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Research paper



RSM Analysis of In-cylinder Pressure in a DICI Engine Fueled with *Argemone Mexicana* Biodiesel-diesel Blends

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Abstract

In the current analysis engine load, compression ratio and bio-diesel blends are taken as input parameters to evaluate the combustion parameter i.e maximum in cylinder pressure with methyl esters of Argemone Mexicana and its diesel blends in a VCR multi-fuel engine. Response surface method of Full Factorial Design (FFD) is used in the present study for modelling and analyzing the combustion parameter with Minitab-14.0 software. The response surface and contour plots of different models are plotted by holding mean value of other input parameter. The developed model, data regression, significance analysis and individual model coefficients were studied and presented for model validation.

Keywords: *Biodiesel, Pressure, Standard Diesel, Transesterification, RSM***.**

1. Introduction

Crude oil is unquestionably a restricted resource and predicting the point in time where crude oil is no longer an economically viable product is indefinite, this fact has been attested by several authors. What is indisputable is there will be a date when this will occur (Pinner, 2007). 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 (Utlu and Koçak, 2008) and need of any country to become self-sufficient has interested in biodiesel fuels.

Argemone Mexicana belongs to papveracae family and the entire species 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 0.3 to 0.12 meters (Singh at al. 2015). The Argemone seeds produce approximately 35% oil. It is non edible and its toxicity is due to the presence of two alkaloids viz. sangiuinarine and dihydro sangiuinarine. After removal of toxic alkaloids Biodiesel can be prepared (Shukla at al. 2005). Biodiesel production from low grade feed stocks, having high FFA using transesterification process is not appropriate. So (Demirbas, 2003) proposed a two step process. The first step is esterification process to reduce FFA content with methanol and acid catalyst followed by the second step, transesterification process, in which oil containing triglyceride (TG) reacts with methanol and base catalyst to form ester and glycerol. Miraculus et al., 2016 obtained optimum performance with lower emission at CR 19 with B30 (30% CIME + 70% DIESEL) using design expert software with designed set of experiments, which was then tested and validated. The Box_Behnken based RSM method was adopted by (Patel et al., 2016) 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.

Adequate investigations have not been carried out on the analytical approach for modelling of engine combustion parameter with Argemone Mexicana methyl esters (AMME) and its diesel blends. Therefore the objective is to formulate and evaluate model for pressure and validate it against experimental results.

2. Material and Methods

In degumming process, first the oil is preheated. In 100 ml of oil 25 ml of phosphoric acid (H_3PO_4) is added and then heated on a magnetic stirrer up to 1 hour at a temperature of 60˚ C. Then the oil was kept with 0.1% aqueous NaOH solution and settled in a beaker for 1 day. After that oil was separated and gum particles are 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 20 ml of methanol is added and then heated on a magnetic stirrer up to 3 hour at a temperature of 65˚C. 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. FFA value is less than 2, hence transesterification process was carried out. In transesterification process first oil is preheated, then 100 ml of oil is mixed with 20 ml of methanol and 0.8gm of Potassium Hydroxide (KOH) and heated on a magnetic stirrer up to 4 hours at a temperature of 55˚C. Then the mixture is settled on a separating funnel for 1 day. Here the residue glycerol is separated from the oil.
The purification of biodiesel is carried by water washing method. Alcohol is highly soluble in water and oil floats on water, therefore some amount water was added in the oil and then the mixture was left to settle on a separating funnel for 1 day. Oil was separated from lower layer by separating funnel and washed with water

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3-4 times to remove the impurities like acids, methanol. Finally the bio-diesel is heated nearly 55-60^{0}C to remove the water particles to obtain the resultant transesterified oil (TEO) shown in Fig.1.



Fig. 1: Transesterified Argemone Mexicana oil (AMME)

Table 1: Properties of blended fuel

Sl N	Properties	Equipment	Method	Diesel	AME	B20	B40	B60
1	Kinematic Viscosity, 40^{0}C	Cannon-Fenske Viscometer	ASTM D445	3.68	5.07	4.1	4.32	4.58
2	Density at 20^{0}C (kg/m^3)	KEM Density-meter	ASTM D4052	830	868	843	849	858
3	Calorific values, (Kj/kg)	Bomb Calorimeter	ASTM D240	42800	41500	42540	42280	41980
4	Flash point (^{0}C)	Pensky Martness Apparatus	ASTM D93	65	130	81	98	110

2.1. Engine Description (Multi-Fuel VCR Engine)

The experimental work was executed through a single cylinder, four stroke and vertical fully computerized multi fuel variable compression ratio engine. The load on the engine was done by adjusting the dynamometer arm length. 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 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.

