*FIP + 0.08207EL*EL + 0.1136CR*CR - 0.000022FIP*FIP \quad (6)$$

$$NOx = 53.42 - 7.0042EL - 25.55CR + 1.635FIP + 0.1979EL*CR + 0.002315EL*FIP + 0.02361CR*FIP + 1.944EL*EL + 0.75CR*CR - 0.00419FIP*FIP \quad (7)$$

Where, EL refers to engine load.

Table 4. ANOVA results for BP, BTE and NHRR

Source	BP		BTE		NHRR	
	F value	p-value	F value	p-value	F value	p-value
Model	2681.7	< 0.0001	1482.3	< 0.0001	72.9	< 0.0001
A-Load	24109.5	< 0.0001	11579.6	< 0.0001	412.3	< 0.0001
B-CR	2.942	0.1171	21.132	0.0010	145.3	< 0.0001
C-FIP	8.561	0.0151	11.767	0.0064	47.07	< 0.0001
AB	1.031	0.3339	8.027	0.0178	4.657	0.0563
AC	2.150	0.1733	1.505	0.2481	9.104	0.0130
BC	1.540	0.2430	0.144	0.7118	0.072	0.7937
A^2	6.474	0.0291	1014.1	< 0.0001	14.18	0.0037
B^2	1.344	0.2733	2.069	0.1809	0.041	0.8444
C^2	4.917	0.0509	0.199	0.6653	1.716	0.2195
Lack of Fit	2.838	0.1385	0.802	0.5926	4.164	0.0718
R^2	0.9996		0.9993		0.9850	
Adj. R^2	0.9992		0.9986		0.9715	
Pred. R^2	0.9971		0.9968		0.9072	
Adeq. Precision	144.455		103.664		35.078	

Table 5. ANOVA results HC and NOx

Source	HC		NOx	
	F value	p-value	F value	p-value
Model	127.6	< 0.0001	552.2	< 0.0001
A-Load	420.3	< 0.0001	4263.4	< 0.0001
B-CR	592.7	< 0.0001	28.97	0.0003
C-FIP	6.567	0.0282	11.36	0.0071
AB	32.84	0.0002	1.334	0.275
AC	0.912	0.3621	0.092	0.7674
BC	0.912	0.3621	1.068	0.3258
A^2	43.79	< 0.0001	398.29	< 0.0001
B^2	1.036	0.3326	0.732	0.4124
C^2	0.01	0.9209	5.873	0.0359
Lack of Fit	0.935	0.5286	2.896	0.134
R^2	0.9914		0.998	
Adj. R^2	0.9836		0.9962	
Pred. R^2	0.913		0.9893	
Adeq. Precision	42.404		66.23	

3.2. Effect of engine input variables on BP and BTE

Performance and engine emissions have been analysed by plotting 3-D surface plots of responses with two independent variables and third variable kept constant. The power available at the crank or output shaft is called brake power. The influence of engine input parameters on BP have been described by surface plots represented in Fig. 2. The brake power keeps increasing with rising load as seen in Fig. 2(a). As a result of advanced CR, BP tends to increase. Increased fuel supply and combustion temperature at improved load and CR conditions induces shorter ignition delay time and superior fuel atomization results in increased BP [27]. Fig. 2(b) portrays BP variation as a function of CR and FIP at 50% load. As the atomization of the fuel improves at higher FIP, brake power shows slight increase with FIP advancement [17]. Experimental result indicated that the maximum BP of the test engine was 3.16 kW at CR 18, 225 bar FIP and 12 kg load and lowest value of BP was found to be 0.03 kW at CR 14, 225 bar FIP and no load condition. Engine load had a significant impact on BTE, as seen in Fig. 2(c). Increased load resulted in improved BTE, conforming to previous studies [28]. Experimental results indicated that the highest BTE of test engine was 31.17% at CR 18, 225 bar FIP and 12 kg load. Fig. 2(d) depicts plot of BTE under varying CR and FIP when 50% load is applied. Increase in CR and FIP impacted BTE positively. From the experiments the lowest value of BTE was found to be 1.87% at CR 14, 225 bar FIP and at nil loading.

