

Research Article

Response surface methodology based optimization of operating parameters of variable compression ratio C.I. engine fuelled with diesel-fish oil blends for minimal emissions.

Rasal Rushikesh M* and Shelke Digvijay B.

¹Dr. D. Y. Patil School of Engineering Academy, Talegaon-Ambi, Savitribai Phule Pune University, India

Accepted 15 June 2016, Available online 20 June 2016, **Special Issue-5 (June 2016)**

Abstract

Rapid decline in conventional hydrocarbon fuel reservoirs is forcing researchers all over the globe to hunt for alternatives for these hydrocarbon fuels. Fish oil extracted from discarded body parts of fish like head, tail, fins, etc. has shown promising results on a fixed compression ratio engine. Lot of studies regarding optimization of fish oil extraction methods are reported in the literature. However no study related to optimization of combustion parameters of diesel engine fueled with fish oil is reported in the literature. This paper presents the same study at three blends of fish oil viz. B15 (15% Fish oil+85% Diesel), B30 (30% Fish oil+70% Diesel), B45 (45% Fish oil +55% Diesel). Together with fish oil blends compression ratio, injection timing and load are the parameters varied in the experimentation. Compression ratio is varied from 15 to 18, injection timing is varied from 20° BTDC to 26° BTDC, and load is varied from 1/4th to full load. Experimentation is carried out as per response surface methodology from concept of design of experiment. HC, CO, CO₂ and NO_x are the combustion parameters kept under observation. A regression model is also postulated for each mentioned combustion parameters to predict them at different levels of input parameters. Model is validated by performing ANOVA. Significance of each input parameter on responses is studied through mean effect plots. Interaction effects between input parameters and various fish oil blends on responses are studied with the help of contour plots and commented in the paper. Further optimization of input parameters is carried out with composite desirability approach. The entire experimentation is confirmed with 95% confidence interval. Compression ratio 15:1, injection advance 21° BTDC and load 3kg and 22.5% fish oil blend were found to be optimal values in the test engine of 3.5kw at 1500rpm.

Keywords: Fish oil, Emission, Design of Experiment (DoE), Response surface method, Parametric optimization.

1. Introduction

The energy problems caused by the progressive depletion of fossil fuel sources, the research for alternative fuels from renewable sources is in growing demand (Gislaine Iastiaque Martins, *et al*, 2015). Numbers of different fuels were tested from the beginning of the idea of alternative fuels. These fuels are used for various applications like traditional boilers, furnaces, etc (Fernando Preto, *et al*, 2008). The cultivated land is limited therefore growing seed oil plants to fulfill the requirement of food and biodiesel is very difficult (Cherng-Yuan Lin, Rong-Ji Li, 2009). Therefore experimentation on the use of fish oil as fuel additive or substitute to conventional diesel is started in the recent past. Several tons of fish waste comes out from fishing industry daily which goes for making fish food and more is wasted. The fish oil contains approximately 90% of the energy content of diesel fuel

and is easy to process into biodiesel fuels, this clean burning source of bio-oil/biodiesel can be used to reduce dependence on imported fuel and improve air quality within the region (Sharanappa Godiganur, *et al*, 2010).

The research on the impact of the transesterification methods on the production of biodiesel and its properties, including temperature, molar ratio methanol to oil and reaction time and its optimization is done in the research (Pedro J, *et al*, 2014). The oil is extracted from discarded parts of marine fishes of mixed species were refined in different steps and afterwards it is transesterified to convert it into biodiesel and the performance and emission characteristics were studied in research (Cherng-Yuan Lin, Rong-Ji Li, 2009).

The study was also carried out by pyrolysis of fish oil by a continuous pyrolysis pilot plant where % of biodiesel was obtained at constant temperature of 525^oc (V.R. Wiggers, *et al*, 2009). The effect of addition of catalyst on trans- esterification methods were studied and the output and the properties were

*Corresponding author: **Rasal Rushikesh M**

compared with canola oil and lard (In Kwon Hong, *et al*, 2013). Usage of biofuels mixtures with traditional fuels or usage of pure biofuels needs experimental as well as numerical testing of their influences (or effects) on engine operating conditions and emission formation. Experimental investigation is usually quite expensive and time-consuming and therefore numerical simulations are commonly used when carrying out the parametric studies of biofuels influences on engines operating conditions, combustion process and emission formations. In (Pedro J. Garcia-Moreno, *et al*, 2014) paper optimization of production of fish oil biodiesel is done by fitting quadratic model and surface response methodology which resulted into higher yield of biodiesel. The pongamia seeds biodiesel is used to study the effect of injection system parameters such as injection pressure, injection timing and nozzle tip protrusion on the performance and emission characteristics of a twin cylinder water cooled naturally aspirated CIDI engine. Response surface methodology is used to predict the response parameters (M. Pandian, *et al*, 2011). The experimentation was carried out on heavy duty diesel engine with 25%, 50% and 75% biodiesel blends by varying the engine speed from 1360 rpm to 2000rpm, the combustion, performance and emission parameters were studied experimentally and numerically by AVL Boost simulation software (Luka Lesnik, *et al*, 2014). In the experimentation carried by varying the load on the engine it is found that the HC, CO and NO_x emissions reduced with marginal increase in CO₂ and smoke (G. Sakthivel, *et al*, 2014). The exhaust gas recirculation method was also used to improve the emission parameters of fish oil biodiesel along with the addition of oxygenate and it is found that there was reduction of CO by 91%, CO₂ by 62% and NO_x by 92% (C. Swaminathan, J. Sarangan, 2012). The tests were conducted on anchovy fish oil at full load condition and speed is varied from 1000 rpm to 2500 rpm, it is found that torque and power decreased by 4% and specific fuel consumption increased by 4.9%, on the other hand emission parameters reduced considerably (Rasim Behcet, 2011). The optimization is done with two different biodiesels was done using response surface methodology at full load and constant speed of 2200 rpm and the optimum concentration of each component was 65.5 vol.% diesel, 23.1 vol.% n-butanol and 11.4 vol.% cotton oil (Alpaslan Atmanl, *et al*, 2015). Thermodynamic model analysis of biodiesel with the help of Taguchi's optimization method to determine the optimum engine design parameters and operating parameters (T. Ganapathy. *et al*, 2009).

