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Challenges in Biochemical Engineering and Biotechnology for Sustainable Environment

Optimization of Emission and Combustion Parameters of Diesel Engine with Polanga Oil – Diesel - Nano Particle Blend using Response Surface Methodology

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Abstract : Response surface methodology (RSM) was employed to optimize the fuel blend ratio and Iron oxide Nanoparticle concentration for diesel engine performance. Diesel engine test was carried out using Polanga oil – Nanoparticle – diesel fuel blend. The diesel engine performance was accessed based on its smoke emission, oxygen release and heat release as response. Experiments were performed at different concentrations of Nanoparticle (100 ppm – 500 ppm), Polanga oil (5-30 vol %), and diesel blends (70 – 95 vol %). From the results, diesel -74% , polanga oil – 26%, nano particle – 150 mg/L of polanga – diesel blend, was found to be the optimum fuel blend and good performance of engine at 80% engine full load with reduction in emission and comparable with pure diesel were observed.
Keywords - Emission, Blend, Diesel, Polanga oil, RSM.

Introduction

Wide varieties of fuels are being investigated as potential substitutes for the diesel fuel derived from diminishing sources. Vegetable oils may provide one such alternative and their potential has been examined in the past years by several researchers. Many of the researchers have indicated that the successful use of vegetable oil is a function of the engine type. The main disadvantages of vegetable oils as diesel fuel were higher viscosity, high acid value, low volatility and the reactivity of unsaturated hydrocarbon chains[1]. Vegetable oils possess 80 to 90% heat content and cetane number of diesel[2]. Principally the viscosity and acid value of vegetable oils must be reduced to avoid poor atomization, incomplete combustion and carbonization in diesel engine[3]. A major problem to be encountered with the more widespread use of the diesel engine, however, is the emission of particulate matter (i.e. smoke) comprising carbon and unburned hydrocarbons and oxides of nitrogen.

One alternative and demonstrably effective way of reducing the emissions is to blend the vegetable oil with the diesel. Polanga oil was blended with pure diesel to reduce viscosity of oil by dilution and to lower the flash point of blend so that engine would start easier[4]. Iron oxide nano particle (50nm size) was doped into poanga oil – diesel fuel blends to improve physico chemical properties and reduce exhaust emission of fuel blends from diesel engine[5]. Internal combustion engine operation is a good example of a system where the interaction between the engine operating parameters is so interwined that a reliable response surface model is not available. To express topology of combustion process in the form of mathematical function response surface method can be used[6]. In this work, the performance of diesel engine was studied with polanga oil blended with diesel and doped with iron oxide nano particle.

Materials and Methods

Materials

Raw polanga oil was purchased from local market. Pure diesel was obtained from Indian Oil Corporation Limited. Iron Oxide (II, III) nanoparticle of 50nm size was purchased from Sigma Aldrich.

Blending Process

A mechanical blender made of stainless steel tank of 50 L capacity fitted with variable speed motor and stirrer was used. A zig - zag blade was provided inside the tank. Weighed quantity of iron oxide nano particle was dispersed in certain quantity of diesel and then blended. Required quantity of diesel and polanga oil were added further according to desired concentration levels of blends and again blending continued to get homogeneous blends. The blends were observed to be stable. The properties of blends were analysed as per ASTM standards. The blended diesel was used as fuel for the engine performance test.

Experimental Setup and Study

Initially a mass ratio between polanga oil – diesel - Nanoparticle fuel blends was used and then it was converted to volume percent. Polanga Oil– diesel– Nanoparticle fuel blend ratio was optimized using RSM[7]. Emission parameters like Smoke Density (SD, HSU), Oxygen (O_2, vol %), combustion parameter, maximum heat release (HR_{max}, $KJ/m^3{*}^0C$) were measured as responses.

The experimental set up consist of a diesel engine, a dynamometer, two fuel tanks, three exhaust emission analysers, a data acquisition system, an operating panel and sensor to measure exhaust temperature. Kirloskar TV-1 vertical cylinder DI diesel engine, water cooling system was used in this study. The engine was 5.4 KW capacity with 1500 rpm fixed speed. Compression ignition system was used. The exhaust gas analysers AVL smoke meter and AVL combustion analyser with sensor were used to analyse the exhaust from the engine. Short term performance test were carried out on a diesel engine with polanga oil – nano particle – diesel blends. The dynamometer was used to load the engine. Fuel flow was measured by means of burette and stop watch arrangements. The fuel system was modified by adding an additional filter and a three way hand operated two position directional control valve which allowed rapid switching between the diesel and the test fuel blends. The speed was checked with infrared type digital tachometer. The performance parameters were calculated from the fundamental relations between the measurements.