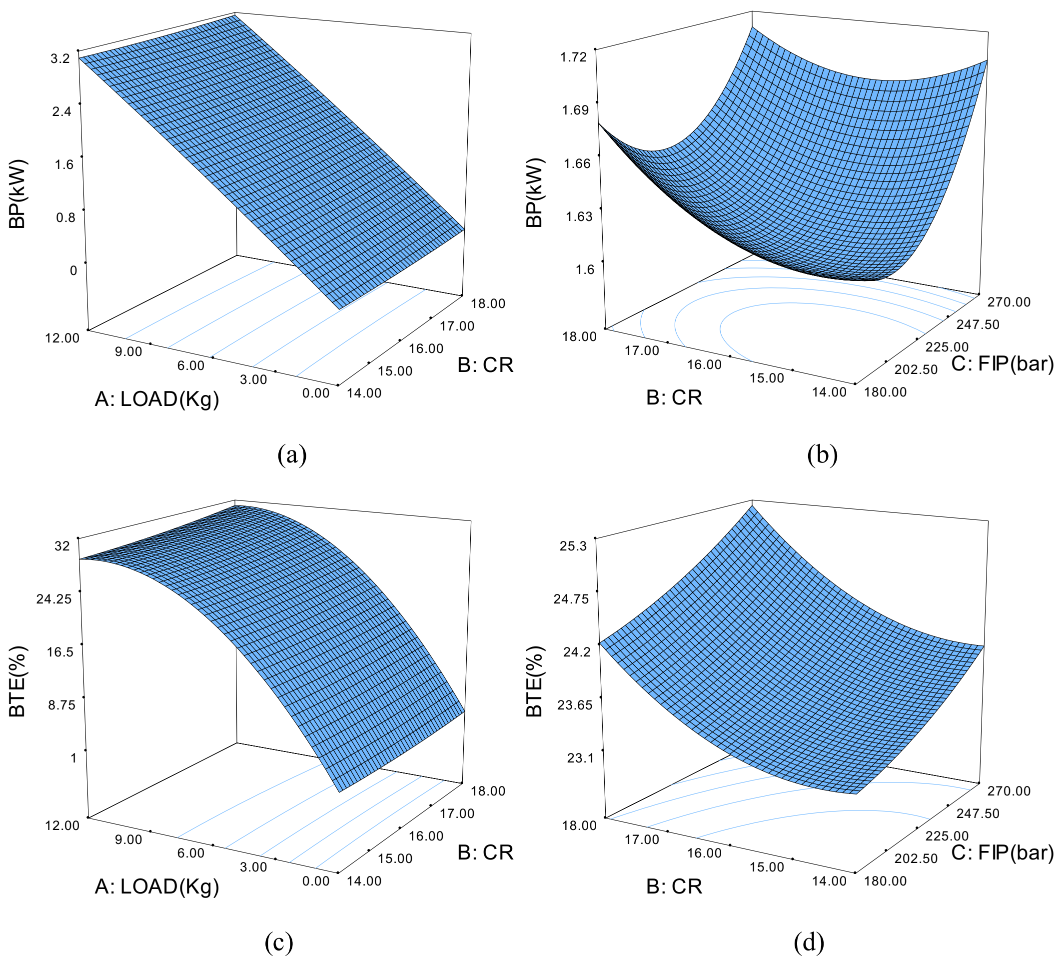
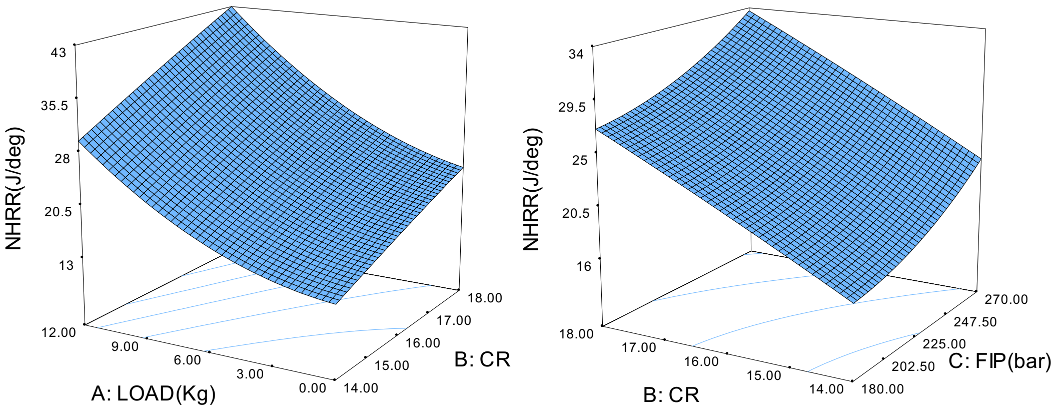


