Iranian Journal of Energy and Environment 8(3): 181-188, 2017

Iranian Journal of Energy & Environment
Journal Homepage: www.ijee.net
IJEET an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

Modeling and Validation of Some Combustion Parameters in a VCR Engine Fuelled with *Argemone mexicana* Biodiesel-Diesel Blends Using RSM

H. Joardar[1], M. K. Parida[1*], A. K. Rout[2] and I. Routaray[3]

[1] *Mechanical Engineering Department, C.V. Raman College of Engineering, Bhubaneswar -752054, India*
[2] *Mathematics Department, C.V. Raman College of Engineering, Bhubaneswar -752054, India*
[3] *School of Mechanical Engineering, KIIT University, Bhubaneswar- 752024, Odisha, India*

PAPER INFO

Paper history:
Received 20 October 2017
Accepted in revised form 25 November 2017

Keywords:
Biodiesel
Combustion
Response Surface Methodology
ANOVA
Sensitivity analysis

ABSTRACT

In the present study the methyl ester of argemone oil, prepared by two step transesterification process due to its high acid value was experimented, in a variable compression ratio (VCR) multi-fuel engine to evaluate the combustion parameters like in cylinder pressure (Pr), net heat release rate (NHRR) and cumulative heat release rate (CHRR). For the current analysis engine load, compression ratio and bio-diesel blends are taken as input parameters. The mathematical models were developed and statistical significance was checked using analysis of variance (ANOVA). A second order model is developed and is found to be adequate by ANOVA results. The validation of the model is carried out by comparing the predicated values of output responses with that of experimental results.

***doi**: 10.5829/ijee.2017.08.03.01*

NOMENCLATURE

FFA	Free fatty acid
DICI	Direct injection compression ignition
BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
CAD	Crank angle degree
AMME	Argemone Mexicana methyl ester
TEO	Transesterified oil
CHRR	Cumulative Heat release rate
NHRR	Net Heat release rate
Pr	In cylinder Pressure
IT	Injection Timing
ANOVA	Analysis of variance
RSM	Response surface methodology
ANN	Artificial neural network
KOME	Karanja oil methyl ester
CIME	Callophilium innophilium methyl ester
BTDC	Before top dead centre
B20	Mthyl ester B20 blend
B40	Mthyl ester B40 blend
VCR	Variable compression ratio
L	Load
CR	Compression ratio
B	Blend
FFA	Free fatty acid

INTRODUCTION

Crude oil is obviously a limited resource and anticipating the point in time where unrefined petroleum is not any more a monetarily reasonable item is uncertain, this fact has been attested by several authors [1]. Continuous price rising coupled with unsteadiness in the world crude oil market and instability in supply due to friction in major oil-producing countries have created interest in the search for an alternative fuel. Increased public awareness on impending health hazards due to impacts of diesel emissions on the environment [2] and need of any country to become self-sufficient has interested in biodiesel fuels. The use of vegetable oil as alternate fuel for compression-ignition (CI) engine was not admired since it tends to choke fuel filters due to high viscosity. Low viscosity and improved volatility of vegetable oils were obtained by Heating and blending it with diesel but polyunsaturated structure remains intact for the oils [3]. Biodiesel production from low grade feed stocks, having high Free fatty acid (FFA) using transesterification process is not appropriate. Threfore, [4] a two step process is proposed. The first step is esterification process to reduce FFA content with methanol and acid catalyst followed by transesterification. The Argemone seeds produce approximately 35% oil. It is non edible and

---

* Corresponding author: M. K. Parida
E-mail: manojparida337@gmail.com

its toxicity is due to the presence of two alkaloids viz. sangiuinarine and dihydro sangiuinarine. After removal of toxic alkaloids biodiesel can be prepared [5]. Argemone Mexicana belongs to papveracae family and the entire species also belongs to the Mexicana prickle poppy. It is commonly known as shialakanta and satyanashi in India and was found on road side, wasteland and field. The plant have yellow flower, branching herb with yellow juice and height varies between 12-30 centimeters [6].