2 Materials and methods

2.1 Fuel preparation

There is abundant fish waste in local fish market. Waste fish oil coming from different industries is collected and primary filtration is done to remove dirt and other suspended particles present in the raw fish oil. Then the oil is kept to settle down to see any

impurity is left behind. Then the chemical process of conversion of the raw fish oil into the fish oil biodiesel is started. At first the raw fish oil is poured into the system with a catalyst. The water content present in the fish oil led to formation of free fatty acids and triglyceride hydrolysis as the reaction temperature increases to higher value. The free fatty acid neutralizes the catalyst and hence soap formation occurs. The fish oil reaction with methanol under the presence of catalyst helps to form glycerin and methyl esters. This process for making biodiesel is comparatively simple. This process is known as transesterification of fish oil. For this test process, the catalyst i.e. potassium hydroxide (1%oil weight) and alcohol is mixed on the volume basis with the fish oil in the ratio of 1:4. As the waste fish oil from industries is used for the production of biodiesel, the color of resulting mixture was dark brown in the beginning of the reaction and then it was turned into a light brown color during the different phases of the reaction process. The reaction is conducted for 2 hr at the temperature of 60°C at an agitation speed of 300 rpm by keeping the pressure at ambient pressure. Biodiesel produced contains no sulfur or particular matter that results to air pollution. After getting the fish oil biodiesel from the above process it is mixed with the conventional diesel on volume basis to form blends as follows B15% (15% fish oil + 85% diesel), B30%(30% fish oil + 70% diesel), B45% (45% fish oil + 55% diesel).

Table 1 Properties of fuel

Sr no	Test description	Diesel	Fish oil		
		B00%	B15%	B30%	B45%
1	Density (gm/cc)	0.830	0.834	0.841	0.844
2	Calorific value(MJ/Kg)	42.5	42.2	41.79	41.35
3	Cetane no.	49	49.7	49.99	50.1
4	Viscosity (mm ² /sec)	2.7	2.9	3.1	3.46
6	Flash Point (°C)	64	88	96	111
7	Fire Point (°C)	71	92	102	117

2.2 Equipments and materials

The experiments are carried on single cylinder water cooled naturally aspirated direct injection compression ignition engine whose specifications are prescribed in Table 2

Table 2 Engine specifications

Number of cylinders	1
Type	4 Stroke, Multifuel, Water cooled
Capacity	661 cc
Stroke length	110 mm
Bore diameter	87.5 mm
Power	3.5 kW at 1500 rpm
Compression ratio range	12:1 to 18:1
Injection variation	0o to 26° Before top dead centre



Fig.1 Engine test setup

The engine test setup consists of Kirloskar TV1 fixed compression engine modified into variable compression ratio engine. The compression ratio is varied by tilting cylinder block with respect to crank case. 1psi, Diaphragm stainless steel type & hermetic sealed is used to measure the pressure inside the cylinder. A crank position sensor Make Kubler-Germany Model 8.3700.1321.0360 is placed at the end of the propeller shaft to measure the position of the crank. An eddy current dynamometer of AG10 Series designed for the testing of engines up to 400kW is used to load the engine. An ICAEngineSoft9.0 software developed by Apex innovations pvt. ltd. is used to record all the readings. The compression ratio is varied from 15 to 18 in step of 1. The injection timing can be altered by changing the position of fuel pump with respect to cam shaft. The injection timing is varied from 20° BTDC to 26° BTDC in step of 2. The load can be varied by eddy current dynamometer. The load is varied from 3kg (1/4th) to 12kg (full load). The mentioned levels of factors were selected because levels of emissions were significantly increasing beyond selected levels of input parameters. For the measurement of emission parameters five gas exhaust gas analyzer is used which can record HC, CO, CO₂, O₂

and NO_x, the specifications of which are mentioned in Table 4.

Table 3 Five gas analyzer specifications

Parameter	Measuring range	Resolution
HC	0-10000 ppm	1 ppm
CO	0-9.999 %	0.00%
CO ₂	0-20 %	0.01%
O ₂	0-25 %	-
NO _x	0-5000 ppm	1 ppm
Repeatability	Less than ± 2 % FS	

2.3 Response surface methodology

The main objective of this work is to check the individual and mix effects of engine operating parameters on emission characteristics of C.I. engine fuelled with blends of fish oil using response surface methodology based design of experiments. The other objective is to find optimal values of compression ratio, injection timing, load and fish oil blends which might end in minimum emissions. For this type of multi-objective parametric optimization, concept of design of experiment is very helpful to evaluate emission characteristics of engine over the range of factors influencing response with minimum number of experiments. Response surface method of DoE (the concept of design of experiment) is used in the present study for modeling and analyzing the response parameters at different levels of factors that affects the responses. Table 4 presents experimental design matrix based on fractional factorial design of response surface methodology generated by “Design expert” (version 10.0) of stat ease, U.S., which contain fifty experimental runs. Required model points in the experimental design were 15. Additional 15 model points and 15 lack of fit points with 5 replicate points were added to support and make model more robust to the terms not included in the model.