Fig. 2. Effect of load, CR and FIP on BP and BTE

3.3. Effect of engine input variables on NHRR

Effect of various engine input parameters such as load, CR and FIP on net heat release rate have been depicted in Fig. 3. The ANOVA response table reveals that the F value (436.48) of the factor load is the largest suggesting that the load has the largest effect on the NHRR followed by the CR and the FIP. The combined impact of load and CR on NHRR has been shown in Fig. 3(a). Results show that highest NHRR was observed to be 42.9 J/deg at full load condition, 18 CR and 225 bar FIP. At 14 CR and no load conditions, the minimum NHRR was measured to be 13.35 J/deg at 225 bar fuel injection pressure. NHRR increases with increasing engine load resulting from the increased volume of fuel burnt in the combustion chamber [29]. A high compression ratio leads to more heat release in the premixed phase of combustion phase as compared to the diffusion phase. NHRR variation with CR and FIP has been depicted in Fig. 3(b). Results show that highest NHRR was found to be 33.72 J/deg at 50% loading condition, 18 CR and 270 bar FIP. At 50% load, 14 CR and 180 bar FIP, net heat release rate was 16.4 J/deg. At higher FIP, homogeneous mixing of fuel takes place due to better atomization which reduces ignition delay. Shorter ignition delay advances start of combustion which causes increase of NHRR [30].

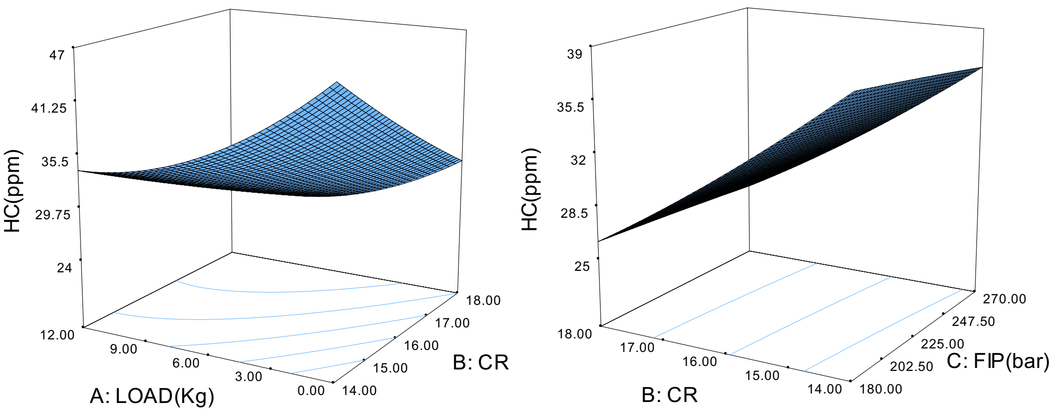


(a) (b)