2.2. Response Surface Methodology (RSM)

To study the impact of the factors or combinations of factors on a process during experimentation, factorial designs are extensively used. In the present investigation, the full factorial design matrix consists of 3 factors (each factor having 4 levels) design of RSM generated from the software ''Mini Tab'' version 14, which contained (43), 64 experimental runs. The CR (R) was varied at four levels from 16 to 18. The fuel blends (B) too was varied from 20 to 100 %. The applied load (L) on the engine was also varied uniformly from 3kg to 12kg at a step of 3kg.

In the current investigation, statistical package MINITAB 14 software of "Math Corporation" was used to develop the experimental planning matrix for RSM and to analyze the collected data (Montgomery, 1997). Let Y be a random variable and x_1, x_2…… x_k be a set of independent variables which are assumed to be continuous. Then

The mathematical representation of Y in RSM is

$$Y = \beta_o + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i}^{k} \sum_{j}^{k} \beta_{ij(i<j)} x_i x_j + \varepsilon \quad (1)$$

3. Results and Discussions

Effect of input parameters on engine output responses for combustion characteristics has been discussed in this section. Mathematical modeling for each response has been formulated with the help of Regression Coefficients and statistical analysis using Predicted value of each response.

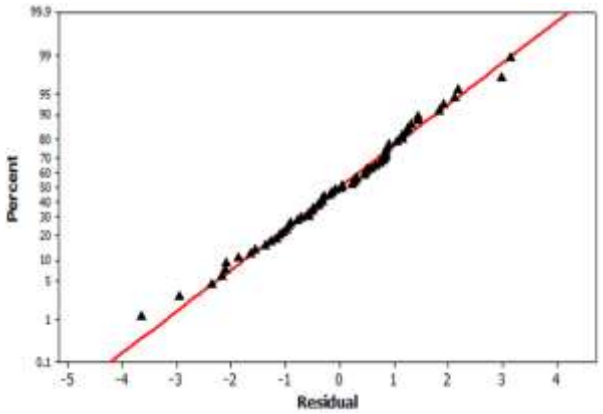


Fig. 2(a): Normal Probability of Residuals

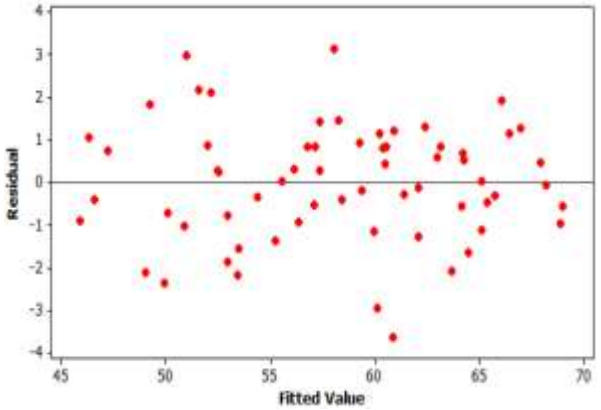


Fig. 2(b): Residuals Vs. The Fitted Value

The normal probability plots of the residuals and the residuals versus the fitted value for predicted responses (Pressure) are shown in Fig. 2(a) and 2(b) respectively. A check on the plots in Fig. 2(a) revealed that the residuals generally fall on a straight line involves that the errors are dispersed normally. Also Fig. 2(b) revealed that they have no obvious pattern and unusual structure. This implies that the models proposed are adequate and there is no reason to suspect any violation of the independence or constant variance assumption.

Table 2: ANOVA Results for P_{max}

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	2434.03	2434.03	270.448	124.18	0.00

Linear	3	2387.03	2256.88	752.295	345.43	0.000
Square	3	42.14	42.14	14.048	6.45	0.001
Interaction	3	4.85	4.85	1.618	0.74	0.531
Residual Error	54	117.60	117.60	2.178		

$$\text{Pressure} = 57.8670+7.3207L+3.6783R-0.1850B-1.4927L^2+0.3990R^2 +0.9759B^2+0.1685LR-0.2562LB+0.3976RB \quad (2)$$