Table 4 Experimental design

Run	CR	IA	Load	Blend	HC	CO	CO ₂	O ₂	NO _x
1	17	26	12	3	8	0.128	2.77	16.03	584
2	16	22	6	1	13	0.079	2.93	16.59	481
3	15	20	12	3	29	0.366	3.29	15.59	347
4	16	20	12	2	30	0.309	2.92	16.26	215
5	15	26	12	0	41	0.242	3.94	14.01	690
6	15	22	6	2	13	0.109	3.01	16.22	401
7	16	20	12	0	30	0.249	3.45	15.15	427
8	18	20	3	2	15	0.09	3.05	16.3	466
9	18	20	3	0	11	0.059	2.81	16.83	487
10	15	20	12	3	29	0.366	3.29	15.59	347
11	18	22	9	1	14	0.091	2.94	16.37	457
12	15	26	3	0	31	0.196	3.2	15.72	299
13	18	24	3	3	18	0.083	3.16	16.01	881
14	18	22	3	1	18	0.082	2.93	16.52	558
15	16	22	3	1	10	0.096	2.73	16.76	446
16	15	24	3	3	22	0.163	3.21	15.97	300
17	18	20	12	1	19	0.23	2.72	16.85	223
18	16	26	6	2	14	0.104	3.07	16.06	575

19	16	22	9	2	27	0.129	3.08	16.05	353
20	17	24	6	1	11	0.087	3	16.35	647
21	16	26	3	3	18	0.143	2.97	16.48	322
22	18	26	3	2	17	0.082	3.1	16.1	896
23	15	26	6	1	10	0.105	3.03	16.37	531
24	17	20	6	3	11	0.068	3.16	15.95	598
25	18	22	12	3	33	0.186	3.16	15.84	490
26	18	20	9	2	18	0.109	3.18	15.86	393
27	17	24	6	1	11	0.087	3	16.35	647
28	15	22	3	0	18	0.09	2.71	17.06	354
29	17	26	9	0	17	0.089	3.22	15.77	775
30	17	24	9	3	43	0.132	3.92	14.39	829
31	16	24	9	1	17	0.098	2.91	16.64	458
32	15	24	3	1	13	0.144	3.04	16.25	465
33	15	20	6	0	18	0.074	3.18	15.79	619
34	18	24	6	0	17	0.06	2.94	16.58	658
35	15	26	6	3	21	0.111	3.15	16.23	475
36	16	24	12	2	30	0.262	2.92	16.18	309
37	15	20	3	2	11	0.11	2.97	16.36	399
38	17	20	3	3	15	0.94	3.15	15.98	550
39	17	26	3	0	23	0.129	3.18	15.4	595
40	16	22	6	1	13	0.079	2.93	16.59	481
41	16	20	3	0	18	0.101	3.16	15.89	513
42	15	20	12	1	27	0.283	2.95	16.5	222
43	18	20	3	3	23	0.83	3.18	16.17	524
44	18	26	12	0	20	0.094	2.74	16.72	647
45	16	24	12	2	30	0.262	2.92	16.18	309
46	18	26	3	2	28	0.089	3.24	15.78	896
47	15	26	12	0	41	0.242	3.94	14.01	690
48	15	24	9	1	24	0.126	3.07	16.4	418
49	18	22	6	3	16	0.068	3.22	15.87	802
50	17	22	9	0	13	0.047	2.91	16.58	542

3 Results and discussion

3.1 Analysis of the model

The principal model analysis is based on the analysis of variance (ANOVA) which provides numerical information for the P value. The analysis of variance for different response parameters such as HC, CO, CO₂ and NO_x emissions are given in Table 4. Model found to be significant as the value of P were less than 0.01. Factors having P value more than 0.1 suggest insignificance of input parameters over the output response. Cubic models for the responses are formed in terms of actual factors and are given below as equations 1 to 4.

1] Cubic model for HC emissions

$$\begin{aligned}
 HC = & 18.39 + 1.37 \times CR + 4.56 \times IA + 16.31 \times LD + 11.07 \\
 & \times BL - 2.69 \times CR \times LD + 2.15 \times CR \times BL - 2.40 \times IA \times LD \\
 & - 2.46 \times IA \times BL - 0.84 \times LD \times BL + 1.10 \times CR^2 - 5.90 \\
 & \times IA^2 + 3.43 \times LD^2 + 4.83 \times BL^2 - 4.05 CR^2 \times BL - 6.63 \\
 & \times CR \times BL^2 - 5.83 \times IA^2 \times LD - 6.75 \times IA^2 \times BL - 5.72 \times \\
 & IA \times LD^2 - 5.28 \times L^2 \times B - 7.80 \times LD^3
 \end{aligned}$$

2] Cubic model for CO emissions

$$\begin{aligned}
 CO = & 0.083 - 0.056 \times IA + 0.011 \times LD + 0.055 \times BL - 0.089 \\
 & \times IA \times BL - 0.055 LD \times BL + 0.127 \times LD^2
 \end{aligned}$$