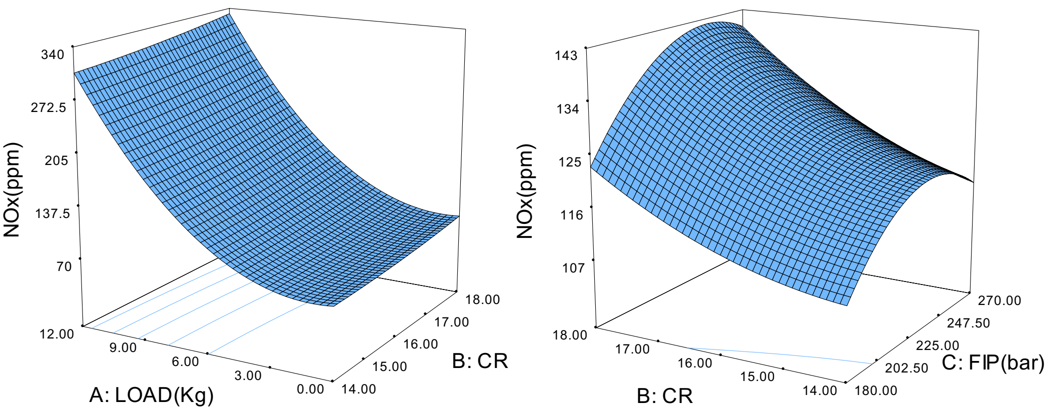
Fig. 3. Effect of load, CR and FIP on NHRR

3.4. Effect of input variables on Emissions

The incomplete combustion of fuel is a significant contributor to the generation of HC emissions. The amount of hydrocarbons released by an engine is based on several different factors such as fuel properties, working conditions of engine, and oxygen content in test fuel [31]. Surface plots shown in Fig. 4 have been used to study the effect of input factors on HC and NOx emissions. The surface plot as shown in Fig. 4(a) confirms that the response HC usually diminishes as load and CR increases. At high load and advanced CR conditions, air fuel mixture burn more effectively generating fewer amounts of HC emissions at high temperature. At a minimum load and 14 CR, the HC emissions are observed to be 48 ppm. However, as the load rises from 0 to 12 Kg and CR from 14 to 18, the HC emissions decrease from 48 ppm to 26 ppm. The influence of CR and FIP is demonstrated by Fig. 4(b) at 50% load. The response indicated an overall decreasing trend with rising CR and FIP. Inversely, the increase of CR suppresses the HC emissions. Rise in FIP has contributed to a small decrease in HC emissions also. With the increase in CR and FIP, HC emission decreases to 27 ppm from 39 ppm when 6 Kg load is applied. NOx is typically produced during combustion process due to heating of a chamber to elevated temperatures. The NOx emission has been plotted against the load and CR at 225 bar FIP in Fig. 4(c). From the plot it is evident that higher CR and loading conditions increases NOx emissions considerably. Highest value of NOx emission was observed to be 332 ppm at 18 CR, 225 bar FIP and 12 Kg load. Fig. 4(d) displays the cumulative impact of CR and FIP at 6 Kg load. Consistent increase in NOx emissions found with CR and FIP advancement. From the experimental observations minimum value of NOx emission was 70 ppm at 14 CR, 225 bar FIP and nil loading condition.



(a) (b)



(c) (d)

Fig. 4. Effect of load, CR and FIP on HC and NOx

4. RSM Optimization and Validation of Results

In this investigation, the RSM numerical optimization is used to find out optimum load, CR and FIP so as to achieve the optimized input factors. In pursuit of optimum engine performance, on the other hand, there have been efforts to minimize pollution levels. The optimized results are portrayed in Fig. 5. Optimal parameters found were 18 CR, 180 bar FIP and 8.11 kg load and the optimum output found were 2.21 kW, 28.24%, 25.3 ppm and 174.6 ppm for BP, BTE, HC, and NOx, respectively. Table 6 shows validation of RSM results. Errors were found within permissible limits. These findings indicate that RSM models were found to be suitable to model and predict input parameters and performance and emissions of engine.

Table 6. Validation of RSM output response at 8.11 kg load, CR 18 and FIP of 180 bar

Response	BP (kW)	BTE (%)	HC (ppm)	NOx (ppm)
RSM response	2.212	28.24	25.29	175.58
Experimental	2.3	29.15	26	183
Error (%)	3.98	3.2	2.81	4.23