Experimental design and data analysis

RSM is a collection of mathematical and statistical techniques that were useful in modeling and analysis of problems in which a response was influenced by several variables and the objective was to optimize the response[8]. The application of RSM reduced the cost of expensive analysis methods and their associated numerical noise. In this work, for the optimization of diesel engine performance parameters, the variables polanga oil (X_1) and nano particle (X_2) could be represented as a function (Y) as follows:

$$Y_1 = f(X_1, X_2) + e \qquad (1)$$

Where "e" represents the noise or error observed in the response Y_1. The surface represented by $f(X_1, X_2)$ is called response surface. The response surface can be represented graphically in three dimensional spaces that help the shape of the response surface.

The optimization of polanga oil – nano particle – diesel fuel blends were carried out using CCD. The data collected were analysed to determine the relationship between the variables and the responses using a regression design.

A factorial experiment was considered in which design variables was varied together, instead of one at a time. Polanga oil concentration (X_1) and nano particle concentration (X_2) were considered as independent variables. Emission and combustion parameters were response variables (Y_1 to Y_3). The lower and upper bounds of independent variables shown in Table 1 were chosen based on the literature survey and preliminary experiments.

Table1. Independent variables and actual factor levels

Variables	Code	Actual Factor Levels				
		-α	-1	0	1	+α
Polanga Oil (% wt)	X_1	6.7	10	18	26	29.3
Nano particle (ppm)	X_2	102	160	300	440	498

The regression analysis was performed to estimate the response function as a second order polynomial.

$$Y=a_0+\sum_{i=1}^{n} aiXi+\sum_{i=1}^{n} aiiXi^2+\sum_{i=1}^{n}\sum_{i=1}^{n} aijXiXj \qquad (2)$$

$i<j$

Where Xi and Xj were design variables, Y were response variables and "a" were tuning parameters. The quadratic regress models for the three response variables (Y_1 to Y_3) were developed in terms of coded factors X_1 and X_2. The coefficients of the model equation and their statistical significance were evaluated using Design Expert Software Version 7.0.0.

Results and Discussion

Experiments were carried out to investigate the emission and combustion characteristics of diesel engine and the results obtained were given in Table 2. The model obtained for the three responses were given below.

$$\text{Smoke density} = 34.00 + 1.28A + 2.20B + 0.62AB + 2.04A^2 + 2.04B^2 \qquad (3)$$

$$O_2 \text{ release} = 12.84 + 0.80A + 0.97B + 0.13AB + 0.44A^2 + 0.46B^2 \qquad (4)$$

$$HR_{max} = 120.00 + 5.73A - 5.83B - 8.30AB + 1.15 A^2 - 7.65B^2 \qquad (5)$$

Experimental results at 80% engine full load were compared with predicted results from the model and it was shown in Fig.1a-1c. From the figures it was inferred that the predicted values were close with the experimental values, which indicates that the prediction of experimental data was quite satisfactory.