3] Cubic model for CO₂ emissions

$$\begin{aligned}
 CO_2 = & 3.064 + 0.036 \times CR + 0.28 \times IA + 0.13 \times LD + 0.30 \times \\
 & BL - 0.11 \times CR \times BL - 0.095 \times IA \times BL - 0.034 \times LD \times \\
 & BL + 0.02 \times IA^2 - 0.18 \times LD^2 + 0.21 \times BL^2 + 0.10 \times CR \\
 & \times LD \times BL - 0.21 \times CR \times BL^2 - 0.23 \times IA^2 \times BL - 0.14 \\
 & \times LD^2 \times BL + 0.19 \times LD \times BL^2 - 0.3 \times IA^3 - 0.25 \times LD^3
 \end{aligned}$$

3] Cubic model for NO_x emissions

$$\begin{aligned}
 NO_x = & 530.26 + 196.41 \times CR + 125.32 \times IA - 150.29 \times LD \\
 & + 78.77 \times BL + 74.33 \times CR \times IA - 68.32 \times CR \times LD \\
 & + 53.52 \times CR \times BL + 43.38 \times IA \times LD - 0.43 \times LD \\
 & \times BL + 7.77 \times CR^2 + 42.87 \times IA^2 - 138.61 \times LD^2 \\
 & + 74.11 \times BL^2 - 59.93 \times CR \times IA \times LD + 52.65 \times CR^2 \\
 & \times IA + 69.4 \times IA^2 \times LD - 98.22 \times IA^2 \times BL - 44.1 \\
 & \times IA \times LD^2 - 63.48 \times IA \times BL^2 + 95.75 \times LD \times BL^2 \\
 & - 105.44 \times CR^3
 \end{aligned}$$

3.2 Evaluation of model

The stability of the all models developed was validated using Analysis of Variance (ANOVA) presented in Table 5 for the various responses. It is found that the models were significant with p values less than 0.0001. The reference limit for p was chosen as 0.1. The regression statistics goodness of fit (R²) and the goodness of

prediction (Adjusted R²) were shown in Table 5 for all the responses. The R² value indicates the total variability of response after the significant factors taken into consideration. The Adjusted R² value accounts for the number of predictors in the model. Both the values show that the model fits the data very well.

Table 5 ANOVA for various responses indicating values of 'p'

Source	HC	CO	CO ₂	NOx
Model	<0.0001	<0.0001	<0.0001	<0.0001
CR	-	-	-	<0.0001
IA	0.0209	0.0243	0.0061	<0.0001
LD	0.0002	-	-	<0.0001
BL	0.0004	0.0282	<0.0001	<0.0001
IA-BL	0.0378	0.0038	0.004	-
CR-BL	-	-	0.008	<0.0001
BL ²	0.0071	-	<0.0001	<0.0001

Table 6 Response surface model evaluation

Model	HC	CO	CO ₂	NOx
mean	20.34	0.17	3.09	511.82
std. deviation	4.67	0.13	0.12	39.8
model degree	cubic	cubic	cubic	cubic
R ²	0.8269	0.4805	0.8671	0.7916
Adj R ²	0.7075	0.408	0.79	0.9485
Pred R ²	0.3529	0.2301	0.5674	0.8825

3.3 Interactive effects of Compression ratio (CR) and fish oil blend (BL)

The interactive effects of compression ratio and fish oil blends on HC, CO₂ and NOx are shown in figure 2 to 4.