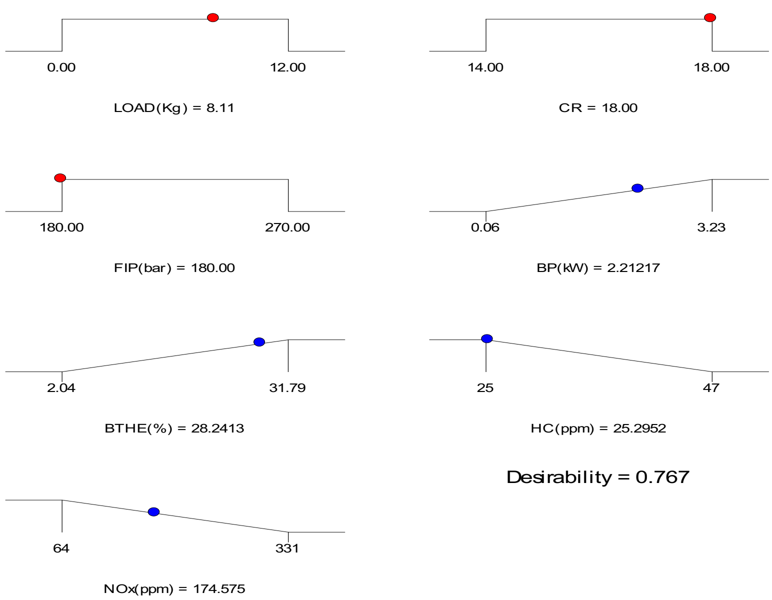


Fig. 5. Optimized results

5. Conclusion

In order to evaluate Jatropha biodiesel blend performance and emissions, tests were performed on VCR engine under variable compression ratio, fuel injection pressure and load with the application of RSM. From the experimental data, effects of input variables on output responses have been studied. RSM models were developed to predict the output responses such as BP, BTE, NHRR, HC and NOx emissions and numerical optimization technique employed to figure out optimum engine input factors for optimum engine performance and exhaust emissions. The response optimizer tool was used optimize engine operating parameters. However, major conclusions of the study can be summarised as follows:

- The engine input factors were optimized and optimum setting of compression ratio, fuel injection pressure and load was 18, 180 bar, and 8.11 Kg, respectively. At above configuration, optimal values for BP, BTE, HC, and NOx, were observed to be 2.21 kW, 28.24%, 25.29ppm, and 175.58ppm respectively.
- The coefficient of determination R^2 for the brake power model was 0.9996 and for HC, NOx, and BTE was 99.14%, 99.8%, and 99.93%, respectively, which confirms the accuracy of the developed RSM models.
- A validation experiment was conducted to validate RSM predicted responses at operating conditions of 8.11 Kg load, 18 CR, and 180 bar FIP, in which percentage error was found to be within 5%.
- The percentage error for BTE, BP, HC, and NOx was determined to be 3.2%, 3.98%, 2.81%, and 4.23% respectively, suggesting that the predicted models were adequate and significant.

Reference

[1] A. S. Silitonga, A. E. Atabani, T. M. I. Mahlia, H. H. Masjuki, I. A. Badruddin, and S. Mekhilef, "A review on prospect of Jatropha curcas for biodiesel in Indonesia," *Renew. Sustain. Energy Rev.*, vol. 15, no. 8,pp.3733–3756,2011, doi: 10.1016/j.rser.2011.07.011.

[2] F. Ayadi, I. Colak, I. Garip, and H. I. Bulbul, "Impacts of Renewable Energy Resources in Smart Grid," *8th Int. Conf. Smart Grid, icSmartGrid 2020*, pp. 183–188, 2020, doi: 10.1109/icSmartGrid49881.2020.9144695.

[3] H. F. Abdelraheem, A. Lang, and M. E. A. Elsayed, "Jatropha curcas: A viable alternative source of clean energy to meet Sudan's growing energy demand," *Proc. - 2013 Int. Conf. Comput. Electr. Electron. Eng. 'Research Makes a Differ. ICCEEE 2013*, pp. 287–293, 2013, doi: 10.1109/ICCEEE.2013.6633949.

[4] V. Kumar and R. K. Saluja, "The effect of operating parameters on performance and emissions of DI diesel engine fuelled with Jatropha biodiesel," *Fuel*, vol. 278, no. April, p. 118256, 2020, doi: 10.1016/j.fuel.2020.118256.