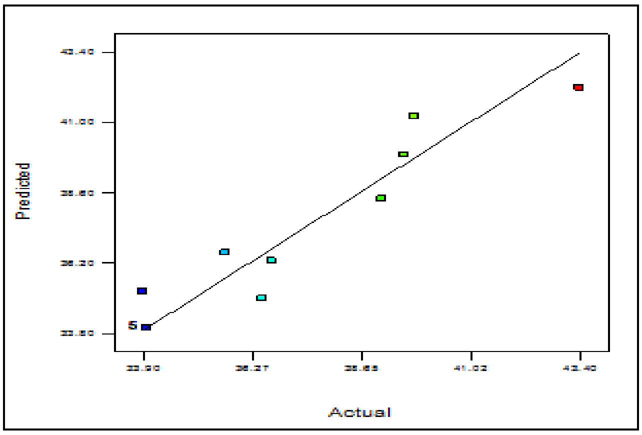

Fig.1a.Plot of Smoke Density

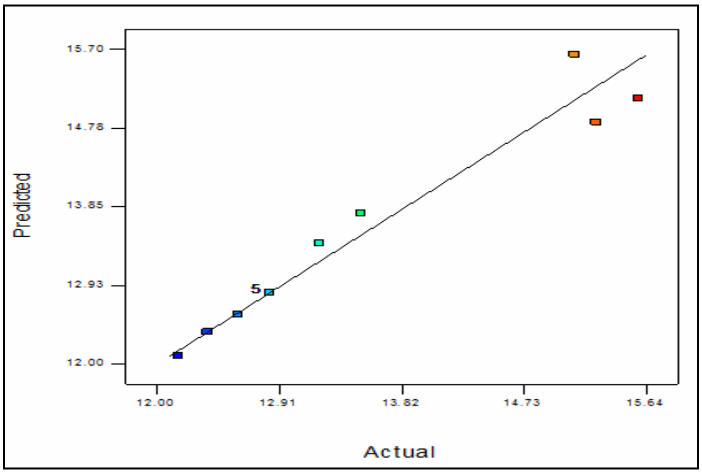

Fig.1b. Plot of Oxygen Release

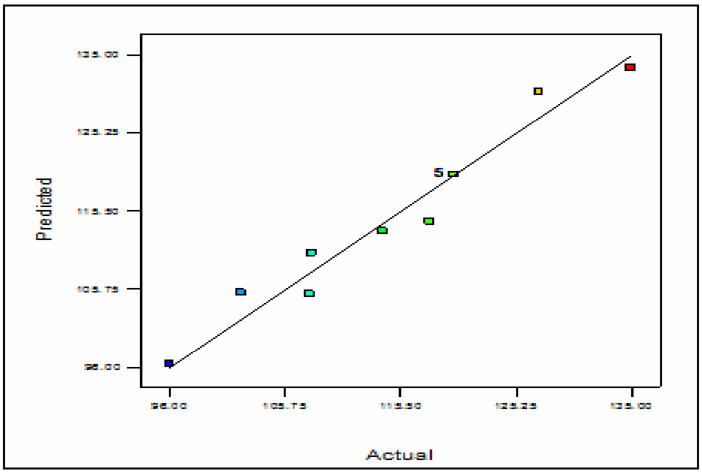

Fig.1c.Plot of Heat Release

Analysis of Variance

Table 2 Experimental design with predicted and observed values

Run no	Coded Variables		Smoke density		O_2		HR_{max}	
	X1	X2	Expt.	Pred	Expt.	Pred.	Expt.	Pred.
1	1	1	43.4	42.18	15.11	15.11	107.8	105.09
2	0	0	34	34.00	12.84	12.84	120	120.00
3	1.41	0	39.6	39.89	15.27	15.27	127.2	130.40
4	0	0	34	34.00	12.84	12.84	120	120.00
5	0	0	34	34.00	12.84	12.84	120	120.00
6	0	1.41	39.8	41.19	15.58	15.58	96	96.45
7	0	0	34	34.00	12.84	12.84	120	120.00
8	0	0	34	34.00	12.84	12.84	120	120.00
9	1	-1	35.7	36.54	13.21	13.21	135	133.36
10	-1.41	0	36.7	36.28	12.61	12.61	118	114.20
11	-1	1	39.1	38.38	13.52	13.52	108	110.24
12	0	-1.41	36.5	34.98	12.38	12.38	114	112.95
13	1	-1	33.9	35.24	12.16	12.16	102	105.31

The statistical significance of the model was justified through the analysis of variance (ANOVA) and it was given in Table 3.

Table 3. ANOVA for the quadratic model.

Response variables	R^2	P – value	Adequate Precision
Smoke density	0.921	0.001	10.621
Oxygen	0.951	0.0002	15.633
Maximum Heat release	0.96	<0.0001	19.944
Desired value	**>0.90**	**<0.05**	**>4**

The goodness of fit of the polynomial model was checked by the determination of coefficient (R^2). The value of R^2 was greater than 0.92 and indicated that 8% of the variability in the response was not explained by the model. ANOVA of the response variables revealed that the models developed were adequate to fit the data. Therefore this model can be used to optimize response variables at their maximum values. The canonical analysis of response surface represented the values of the independent variables at a stationary point. The significance of each coefficient of the model was determined by P – values. $P < 0.05$ signifies that the linear, quadratic and interaction effects were highly significant between the independent variables. In this study, for all the responses the lack of fit was insignificant. Adequate Precision measured the signal to noise ratio. A ratio greater than 4 was an adequate signal which indicated that the model can be used to navigate the design space.

Emission Studies

The surface plots of RSM as a function of two factors (oil, Nanoparticle) were helpful in understanding both the main and the interaction effects of two factors. The effect of Polanga oil concentration and iron oxide nano particle concentration on engine parameters during operation of diesel engine were shown in Fig. 2 - 4.

Fig.2 indicated that smoke density decreased upto 26% oil and 150 ppm Nanoparticle concentrations and then steadily increased. The contributing factors for smoke density was presence of oxygen, aromatics in fuel blends and spraying quality of fuel blends[9]. Initially limited quantity of fuel bound oxygen and aromatics might have prevented formation of CO_2. Also low ignition temperature reduced smoke. Beyond maximum concentration of oil and nano particle, the improvement of smoke was due to enrichment of oxygen present in nano particle[10].

Fig.3 shows that O_2 release increased continuously with raise in oil and nano particle concentrations. Oxygen supplied through air and nano particle was more than stoichiometric requirement for combustion of fuel blend[11].