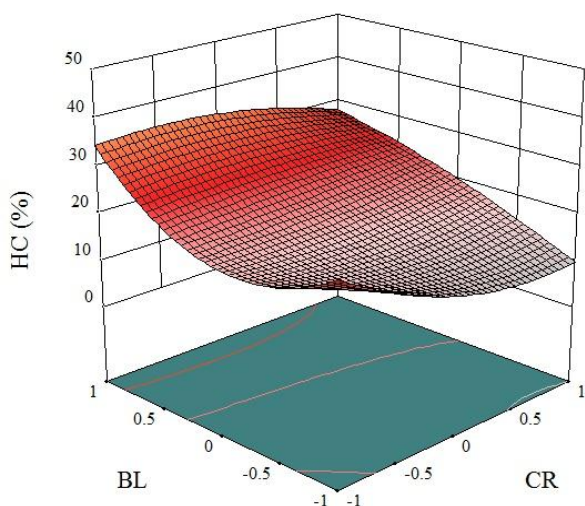


Fig.1 Interaction effect of Compression ratio and fish oil blend on HC

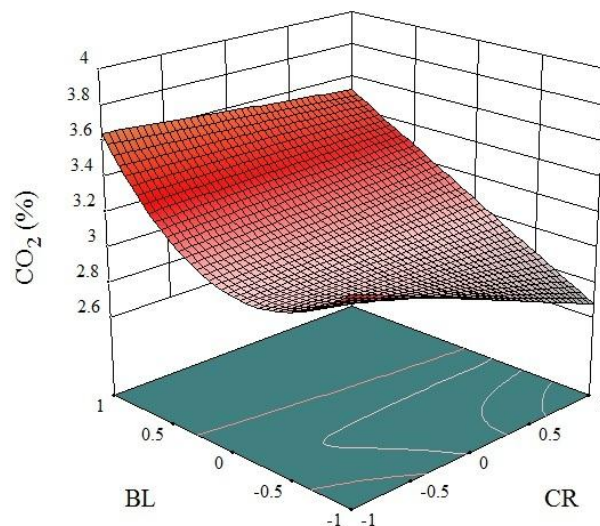


Fig.3 Interaction effect of Compression ratio and fish oil blend on CO₂

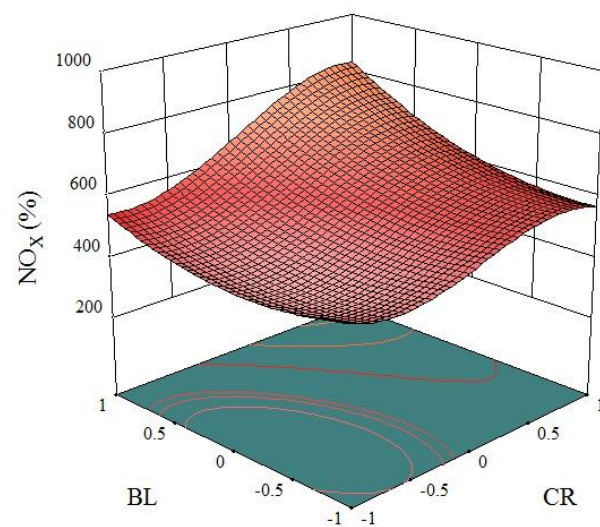


Fig.4 Interaction effect of Compression ratio and fish oil blend on NOx

At a given compression ratio as % of fish oil blend increases the values of HC, CO₂ and NOx decreases up to certain limit and again starts increasing towards higher % of fish oil blends. At given % of fish oil blend values of HC and CO₂ decreases whereas NOx increases with increase in compression ratio. Therefore in order to reduce HC, CO₂ and NOx it is always better to run the engine at lower compression ratio and fish oil blends.

3.4 Interactive effect of Injection Advance (IA) and Fish oil blends

The interactive effects of injection timing ratio and fish oil blends on HC, CO and CO₂ are shown in figure 5 to 7. On lower side of injection timing the HC values increases with increase in % of fish oil however on higher side of injection timing slight decrease in HC values is observed. On lower side of injection timing with increase in % of fish oil blend CO % increases and

on the higher side of injection timing CO% decreases with increase in % of fish oil blends. In case of CO₂ at a given % of fish oil blend with increase in the injection timing the CO₂ % decreases in the beginning and then goes on increasing. Again at higher injection timing CO₂ % decreases with increase in % of fish oil blend.

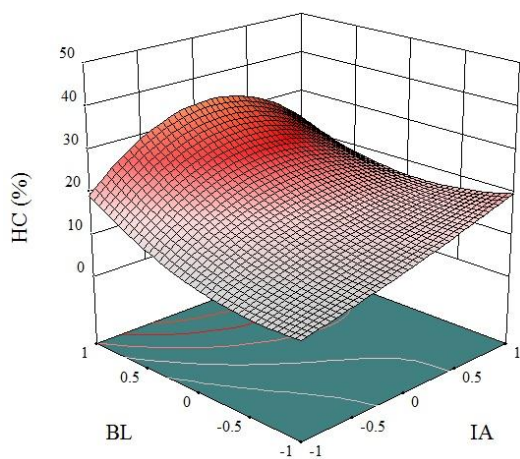


Fig.5 Interaction effect of Injection advance and fish oil blend on HC

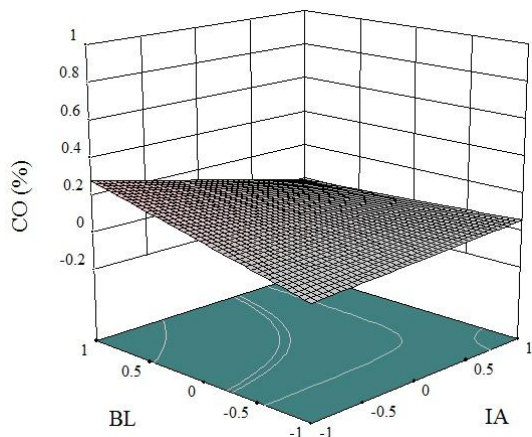


Fig.6 Interaction effect of Injection advance and fish oil blend on CO

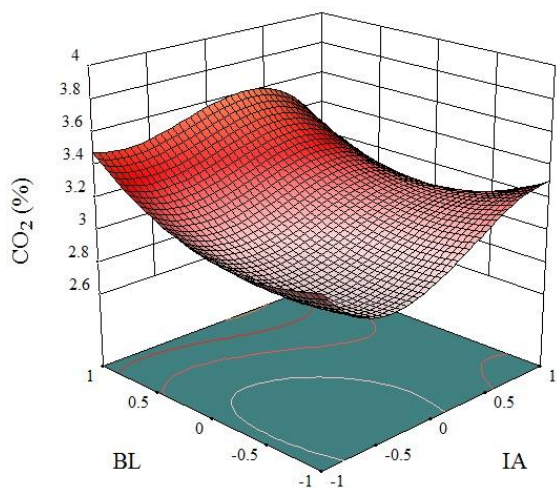


Fig.7 Interaction effect of Injection advance and fish oil blend on CO₂

3.5 Interactive effect of Load (LD) and Fish oil blend

The interactive effects of load and fish oil blends on CO are shown in figure 8. At a given % of fish oil blend as load goes on increasing CO% decreases in the beginning and at higher load CO% increases rapidly. At a given load with increase in % of fish oil blend CO% increases. Therefore to have minimum CO% it is better to run the engine at moderate load and low % of fish oil blend.