Combustion parameters in Direct injection compression ignition (DICI) engine were investigated using karanja biodiesel and its blend varying engine load while engine speed were maintained around 1500 rpm [7]. Combustion characteristics showed for karanja oil blends were having shorter delay period and slower combustion leads to longer period for combustion. Lower concentration of blend also alters the combustion process due to improper fuel atomization/mixing process. Higher blends are not suitable for unmodified engine. However, up to 20% blended fuel was recommended without any engine alteration. The effect of varying compression ratio (CR) (16-18) on the combustion parameters of a CI engine fueled with Callophilium innophilium methyl ester (CIME) and its diesel blends were investigated at constant speed and peak load condition [8]. The study revealed that delay period of blends was shorter while combustion duration was more as compared to diesel. The burning efficiency of a VCR engine with CR variation (15-18) with (0-50%) volume was investigated using castor biodiesel [9]. Highest value of gas temperature (mean) is recorded for diesel and it increases with CR for all the blends. Maximum in cylinder pressure is obtained at CR 18 for B50 and it increases with CR. Maximum value of NHRR is obtained for diesel at CR 15 and it decreases with increasing CR. For CR 15 and 18, methyl ester blends is better for B20 and poor for B50. This study is performed to find the effect of CR on emission characteristics fuelled with neat Karanja oil blends (10 and 20%) and Karanja oil methyl ester (KOME) blends (20, 40 and 60%) and compare the results with diesel at compression ratios of 16:1, 17:1, 18:1 [10]. Minimum value of CO is 0.04 for 20% blend of KOME (B20), while maximum CO_2 is 4.45% at higher compression ratio is recorded. B40 blend showed lowest hydrocarbon and NOx emissions that are 22 and 552 ppm, respectively. K10 and K20 show marginally higher emissions than diesel. Overall at higher compression ratios B40 has the lowest emissions.

Optimum performance obtained with lower emission at CR 19 with B30 (30% CIME + 70% diesel) using design expert software [11] with designed set of experiments, which was then tested and validated. ANN model based on the standard back propagation algorithm was developed to optimize engine output performance parameter like brake power (B.P.), brake thermal efficiency (B.T.E.), specific fuel consumption (SFC) and smoke intensity using jatropha biodiesel [12]. The optimized result for best blending was found to be jatropha blended diesel fuel 50 at 100% load. The respective output as BP is 4.90 kW, BTE is 29.74%, BSFC is 0.29 kg/kW-h and smoke intensity is 3. The Box_Behnken based RSM method was adopted according to literature [13] to express response, BTE as a function of variation of input. The optimum combination of input parameters of CR 18, IP 220 bar and IT 200 BTDC was suggested after validation of ‘Regression Model’ is carried out with error less than 1% for maximum BTE.

The analytical approach and modelling of combustion parameters like cylinder pressure, NHRR and CHRR for bio-diesel and its blends were inadequate. Therefore the objective is to formulate mathematical statistical modelling of output responses using response surface methodology and its validation against experimental results.

MATERIAL AND METHODS

Bio-diesel (AMME) preparation

In degumming process, first the oil is preheated. In 100 ml of oil 27 ml of phosphoric acid (H_3PO_4) is added and then heated on a magnetic stirrer up to 1 hour at a temperature of 55º C. Then the oil is settled on a beaker for 1 day. After that oil is separated and gum particles were removed. After separating the oil, we proceed for the next process i.e. esterification. In esterification process preheat oil is taken, in 100 ml of oil 2ml of sulphuric acid and 22 ml of methanol is added and then heated on a magnetic stirrer up to 2 hours at a temperature of 65ºC. Then the oil is settled on a separating funnel for 1day. After separating the oil from the separating funnel acidic value of the oil is measured as we know that free fatty acid (FFA) value is around half of the acidic value and here FFA value is less than 2 hence we proceed for the transesterification process. If not then repeat the esterification process again until the FFA value is below 2. Here we remove alcohol from the oil. In trans-esterification process first oil is preheated, then 100 ml of oil is mixed with 22 ml of methanol and 0.7g of potassium hydroxide (KOH) heated on a magnetic stirrer up to 3 hours at a temperature of 60ºC. Then the mixture is settled on a separating funnel for 1 day. Here the residue glycerol is separated from the oil. After that if some amount of alcohol is present in the oil then we can go for further two processes, such as water washing and Heating. We know that alcohol is highly soluble in water and oil floats on water. So we add some amount water in oil and then the mixture is settled on a separating funnel for 1 day. After that oil is separated. Then we heat the oil on magnetic stirrer at 80 ºC to remove the residual alcohols present in the oil. Finally, the sample of clear prepared biodiesel is shown in Figure 1.

Figure 1. Pure bio-diesel (*Argemone Mexicana* Methyl Ester)

Biodiesel Properties

The specific gravity and viscosity of Argemone oil was reduced after transesterification process and found to be within the acceptable limit. Argemone Mexicana methyl ester (TEO) biodiesel was characterized by its important physical and chemical properties were measured by the equipments using standard test procedure as per ASTM. The properties of the blended fuel and its comparison with standard diesel are summarized in Table 1. Due to oxygen content, the lower heating value of the biodiesel and the blend fuels are less than standard diesel. The flash point of biodiesel is still higher than diesel although it was reduced by transesterification process. It is safe to store as small amount of addition of biodiesel increases the flash point of the blend.