[5] S. Semwal, A. K. Arora, R. P. Badoni, and D. K. Tuli, "Biodiesel production using heterogeneous catalysts," *Bioresour. Technol.*, vol. 102, no. 3, pp. 2151–2161, 2011, doi: 10.1016/j.biortech.2010.10.080.

[6] B. Zafar, "Design of a Renewable hybrid photovoltaic- Electrolyze-PEM / Fuel Cell System using Hydrogen Gas," vol. 3, no. 4, 2019.

[7] A. A. S. A. El-gharabawy, "Cost Analysis for Biodiesel Production from Waste Cooking Oil Plant in Egypt," *Int. J. SMART GRID*, vol. 1, no. 1, 2017.

[8] S. H. Ghosh, "Synthesis of biodiesel from oils of jatropha,karanja and putranjiva to utilize in Ricardo VCR engine and its performance and emission measurement," *Proc. Therm. Eng. Conf.*, pp. 731–8, 2008.

[9] M. E. Shayan, "The Biomass Supply Chain Network Auto- Regressive Moving Average Algorithm," vol. 5, no. 1, 2021.

[10] A. A. S. A. El-gharabawy, "Cost Analysis for Biodiesel Production from Waste Cooking Oil Plant in Egypt," *Int. J. SMART GRID*, vol. 1, no. 1, 2017.

[11] K. K. Radha, A. A. Kumari, S. N. Sarada, E. L. Nagesh, and K. Rajagopal, "Alternative fuels for a single cylinder direct injection diesel engine," *Proc. - 1st Int. Conf. Emerg. Trends Eng. Technol. ICETET 2008*, pp. 1083–1088, 2008, doi: 10.1109/ICETET.2008.261.

[12] M. Mofijur, H. H. Masjuki, M. A. Kalam, and A. E. Atabani, "Evaluation of biodiesel blending, engine performance and emissions characteristics of Jatropha curcas methyl ester: Malaysian perspective," *Energy*, vol. 55, pp. 879–887, 2013, doi: 10.1016/j.energy.2013.02.059.

[13] M. El-Kasaby and M. A. Nemit-Allah, "Experimental investigations of ignition delay period and performance of a diesel engine operated with Jatropha oil biodiesel," *Alexandria Eng. J.*, vol. 52, no. 2, pp. 141–149, 2013, doi: 10.1016/j.aej.2012.12.006.

[14] A. Singh, S. Sinha, A. K. Choudhary, H. Panchal, M. Elkelawy, and K. K. Sadasivuni, "Optimization of performance and emission characteristics of CI engine fueled with Jatropha biodiesel produced using a heterogeneous catalyst (CaO)," *Fuel*, vol. 280, no. June, p. 118611, 2020, doi:

10.1016/j.fuel.2020.118611.

[15] A. Pandhare and A. Padalkar, "Investigations on Performance and Emission Characteristics of Diesel Engine with Biodiesel (Jatropha Oil) and Its Blends," vol. 2013, 2013.

[16] H. Patel, V. Rajai, P. Das, S. Charola, A. Mudgal, and S. Maiti, "Study of Jatropha curcas shell bio-oil-diesel blend in VCR CI engine using RSM," *Renew. Energy*, vol. 122, pp. 310–322, 2018, doi: 10.1016/j.renene.2018.01.071.

[17] S. Uslu, "Optimization of diesel engine operating parameters fueled with palm oil-diesel blend: Comparative evaluation between response surface methodology (RSM) and artificial neural network (ANN)," *Fuel*, vol. 276, no. April, p. 117990, 2020, doi: 10.1016/j.fuel.2020.117990.

[18] M. K. Parida, H. Joardar, A. K. Rout, I. Routaray, and B. P. Mishra, "Multiple response optimizations to improve performance and reduce emissions of Argemone Mexicana biodiesel-diesel blends in a VCR engine," *Appl. Therm. Eng.*, vol. 148, pp. 1454–1466, 2019, doi: 10.1016/j.applthermaleng.2018.11.061.

[19] Y. Sun, M. Sun, and X. Tang, "Influence Analysis of Renewable Energy on Crude Oil Future Market," *2019 3rd IEEE Int. Conf. Green Energy Appl. ICGEA 2019*, pp. 167–171, 2019, doi: 10.1109/ICGEA.2019.8880778.