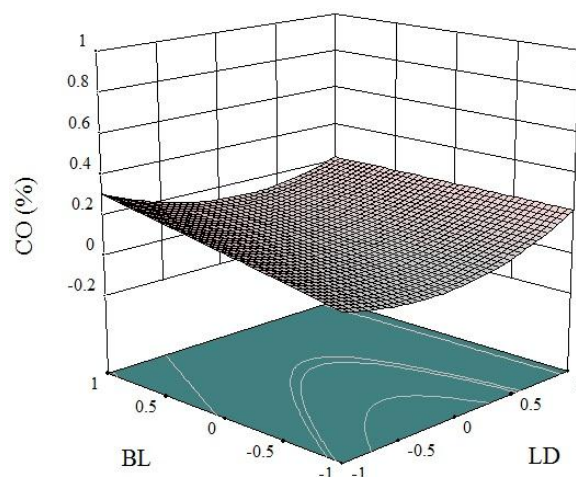


Fig.8 Interaction effect of Load and fish oil blend on CO

4 Significance of input parameters on HC, CO, CO₂ and NO_x

In order to identify the significance of input parameters on the mentioned emission parameters, main effect plots are plotted and are presented in figures 9 to 12. Main effect plots for HC shows strong significance of load and fish oil blend on HC percentage in emission, however compression ratio and ignition timing are the insignificant factors. In order to have minimum HC emissions it is better to run engine at 17:1 compression ratio, 22° BTDC injection advance, 6 kg load and 15% fish oil and diesel blend. Main effect plot for Co shows significance of all input parameters except compression ratio. In order to have minimum CO emissions it's better to run engine at 17:1 compression ratio, 22° BTDC injection advance, 6 kg load and no fish oil diesel blend. Main effect plots for CO₂ shows highest significance of fish oil blend together with all other input parameters. In order to have minimum CO₂ emissions it's better to run engine at 16:1 compression ratio, 22° BTDC injection advance, 3 kg load and 15% fish oil diesel blend. At higher values of fish oil blending CO₂ percentage increases though. Main effect plots for NO_x shows significance of all input parameters. Compression ratio shows highest significance on NO_x. With increase in fish oil blending NO_x decreases up to 30% blending and then increases for 45% blend. In order to have minimum NO_x emissions it's better to run engine at 16:1 compression ratio, 20 DBTDC injection advance, 12 kg load and 30% fish oil diesel blend. Amongst selected input factors,

fish oil blending has shown its significance on all the emission parameters.