TABLE 1. Properties of *Argemone mexicana* methyl ester and blends

Properties	Equipment	Method	AMME	Diesel	B20	B40
Kinematic Viscosity, 40^0C (cst)	Redwood viscometer	ASTM D445	5.07	3.60	4.1	4.32
Density at 20^0C (kg/m^3)	KEM Density-meter	ASTM D4052	868	836	843	849
Calorific values, (Kj/kg)	Bomb calorimeter	ASTM D240	41500	42800	42540	42280
Flash point (^{0}C)	Pensky martness apparatus	ASTM D93	130	65	81	98

Experimental procedure

The experimental work was executed through a single cylinder, four stroke and vertical fully computerized multi fuel variable compression ratio engine. The engine speed was maintained around 1500±3% rpm by controlling the fuel flow by governor. The engine was tested for standard diesel, B20 and B40 for varying compression ratio from 16 to 18 by adjusting the stroke volume through a tilted cylinder block arrangement. In cylinder and diesel line pressure are measured by two pressure transducers. For pressure crank-angle diagrams, these signals are interfaced with computer. Signals from these pressure transducers are fed to charge amplifier. To communicate signals for top dead center (TDC) and crank angle a high precession encoder is used. The data acquisition system which is interfaced with computer receives signals from charge amplifier and the crank angle encoder to draw p- θ diagram. Lab view based "Engine soft" records various combustion parameter. Pressure data were measured of 10 consecutive engine cycles in order to eliminate cyclic variation and average values were taken to analyze and calculate the combustion parameters such as the peak pressure within the cylinder, NHRR and CHRR.

Design of experiments and data collection

In this study responses as Pr, NHRR and CHRR were approximated during a series of experiments according to the experimental plan established on central composite face centred (CCF) design, as shown in Table 2 to expand the equation of the response surface. In Table 3 the values of these coefficients are reflected. Referring to Table 4 it may be seen that most of the terms in equations (2, 3 and 4) are significant since the p-value connected with these terms is less than 0.05 (95% confidence level).

TABLE 2. Design layout and experimental results for Pr, NHRR and CHRR

Exp. No	L	R	B	Pr	NHR (KJ/m^2)	CHR (KJ)
1	0	16	0	45.67	37.45	0.49
2	12	16	0	61.27	57.66	0.94
3	0	18	0	54.47	44.85	0.62
4	12	18	0	71.44	63.20	0.97
5	0	16	40	47.45	41.79	0.63
6	12	16	40	61.42	63.11	0.93
7	0	18	40	56.26	28.23	0.64
8	12	18	40	71.05	52.25	0.93
9	0	17	20	48.35	42.96	0.42
10	12	17	20	63.55	65.03	0.80
11	6	16	20	54.70	55.88	0.78
12	6	18	20	63.80	53.93	0.80
13	6	17	0	57.83	63.21	0.66
14	6	17	40	58.26	57.94	0.69
15	6	17	20	57.13	61.64	0.64
16	6	17	20	57.12	60.62	0.64
17	6	17	20	57.24	61.67	0.65
18	6	17	20	57.06	60.59	0.63
19	6	17	20	57.20	61.57	0.67
20	6	17	20	57.29	60.65	0.63

Response surface methodology

The relationship between the measured responses and input parameters is determined by RSM producers [14]. In this regard the collected data is analyzed using regression. Let $\overline{H}$ be a random variable and x_1, x_2………

x_k be a set of independent variables which are assumed to be continuous. Then

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

In present study, statistical package of MINITAB 14 software (Math Corporation) was used to develop the experimental planning matrix for RSM and to analyze the collected data. The final models for Pr, NHRR and CHRR so developed are expressed as:

$$\begin{aligned}\mathrm{Pr} &= 57.2125 + 7.653L + 4.651R + 0.376B - 1.3214L^2 + 1.9786R^2 \\ &+ 0.7736B^2 + 0.2738L \times R - 0.4763L \times B - 0.0662R \times B\end{aligned} \quad (2)$$

$$\begin{aligned}NHR &= 60.9285 + 10.597L - 1.343R - 2.305B - 6.6414L^2 - 5.7314R^2 \\ &- 0.0614B^2 + 0.105L \times R + 0.8475L \times B - 4.67R \times B\end{aligned} \quad (3)$$

$$\begin{aligned}CHR &= 0.6462 + 0.177L + 0.019R + 0.014B - 0.0405L^2 + 0.1395R^2 \\ &+ 0.0245B^2 - 0.0137L \times R - 0.0263L \times B - 0.0188R \times B\end{aligned} \quad (4)$$

TABLE 3. Regression coefficients for Pr, NHRR and CHRR.