[20] S. Raj and M. Bhandari, " Comparison of Methods of Production of Biodiesel from Jatropha Curcas ," *J. Biofuels*, vol. 8, no. 2, p. 58, 2017, doi: 10.5958/0976-4763.2017.00009.5.

[21] Y. S, A. W, B. A, C. LF, and M. NA, "Oil Extraction From Calophyllum inophyllum L. via Soxhlet Extraction," *ResearchGate*, pp. 1–6, 2015.

[22] A. Singh, S. Sinha, A. K. Choudhary, and H. Chelladurai, "Biodiesel production using heterogeneous catalyst, application of Taguchi robust design and response surface methodology to optimise diesel engine performance fuelled with Jatropha biodiesel blends," *Int. J. Ambient Energy*, vol. 0, no. 0, pp. 1–12, 2020, doi: 10.1080/01430750.2020.1789741.

[23] A. Sharma, Y. Singh, A. Tyagi, and N. Singh, "Sustainability of the polanga biodiesel blends during the application to the diesel engine performance and emission parameters—Taguchi and RSM approach," *J. Brazilian Soc. Mech. Sci. Eng.*, vol. 42, no. 1, 2020, doi: 10.1007/s40430-019-2102-3.

[24] Y. Singh, A. Sharma, G. Kumar Singh, A. Singla, and N. Kumar Singh, "Optimization of performance and emission parameters of direct injection diesel engine fuelled with pongamia methyl esters-response surface methodology approach," *Ind. Crops Prod.*, vol. 126, no. October, pp. 218–226, 2018, doi: 10.1016/j.indcrop.2018.10.035.

[25] T. S. Singh and T. N. Verma, "Taguchi design approach for extraction of methyl ester from waste cooking oil using synthesized CaO as heterogeneous catalyst: Response surface methodology optimization," *Energy Convers. Manag.*, vol. 182, no. October 2018, pp. 383–397, 2019, doi: 10.1016/j.enconman.2018.12.077.

[26] R. R. Neela Rajan, R. Rajesh, and M. R. Elayidom, "Optimization of production of transesterified Jatropha curcas oil using Response Surface Methodology," *2016 Int. Conf. Energy Effic. Technol. Sustain. ICEETS 2016*, pp. 187–193, 2016, doi: 10.1109/ICEETS.2016.7582923.

[27] M. Venkatraman and G. Devaradjane, "Experimental investigation of effect of compression ratio, injection timing and injection pressure on the performance of a CI engine operated with diesel-pungam methyl ester blend," *Proc. Int. Conf. Front. Automob. Mech. Eng. - 2010, FAME-2010*, pp. 117–121, 2010, doi: 10.1109/FAME.2010.5714814.

[28] N. K. Singh, Y. Singh, A. Sharma, and E. A. Rahim, "Prediction of performance and emission parameters of Kusum biodiesel based diesel engine using neuro-fuzzy techniques combined with genetic algorithm," *Fuel*, vol. 280, no. June, p. 118629, 2020, doi: 10.1016/j.fuel.2020.118629.

[29] A. Dhar and A. K. Agarwal, "Performance , emissions and combustion characteristics of Karanja biodiesel in a transportation engine," *Fuel*, vol. 119, pp. 70–80, 2014, doi: 10.1016/j.fuel.2013.11.002.

[30] C. Patel, A. K. Agarwal, N. Tiwari, S. Lee, C. S. Lee, and S. Park, "Combustion, noise, vibrations and spray characterization for Karanja biodiesel fuelled engine," *Appl. Therm. Eng.*, vol. 106, pp. 506–517, 2016, doi: 10.1016/j.applthermaleng.2016.06.025.

[31] A. Mejiá, M. Leiva, A. Rincón-Montenegro, A. Gonzalez-Quiroga, and J. Duarte-Forero, "Experimental assessment of emissions maps of a single-cylinder compression ignition engine powered by diesel and palm oil biodiesel-diesel fuel blends," *Case Stud. Therm. Eng.*, vol. 19, no. December 2019, pp. 1–13, 2020, doi: 10.1016/j.csite.2020.100613.