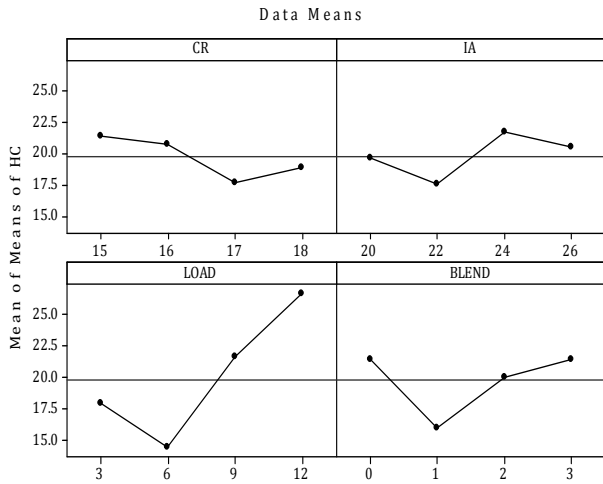


Fig.9 Mean of means of HC

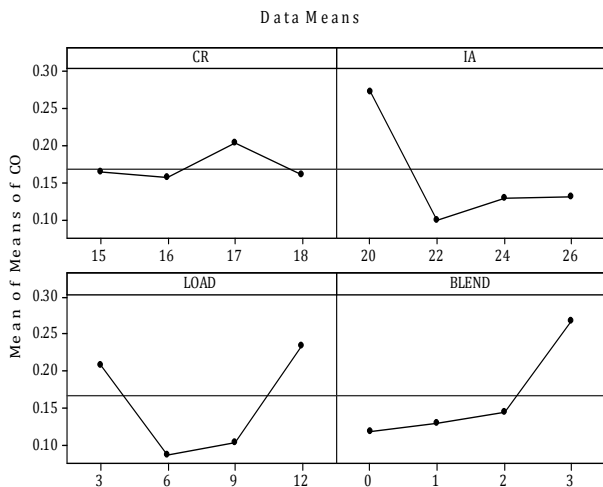


Fig.10 Mean of means of CO

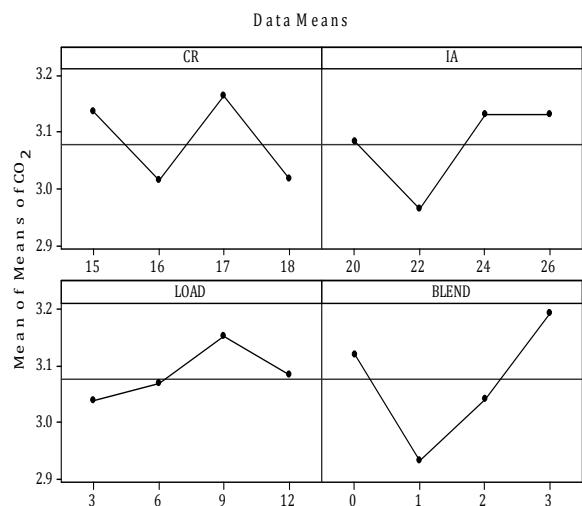


Fig.11 Mean of means of CO₂

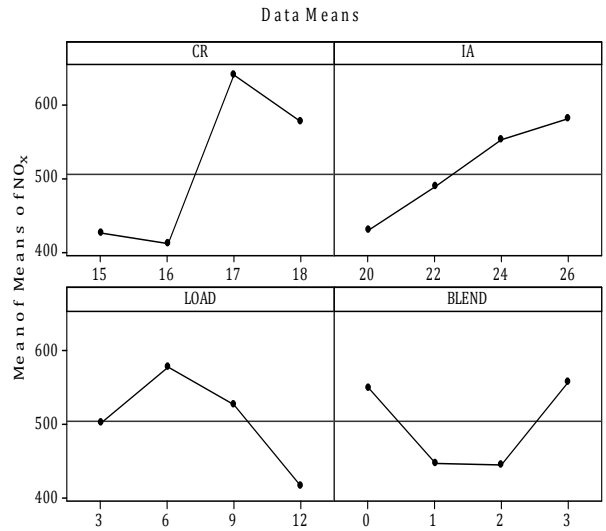


Fig.12 Mean of means of NOx

5. Optimization

The detailed discussion regarding interaction between various input parameters and significance study suggest different input parameters for minimum emission levels of HC, CO, CO₂ and NOx. Since it's difficult to run engine at different levels for individual emission parameters it is decided to optimize levels of input parameters for minimal emissions. Composite desirability based approach found suitable in this regard (M. Pandian, *et al*, 2011). In desirability approach different best solutions were obtained and the solution with highest composite desirability is chosen for optimum levels of input parameters. The higher values of composite desirability justifies that the combination of input variables satisfies the goals defined for the responses very well.

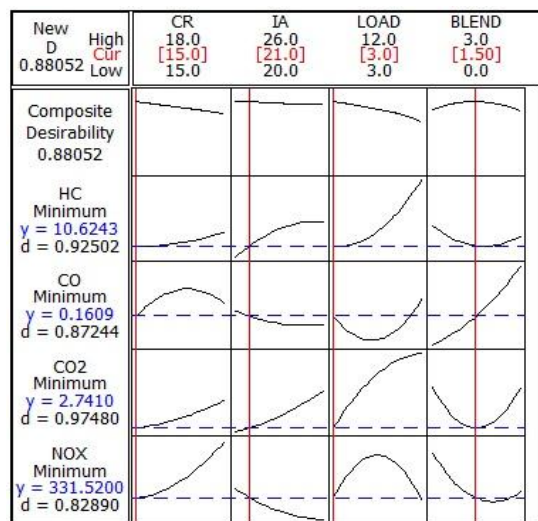


Fig.13 Optimizer plot

Figure- shows response optimizer plot for all the input parameters for minimum emission parameters. Highest desirability of 0.97 is obtained for CO₂,

followed by 0.92 for HC, 0.87 for CO and 0.83 for NO_x. Composite desirability of 0.88 is obtained for CR 15:1, IA 21° BTDC, Load 3kg and fish oil blend 22.5%. Confirmation experiment is conducted by setting the optimal values of compression ratio, injection timing, load and blend suggested by response optimizer plot. The fig.13 given below shows the predicted values of the input parameters Compression ratio, Injection advance, Load, Fish oil Blend for minimum emission parameters HC, CO, CO₂ and NO_x with their desirability.

Table 7 presents the comparison between modeled emission values and experimental emission values at CR 15, IA 21° BTDC, Load 3kg, Fish oil blend 22.5%.

Table 7 Predicted and experimental emissions

Emission	Predicted	Experimental
HC	10.62	11
CO	0.1609	0.11
CO ₂	2.74	2.97
NO _x	331.52	399

Conclusions

The following are the conclusions drawn after performing the several tests in a single cylinder diesel engine by varying the compression ratio, injection timing, load and fish oil blend.

- 1) The statistical analysis helped to identify the significant parameters which are most influencing the emission characteristics. This experimental design remarkably saved the time required by minimizing the number of experiments to be performed and provided statistically proven models for all the responses.
- 2) Advancing the injection timing from 20° BTDC to 26° BTDC helped to reduce the HC, CO and CO₂.
- 3) Increasing the % of fish oil blend up to B2 (30%) contributed to lower down the emission parameters HC, CO, CO₂ and NO_x.
- 4) At moderate load all the blends of fish oil resulted in minimum CO emissions.
- 5) Desirability approach of the response surface method was the simplest approach. The desirability of 0.88 is obtained at optimum operating parameters viz. compression ratio 15, injection timing 21° BTDC, Load 3kg, fish oil blend 22.5% and the values of HC, CO, CO₂ and NO_x emissions are 10.62ppm, 0.16%, 2.74%, 331.52ppm respectively.
- 6) The entire experimentation is carried out at 95% confidence interval
- 7) It is observed during performance characteristics analysis that amongst the selected input parameters load is most significant, the significance is so strong that it was difficult to identify effect of other input parameters on performance parameters like brake power, brake thermal efficiency and brake specific fuel consumption. In this work optimization of performance characteristics will be carried out at full load condition using same methodology.