	(Pr)		(NHR)		(CHR)	
Term	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Constant	57.2125	0.000	60.9285	0.000	0.6462	0.000
L	7.6530	0.000	10.5970	0.000	0.1770	0.000
R	4.6510	0.000	-1.3430	0.000	0.0190	0.006
B	0.3760	0.000	-2.3050	0.000	0.0140	0.027
L*L	-1.3214	0.000	-6.6414	0.000	-0.0405	0.003
R*R	1.9786	0.000	-5.7314	0.000	0.1395	0.000
B*B	0.7736	0.000	-0.0614	0.028	0.0245	0.039
L*R	0.2738	0.000	0.1050	0.009	-0.0137	0.047
L*B	-0.4763	0.000	0.8475	0.011	-0.0262	0.001
R*B	-0.0662	0.018	-4.6700	0.000	-0.0188	0.011

RESULTS AND DISCUSSION

The purpose of this study is to check the individual and mix effects of engine input parameters on combustion characteristics of C.I. engine fuelled with blends of Argemone oil using RSM based design of experiments. For modelling and analyzing, concept of DoE is very helpful to evaluate combustion characteristics of engine over the range of factors influencing response with minimum number of experiments. RSM is used in the present study for modelling and analyzing the response parameters at different levels of factors that affects the responses.

Analysis of the model

The principal model analysis is based on ANOVA, which gives p value. The analysis of variance for different response parameters such as Pr, NHRR and CHRR are given in Tables 4-6, respectively. Model found to be significant as the value of p were less than 0.05 (95% confidence level). Second order models for the responses are formed in terms of actual coefficients and are given in the equations 2 to 4. The plots of the residuals and normal probability plots of the residuals versus the predicted response for combustion characteristics (Pr, NHR, and CHR) are shown in Figures 2–4, respectively. A check on the plots in Figures 2a, 3a and 4a revealed that the residuals generally fall on a straight line involves that the errors are dispersed normally. Figures 2b, 3b and 4b exposed that they have no unusual structure and obvious pattern. This means that the models proposed are adequate. Another important coefficient is R^2 (determination coefficients) and its value (0.999) for P_r (Table 4) approaches to unity; which shows a good correlation between predicted and experimental values. The calculated values of F-ratio for lack of fit in Table 4 are compared with the standard values of F-ratio corresponding to their degrees of freedom. The F value ($F = 4.59 < 5.05$; $F_{0.05,5,5} = 5.05$) for lack of fit is smaller

TABLE 4. Analysis of variance for Pressure (Pr)

Source	DF	Sum of Squares	Adj. mean Square	F-value	P-value	
Regression	9	824.527	91.614	4508.87	0.000	Significant
Linear	3	803.416	267.805	13180.29	0.000	
Square	3	18.662	6.221	306.15	0.000	
Interaction	3	2.449	0.816	40.18	0.000	
Residual Error	10	0.203	0.020			
Lack-of-Fit	5	0.167	0.033	4.59	0.062	Not Significant
Pure Error	5	0.036	0.007			
Total	19	824.730				
					R^2	0.999
					R^2 (adj)	0.998

TABLE 5. Analysis of variance for NHRR

Source	DF	Sum of Squares	Adj. mean Square	F-value	P-value	
Regression	9	1992.18	221.353	368.96	0.000	Significant
Linear	3	1194.13	398.044	663.48	0.000	
Square	3	617.74	205.913	343.23	0.000	
Interaction	3	180.31	60.102	100.18	0.000	
Residual Error	10	6.00	0.600			
Lack-of-Fit	5	4.47	0.894	2.93	0.132	Not Significant
Pure Error	5	1.53	0.305			
Total	19	1998.18				
					R^2	0.997
					R^2 (adj)	0.994

TABLE 6. Analysis of variance for CHRR

Source	DF	Sum of Squares	Adj. mean Square	F-value	P-value	
Regression	9	0.417979	0.046442	157.93	0.000	Significant
Linear	3	0.318860	0.106287	361.44	0.000	
Square	3	0.089282	0.029761	101.20	0.000	
Interaction	3	0.009837	0.003279	11.15	0.002	
Residual Error	10	0.002941	0.000294			
Lack-of-Fit	5	0.001807	0.000361	1.59	0.311	Not Significant
Pure Error	5	0.001133	0.000227			
Total	19	0.420920				
					R^2	0.993
					R^2 (adj)	0.987

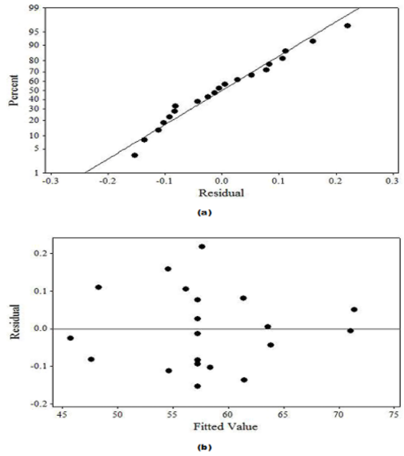

Figure 2. (a)Normal probability plot of residuals for Pr data (b) Plot of residuals vs. predicted response for Pr data