$$\text{Pressure} = 57.8670+7.3207L+3.6783R-1.4927L^2 \quad (3)$$

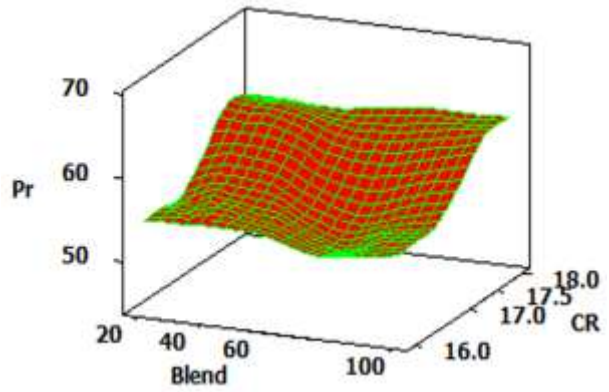


Fig. 3(a): Surface plot Pr Vs. Blend, CR

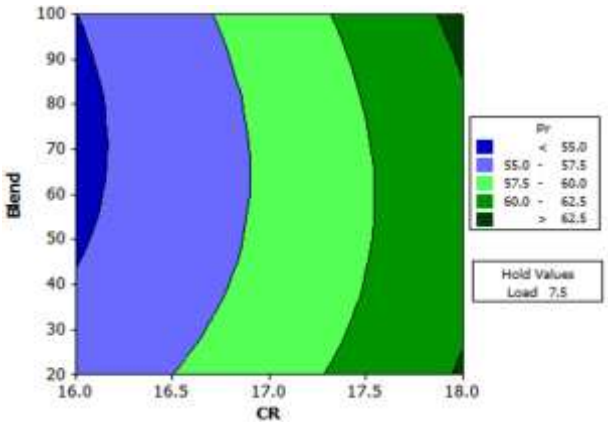


Fig. 3(b): Contour plot Pr Vs. Blend, CR

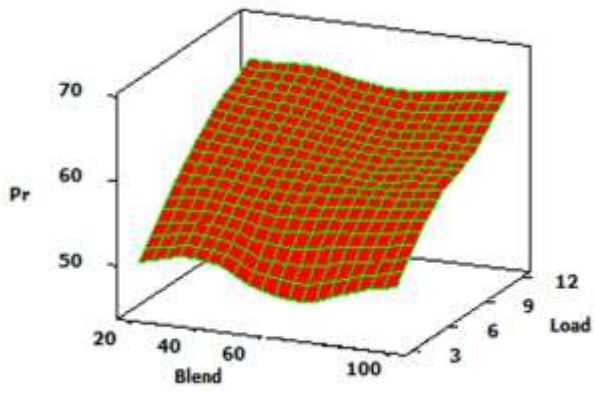


Fig. 4(a): Surface plot Pr Vs. Blend, Load

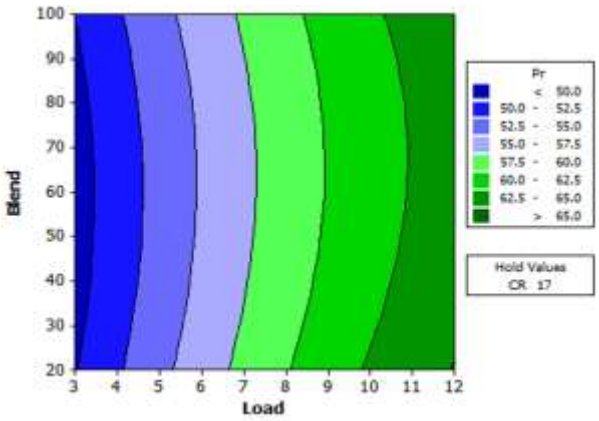


Fig. 4(b): Contour plot Pr Vs. Blend, Load

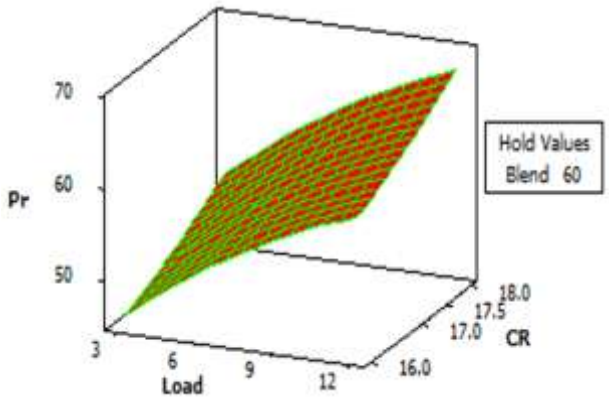


Fig. 5(a): Surface plot Pr Vs.CR, Load

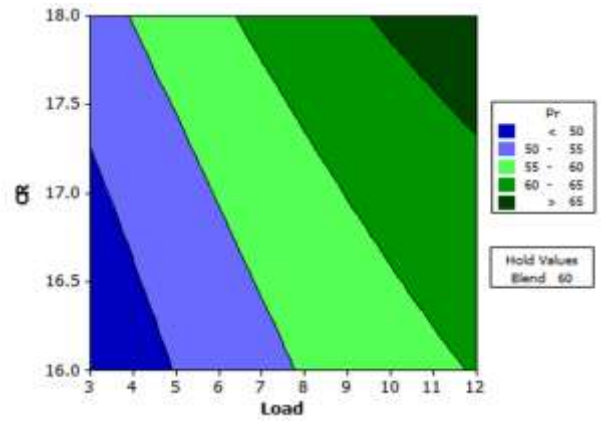


Fig. 5(b): Contour plot Pr Vs. Load, CR

The principal model analysis was based on ANOVA which gives p value is given in Table 2. The Quadratic model found to be significant as the values of p were less than 0.05 (95% confidence level) except for the interaction factors. The pressure model was developed in terms of actual coefficients and is given below as Equations (2 & 3). The obtained R^2 (determination coefficients) value (0.954) for pressure (P_{max}) from Table 3 approaches to unity. The Predicted R-squared value is very close to Adj R-squared value. Hence the model indicates a good correlation between the experimental and the predicted values and can be used to predict the responses very well. The 3D surface graphs for the response Pressure are shown in Fig. 3(a), 4(a) and 5(a) by holding mean value of other input parameter constant. All the surface graphs have curvilinear profile in accordance to the quadratic model fitted. Fig. 3(a) indicates that the cylinder pressure increases with increase in the value of compression ratio due to higher mean gas temperature and little variation is observed with percentage of biodiesel in the blend with hold value of load (Vasudeva et al., 2016).

Fig. 4(a) revealed Pressure almost remains same with blend variation and increases with applied load may be due to superior combustion of Argemone mexicana biodiesel blends at higher loads. Fig. 5(a) shows that Pressure increases with increasing the load and CR for hold value of blend on the engine.