References

- Vanessa F. de Almeida, Pedro J. García-Moreno, Antonio Guadix, Emilia M. Guadix, (2015) Biodiesel production from mixtures of waste fish oil, palm oil and waste frying oil: Optimization of fuel properties. *Fuel Processing Technology*, 133, 152-160.
- Gislaine Iastiaque Martins, Deonir Secco, Helton Aparecido Rosa, Reinaldo Aparecido Bariccatti, Bruna Dresch Dolci, Samuel Nelson Melegari de Souza, Reginaldo Ferreira Santos, Tiago Roque Benetoli da Silva, Flavio Gurgacz., (2015), Physical and chemical properties of fish oil biodiesel produced in Brazil. *Renewable and Sustainable Energy Reviews*, 42, 154-157.
- Mohammed Takase, Ting Zhao, Min Zhang, Yao Chen, Hongyang Liu, Liuqing Yang, Xiangyang Wu., (2015), An expatiated review of neem, jatropha, rubber and karanja as multipurpose non-edible biodiesel resources and comparison of their fuel, engine and emission properties. *Renewable and Sustainable Energy Reviews*, 43, 495-520.
- Apaslan Atmanli, Bedri Yüksel, Erol İleri, A. Deniz Karaoglan., (2015), Response surface methodology based optimization of diesel-n-butanol - cotton oil ternary blend ratios to improve engine performance and exhaust emission characteristics. *Energy Conversion and Management*, 383-394.
- G. Sakthivel, G. Nagarajan, M. Ilankumaran, Aditya Bajirao Gaikwad, (2014), Comparative analysis of performance, emission and combustion parameters of diesel engine fuelled with ethyl ester of fish oil and its diesel blends. *Fuel*, 132, 116-124.
- Luka Lešnik, Jurij Iljaz, Aleš Hribernik, Breda Kegl, (2014), Numerical and experimental study of combustion, performance and emission characteristics of a heavy-duty DI diesel engine running on diesel, biodiesel and their blends. *Energy Conversion and Management*, 81, 534-546.
- Pedro J. García-Moreno, Mohriam Khanum, Antonio Guadix, Emilia M. Guadix, (2014), Optimization of biodiesel production from waste fish oil. *Renewable Energy*, 68, 618-624.
- Kwon Hong, Jung Woo Park, Seung Bum Lee, (2013), Optimization of fish-oil-based biodiesel synthesis. *Journal of Industrial and Engineering Chemistry*, 19, 764-768.
- D.C. Rakopoulos, (2013), Combustion and emissions of cottonseed oil and its bio-diesel in blends with either n-butanol or diethyl ether in HSDI diesel engine. *Fuel*, 105, 603-613.
- R. Yahyaee, B.Ghobadian, G.Najafi, (2013), Waste fish oil biodiesel as a source of renewable fuel in Iran. *Renewable and Sustainable Energy Reviews* 17, 312-319.
- Probir Kumar Bose, Madhujit Deb*, Rahul Banerjee, Arindam Majumder, (2013), Multi objective optimization of performance parameters of a single cylinder diesel engine running with hydrogen using a Taguchi-fuzzy based approach. *Energy*, 375-386.
- Hornng-Wen Wu, Zhan-Yi Wu, (2013), Using Taguchi method on combustion performance of a diesel engine with diesel/biodiesel blend and port-inducting H₂. *Applied Energy*, 362-370.
- C. Swaminathan, J. Sarangan, (2012), Performance and exhaust emission characteristics of a CI engine fueled with biodiesel (fish oil) with DEE as additive. *Biomass and bioenergy*, 39, 168-174.
- Hornng-Wen Wu, Zhan-Yi Wu, (2012), Combustion characteristics and optimal factors determination with Taguchi method for diesel engines port-injecting hydrogen. *Energy*, 411-420.
- Rasim Behçet, (2011), Performance and emission study of waste anchovy fish biodiesel in a diesel engine. *Fuel Processing Technology*, 92, 1187-1194.
- Kian Fei Yee, Keat Teong Lee, Riccardo Ceccato, Ahmad Zuhairi Abdullah, (2011), Production of biodiesel from *Jatropha curcas* L. oil catalyzed by SO₂₄ /ZrO₂ catalyst: Effect of interaction between process variables. *Bioresource Technology*, 102, 4285-4289.
- M. Pandian, S.P. Sivapirakasam, M. Udayakumar, (2011), Investigation on the effect of injection system parameters on performance and emission characteristics of a twin cylinder compression ignition direct injection engine fuelled with pongamia biodiesel-diesel blend using response surface methodology. *Applied Energy*, 2663-2676.
- Sharanappa Godiganur, Ch. Suryanarayana Murthy, Rana Prathap Reddy, (2010), Performance and emission characteristics of a Kirloskar HA394 diesel engine operated on fish oil methyl esters. *Renewable Energy*, 35, 355-359.
- Niraj Kumar, Varun and Anoop Kumar, (2010), Biodiesel as an alternative fuel for CI engines: environmental effect. *Indian Journal of Science and Technology*, 3, 602-606.
- Jibrail Kansedo, Keat Teong Lee, Subhash Bhatia, (2009), Cerbera odollam (sea mango) oil as a promising non-edible feedstock for biodiesel production. *Fuel*, 88, 1148-1150
- V.R. Wiggers, A. Wisniewski Jr., L.A.S. Madureira, A.A. Chivanga Barros, H.F. Meier, (2009), Biofuels from waste fish oil pyrolysis: Continuous production in a pilot plant. *Fuel*, 88, 2135-2141.
- Cherng-Yuan Lin, Rong-Ji Li, (2009), Engine performance and emission characteristics of marine fish-oil biodiesel produced from the discarded parts of marine fish. *Fuel Processing Technology*, 90, 883-888.
- T. Ganapathy, K. Murugesan, R.P. Gakkhar, (2009), Performance optimization of *Jatropha* biodiesel engine model using Taguchi approach. *Applied Energy*, 2476-2486.
- Fernando Preto, Frank Zhang, Jinsheng Wang, (2008), A study on using fish oil as an alternative fuel for conventional combustors. *Fuel*, 87, 2258-2268.