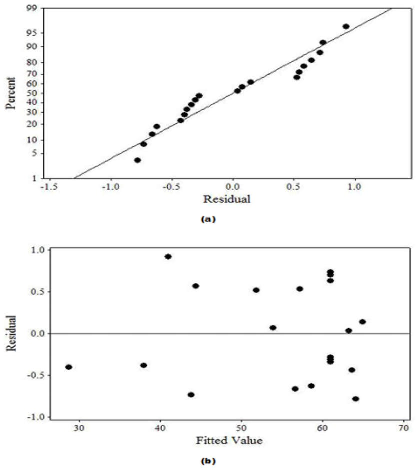

Figure 3. (a)Normal probability plot of residuals for NHRR data (b) Plot of residuals vs. predicted response for NHRR data

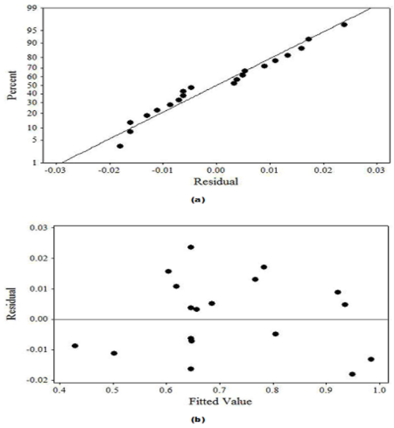

Figure 4. (a)Normal probability plot of residuals for CHRR data (b) Plot of residuals vs. predicted response for CHRR data

than the standard value indicating that the model is adequate. It has been also seen that R^2 values 0.997 and 0.993 for NHRR and CHRR respectively are very closer to unity and lack of fits are not significant from Table 5 and Table 6. It indicates that both the models (NHRR and CHRR) are adequate.

The main and interaction effect plot for Pr, NHRR and CHRR have been shown in Figures 5 (a, b, c) and 6 (a, b, c), respectively. The plots show the variation of individual and interaction responses with three input parameters (L, R and B). In the plot x axis shows the value of each parameter at three level and y axis indicates the response value. From the main effect plots it can be learnt that the Pr increases very sharply with increases load and compression ratio level but not significantly changes the value of Pr with increases of blend. The value of NHRR and CHRR are also increases with increases the load and compression ratio but decreases with increases the blend value. Interaction plots were constructed and from the figures it can be ascertained that all the interactions are important for all the responses. The 3D surface graphs for all the responses (Pr, NHRR and CHRR) are shown in Figures 7–9. All the surface graphs have curvilinear profile in accordance to the quadratic model fitted. It has been observed that all the three combustion parameter (Pr, NHRR, and CHRR) values increases with increasing the load and compression ratio but hold value of blend on the engine. Similarly, output parameter values are also increasing with increases the load and blend for holding the value of compression ratio (Figures 7b, 8b and 9b). From the Figure 7(c) it is indicated that the cylinder pressure increases with increased value of compression ratio and proportion of bio-diesel in the blended fuel and vice versa with hold value of load on the engine. Figure 8(c) reflects that NHRR gradually increases from the mean value of compression ratio and blend percent up to the central values and reaches the peak value nearly at the central values of both the input control factors. Again, in the range of central value to maximum value of the input parameters compression ratio and blend percent, the output NHRR follows a decreasing trend. It is displayed in the Figure 9(c) that CHRR is higher for initial values of both the compression ratio and blend percent and then it decreases towards the central values. This might be due to burning of the accumulated fuel in the initial part of the combustion process. Further it is observed that NHRR stabilised to a minimum value and then gradually increases with the increase of compression ratio and blend percent and reaches the maximum value for the highest value of both the control parameters.

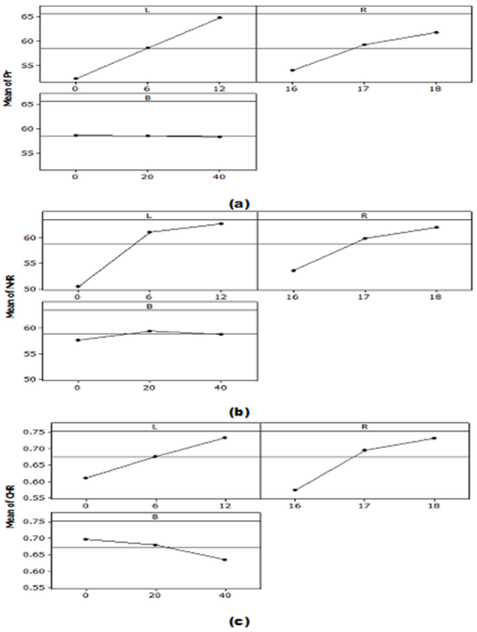

Figure 5. a) Main effect plot for pressure (Pr) b) Main effect plot for net heat release (NHR) c) Main effect plot for cumulative heat release (CHR)