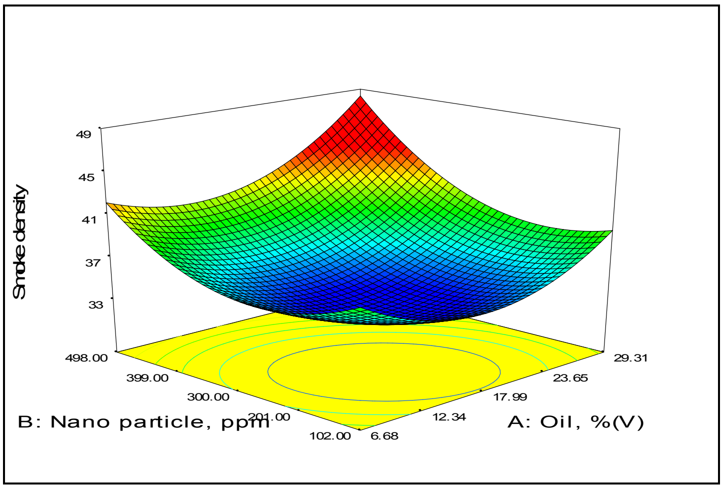

Fig.2 Response Surface Plot for Smoke Density

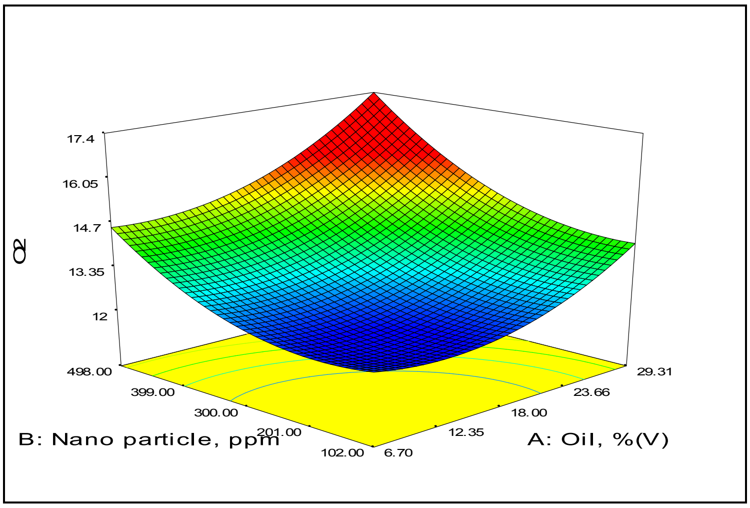

Fig.3 Response Surface Plot for Oxygen

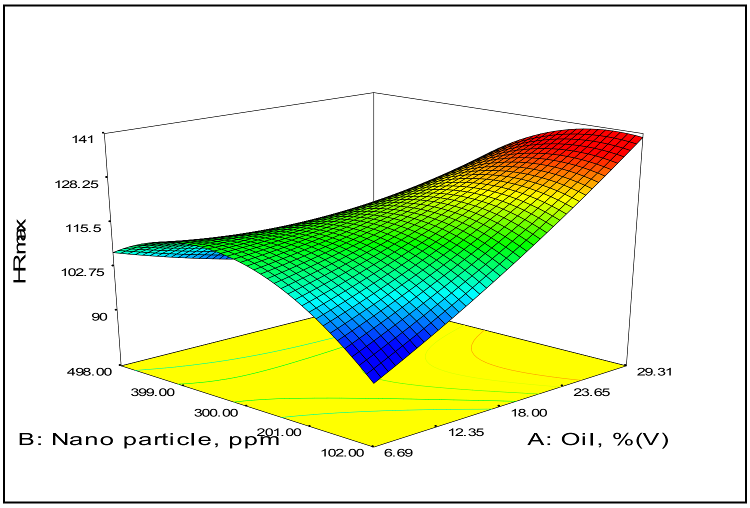

Fig.4.Response Surface Plot for Heat Release

Combustion Analysis

Fig.4 depicted the interactive effects of oil and nano particle on heat release. Improvement in oil concentration increased heat release to maximum value. Diffusion burning of diesel and oil resulted more burning with high heat release[12]. Nano particle attributed for more heat release and then reduced. Iron oxide formed condensation site in combustion zone. Carbon particle condensed on them and burnt. The condensation sites might have reduced beyond certain concentration and combustion time and caused low heat release[13].

Conclusions

Doping of nano particle into polanga oil – diesel fuel blends modified fuel blend properties closer to diesel properties. Engine performance with polanga oil – nano particle – diesel fuel blends was comparable to petroleum diesel operations. Polanga oil with nano particle could be partly (25%) replaced for diesel. By statistical analysis the developed model proved to be reliable and adequate for the proposed optimization by Response Surface Methodology. From the experimental results the optimum blend ratio and the engine operating parameters at 80% engine full load were: Diesel: 74% volume, Polanga Oil: 26% volume and 150 mg iron oxide nano particle. At these optimized conditions, Oxygen is 12.6% volume, Heat release is 119.8 KJ/m^3 ^0C,. smoke density is 42.6.

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