The contour plots of model pressure are shown in Fig. 3(b), 4(b) and 5(b) respectively by holding mean value of other input parameter. Fig. 3(b) shows higher pressure values occurs at high compression ratio (17.5-18) for entire range of blend variation. Fig. 4(b) explains that almost vertical strips imply higher values of pressure in higher load region with nominal effect of blend as shown by the slope of the contour lines. In Fig. 5(b) negative slope of the contour lines revealed constant response for pressure are obtained with increasing compression ratio allied with decreasing load torque.

3.1. Model Validation

The developed models for its evaluation and significance analysis were studied and presented in Table 3 for validation. Greater Predictive ability of model is recommended by larger value of Predicted R^2. R^2 and adjusted R^2 from Table 3 indicate that the estimated models fit the experimental data satisfactorily. (Lee et al., 2010) suggested that for a good fit of a model, R^2 should be at least 80 %. The R^2 for these response variables was higher than 80 %, indicating that the regression models explained the mechanism well.

Table 3: Response Model Evaluation

Model	Mean	SD	R^2	R^2 (Adj)	Model degree	R^2 (Pred.)
Pressure	58.29	6.364	0.954	0.946	Quadratic	0.9188

3.2. Validation

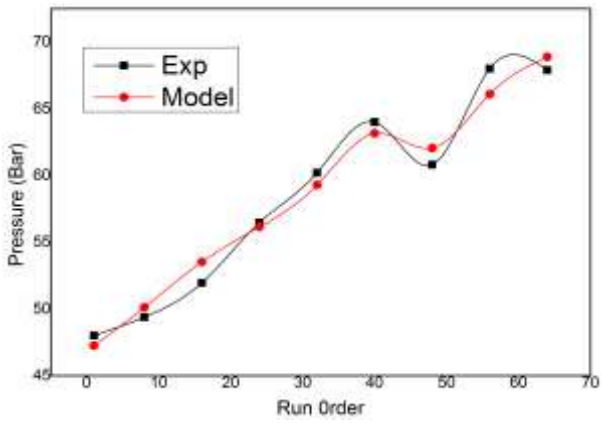


Fig. 6: Pressure Error (%) = 0.3

The predicated value of pressure model is compared with that of experimental one for validation of 'Regression Model' which is shown in (Fig 6) graph by different colours. It is clear from graph that predicted results are very close to actual targets and also concludes that model has good prediction capability with error less than 1%.

4. Conclusion

- Experimental investigation has been the carried to study the outcome of operating parameters on pressure with Argemone biodiesel using FFD consisting of 64 runs.
- The mathematical model (Quadratic) was developed with Regression coefficient & its statistical significance was checked using Analysis of Variance.
- Model is found to be statistical significant as the values of p were less than 0.05.
- The mathematical model is validated against experimental results with < 1% error.

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