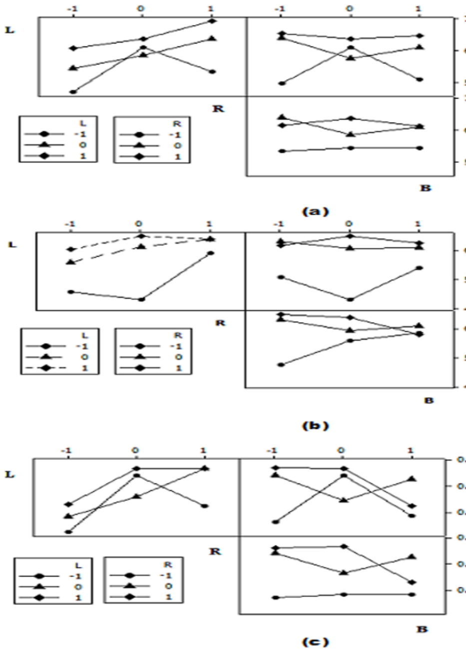

Figure 6. a) Interaction plot for pressure (Pr) b) Interaction plot for net heat release (NHR) c) Interaction plot for cumulative heat release (CHR)

Sensitivity analysis

The sensitivity equations for load and NHRR in (2) and (3) are differentiated with respect to input parameters. The sensitivity equations (5) to (10) represent the sensitivity of pressure and net heat release for load, compression ratio and blend respectively.

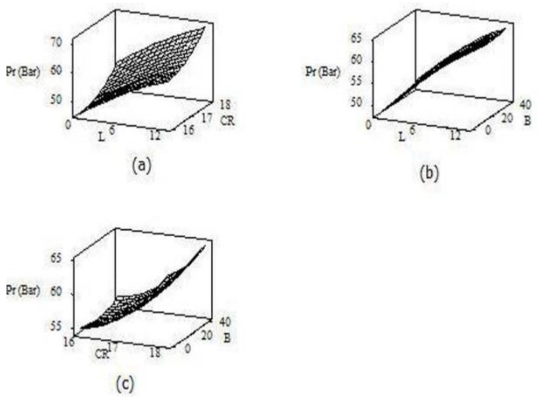

Figure 7. RSM plot for pressure (Pr)

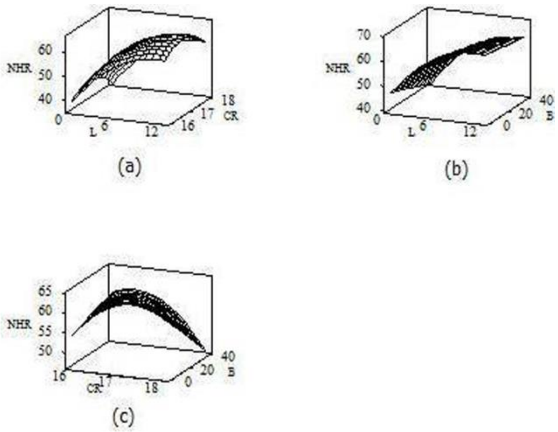

Figure 8. RSM plot for net heat release (NHR)

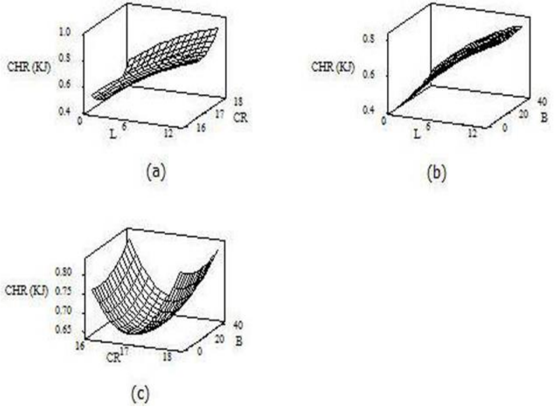

Figure 9. RSM plot for cumulative heat release (CHR)

$$\frac{\partial P_r}{\partial L} = 7.653 - 2.6428L + 0.2738R - 0.4763B \tag{5}$$

$$\frac{\partial P_r}{\partial R} = 4.651 + 0.2738L + 3.9572R - 0.0662B \tag{6}$$

$$\frac{\partial P_r}{\partial B} = 0.376 - 0.4763L - 0.0662R + 1.5472B \tag{7}$$

$$\frac{\partial (NHR)}{\partial L} = 10.597 - 13.282L + 0.105R + 0.847B \tag{8}$$

$$\frac{\partial (NHR)}{\partial R} = -1.343 + 0.105L - 11.462R - 4.67B \tag{9}$$

$$\frac{\partial (NHR)}{\partial B} = -2.305 + 0.8475L - 4.67R - 0.1228B \tag{10}$$

Sensitivity of Pr and NHRR to L, R and B as calculated from equations (5)-(10) are shown in tables 7 and 8 and Figure 10 and Figure 11 respectively. In small variation of load causes large changes in Pr and NHRR when the load increases. The results reveal that the Pr and NHRR are more sensitive to load than compression ratio and blend of the fuel.

Table 7. Pressure sensitivities on processes parameters (B = 0)

Compression ratio (R)	Load (L) (Kg)	Sensitivity $\frac{\partial P_r}{\partial L}$	$\frac{\partial P_r}{\partial R}$	$\frac{\partial P_r}{\partial B}$
	0	10.022	0.42	0.918
16	6	7.3792	0.6938	0.442
	12	4.7364	0.9676	-0.034
	0	10.2958	4.3772	0.852
17	6	7.653	4.651	0.376
	12	5.0102	4.9248	-0.1003
	0	10.5696	8.3344	0.7861
18	6	7.9268	8.6082	0.3098
	12	5.284	8.882	-0.1665

Table 8. Net Heat Release sensitivities on processes parameters (B = 0)

Compression ratio (R)	Load (L) (Kg)	Sensitivity $\frac{\partial(NHR)}{\partial L}$	$\frac{\partial(NHR)}{\partial R}$	$\frac{\partial(NHR)}{\partial B}$
	0	23.774	10.014	1.5175
16	6	10.492	10.119	2.365
	12	-2.79	10.224	3.2125
	0	23.879	-1.448	-3.1525
17	6	10.597	-1.343	-2.305
	12	-2.703	-1.238	-1.4575
	0	23.984	-12.91	-7.8225
18	6	10.702	-12.805	-6.975
	12	-2.58	-12.7	-6.1275

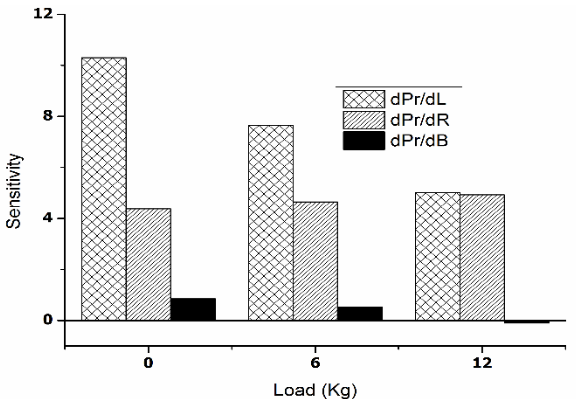

Figure 10. Sensitivity analysis result on Pressure (Pr)

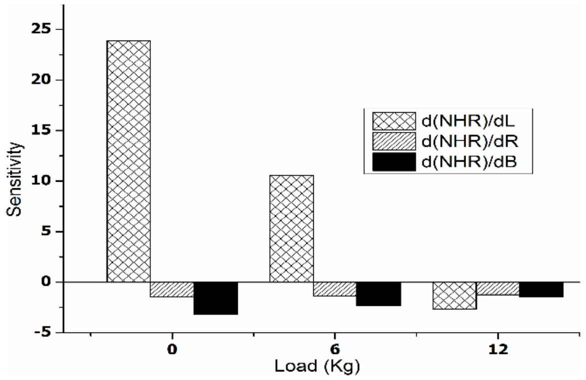

Figure 11. Sensitivity analysis result on net heat release (NHR)

Confirmation test

Figures 12 (a, b and c) are demonstrated for the differentiation between measured and predicted responses. With a 95% confident interval, the predict values of the pr, NHRR and CHRR are very close to those readings recorded experimentally.

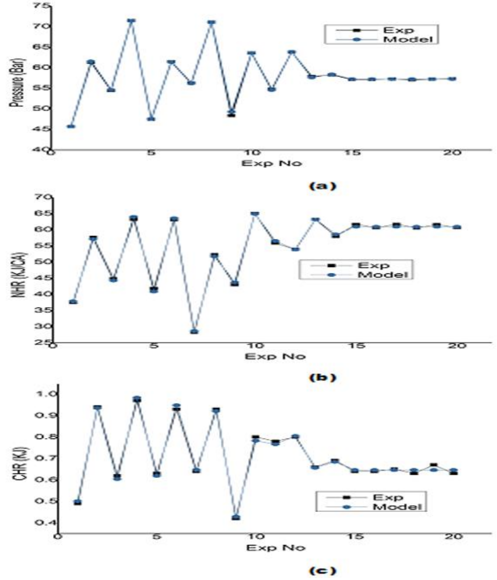

Figure 12. The comparison between experimental and model value for the a) Pressure (Pr), b) Net heat release (NHR), c) Cumulative heat release (CHR)

CONCLUSION

Argemone mexicana methyl ester was tested for combustion analysis with variation of blends, load and compression ratio. Quadratic model is formulated for output responses (Pr, NHRR and CHRR. The results of ANOVA suggested that the proposed model is best fit and the validation of the models are carried out by comparing the predicted values of output responses with that of experimental results. The sensitivity analysis revealed that load is most important parameter for the output responses followed by compression ratio and blend.

REFERENCES

1. Enweremadu, C.C., H.L. Rutto and N. Peleowo, 2011. Performance evaluation of a diesel engine fueled with methyl ester of shea butter. World Academy of Science, Engineering and Technology, 79: 142-146.
2. Utlu, Z. and M.S. Koçak, 2008. The effect of biodiesel fuel obtained from waste frying oil on direct injection diesel engine performance and exhaust emissions. Renewable Energy, 33(8): 1936-1941.
3. Bora, D.K., 2009. Performance of single cylinder diesel engine with karabi seed biodiesel.
4. Demirbas, A., 2005. Biodiesel production from vegetable oils via catalytic and non-catalytic supercritical methanol transesterification methods. Progress in energy and combustion science, 31(5): 466-487.
5. Shukla, A., A. Dixit and R. Singh, 2005. Detection of argemone oil in mustard oil. Journal of Oleo Science, 54(2): 81-83.
6. Singh, P., S.K. Duran and A. Singh, 2015. Optimization of biodiesel from argemone oil with different reaction parameters and performance analysis in CI engine. International Journal of Research in Engineering and Technology, 4: 2321-7308.
7. Agarwal, A.K. and A. Dhar, 2013. Experimental investigations of performance, emission and combustion characteristics of Karanja oil blends fuelled DICI engine. Renewable energy, 52: 283-291.
8. Nayak, S.K., S.K. Nayak, P.C. Mishra and S. Tripathy, 2015. Influence of compression ratio on combustion characteristics of a VCR engine using Calophyllum inophyllum biodiesel and diesel blends. Journal of Mechanical Science and Technology, 29(9): 4047-4052.
9. Singh, B. and S. Shukla, 2016. Experimental analysis of combustion characteristics on a variable compression ratio engine fuelled with biodiesel (castor oil) and diesel blends. Biofuels, 7(5): 471-477.
10. Patnaik, P. and S. Acharya, 2013. EFFECT OF COMPRESSION RATIO ON EMISSION OF CI ENGINE USING NEAT KARANJA OIL AND KARANJA OIL METHYL ESTER BLENDS. International Journal of Engineering-Transactions C: Aspects, 27(3): 403.
11. Miraculas, G.A., N. Bose and R.E. Raj, 2016. Optimization of Biofuel Blends and Compression Ratio of a Diesel Engine Fueled with Calophyllum inophyllum Oil Methyl Ester. Arabian Journal for Science and Engineering, 41(5): 1723-1733.
12. Kawade, G.H., S. Satpute and K. Parane, 2015. Optimization of CI engine performance parameters for jatropha biodiesel blending fuel by using ANN software. International Research journal of engineering and technology, 2(03): 1151-1156.
13. Patel, P.D., A. Lakdawala and R.N. Patel, 2016. Box–Behnken response surface methodology for optimization of operational parameters of compression ignition engine fuelled with a blend of diesel, biodiesel and diethyl ether. Biofuels, 7(2): 87-95.
14. Montgomery, D.C., Design and analysis of experiments2017: John Wiley & Sons.

Persian Abstract

DOI: 10.5829/ijee.2017.08.03.01

چکیده

در مطالعه حاضر روغن آرژمون متیل استر به وسیله فرآیند ترنس استریفیکاسیون دو مرحله ای آماده شد و در یک موتور با نسبت تراکم متغیر به منظور تایین پارامترهای احتراق از جمله فشار، انرژی خالص آزاد شده و حرارت نسبی آزاد شده مورد آزمایش قرار گرفت. در این آزمایش بار اعمالی به موتور، نسبت تراکم و درصد ترکیب بیودیزل به عنوان پارامترهای ورودی مورد مطالعه قرار گرفت. مدل ریاضی این فرآیند محاسبه و به وسیله آنالیز آنوا معنی دار بودن آن سنجیده شد. یک مدل درجه دوم توسعه داده شد و توسط آنوا به عنوان مدل بهینه تایید شد. اعتبار سنجی مدل فوق به وسیله مقایسه خروجی های مدل و نمونه واقعی به انجام رسید.