International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.8, No.12 pp 569-575, 2015

Meta Modeling Of Emission Parameters Of Refined Corn Methy Esters In 4s Diesel Engine Using Response Surface Methodology

Hemanandh J., Narayanan K.V.

Department of Mechanical Engineering, Sathyabama University, Chennai, TamilNadu, India.

Abstract: This paper presents the mathematical modeling for the design parameters of Injection timing (Ti), Injection pressure (Pi), and blend ratio of the Kirloskar, single cylinder, 4.3 kW, 4S , direct ignition, air cooled, vertical, constant speed, stationary engine, for the compression ratio 17.5:1, at full load condition. The transesterified, refined corn oil methyl esters were used as the fuel and compared with petro diesel. The fatty acid methyl esters of refined corn oil were blended with diesel in different proportions and used as the fuel. The injection pressure, injection timing, and blend ratio were considered as input parameters and CO and HC were the output parameters. The Analysis of Variance (ANOVA) and regression analysis were used to predict the response parameters. The mathematical model to predict the responses of CO and HC was developed. The models were developed and compared with R-squared value.
Keywords: Refined Corn oil methyl esters, 4S – Diesel Engine, Emissions, L_{27} model, Response Surface Methodology.

1.0 Introduction:

The resources of petroleum are getting reduced day by day. Increasing demand of fuels as well as increasing stringent regulations have necessitated the search for alternative fuels. With the commercialization of bioenergy, it has provided an effective way to fight against the problem of petroleum scarcity and its bad influence on environment. Biodiesel as an alternative fuel for diesel is also called Ethyl or butyl or fatty acid methyl esters that can be obtained from agricultural feed stocks, vegetable oils or animal fats. McCarthy et al., [1] found the usage of bio-diesels in Internal Combustion engines causing reduction of performance and increase in fuel consumption, when the blend ratio increased. The emissions of bio-diesels were found to be higher for some gases, and lower for some others. Qi et al., [2] investigated the use of Soyabean crude oil, ~~as~~ a biodiesel prepared from alkaline catalyzed transesterification. Its properties were compared, and the Brake Specific Fuel consumption was found to be higher than that of diesel, due to the biodiesel's lower heating value. Yousef Haik et al., [3] showed that the use of raw Algae oil and methyl esters could run the IC engine smoothly, though it caused an increase in the combustion noise and a reduction in the engine output. This can be reduced by varying the injection timing and compression ratio. Sukumar Puhan et al., [4] conducted the fuel analysis of vegetable oil Biodiesel (93% unsaturated fatty acid); it resulted in higher emission of oxides of nitrogen and increased thermal efficiency (29.76%), compared with the diesel fuel. Ismet Celikten et al.,[5] studied the performance and emission by using Rapeseed oil and Soyabean oil methyl esters and observed that they were the same as those of diesel fuel when injection pressure was as high as 300 bar. When injection pressure was increased, the power, output and emission of NOx increased, whereas CO and smoke decreased. Jinlin Xue et al., [6] found that biodiesel and the blends of biodiesels could be used as alternative fuel instead of diesel without any engine modifications due to their reduced emission, lower heating value, and improved thermal efficiency. Marcelo J et al., [7] employed the Analysis of Cast Iron and Aluminum pistons and showed that Aluminum pistons reached the steady state faster and underwent lower temperature, lower temperature gradients and lower thermal stresses than Cast Iron pistons. Osmano Souza Valente et al., [8] performed a comparative study of Soyabean oil biodiesel and Castor oil biodiesel and showed that Soyabean oil caused lower fuel consumption, higher CO, and HC emission at increased loads, and similar CO_2 emission. Hemanandh and Narayanan [9] studied the brake specific fuel consumption and the brake thermal efficiency by modeling and analyzing using R –squared value. Kaliamoorthy and paramasivam [10] used Taguchi based design of experiments and found that 20% karanja biodiesel was suitable for diesel engine at 230 bar injection pressure and 27° injection timing at 70% of load.

2.0 Materials and Methods

The refined corn oil was purchased from the local market. The catalyst NaOH and methanol were procured from the suppliers. In the first phase, the fuel blends were prepared. In the second phase the injection pressure and injection timing at various levels were modified and the engine emissions were recorded.

2.1 Fuel Preparation:

The degummed refined corn oil was produced using transesterification process. 400 ml of methanol and 7% of sodium hydroxide were added with the vegetable oil and stirred for 15 minutes. The refined corn oil mixture was heated up to 70 ºC to 80 ºC for 1 hour at a constant speed of 200rpm. The oil colour turned to red orange. The mixture was allowed to cool at room temperature in the separator for 24 hours. Three layers were formed: biodiesel (methyl esters), methanol, and glycerol. The methyl esters were separated from the separator and washed with distilled water to reduce the impurities in the esters and hence pure methyl esters could be obtained. The biodiesel was blended with diesel in various proportions such as B10, B20, and B40 by volume.

2.2 Experimental Set-Up

The kirloskar 4S DI diesel engine with rated power of 4.3 kW, vertical, 4 stroke single cylinder, air cooled, with a compression ratio of 17.5:1 and a constant speed of 1500 rpm was used to conduct the experiment. The engine was run by the alternator that also loaded the engine. The BOSCH fuel injector was used to vary the injection pressure nozzle. The injection timing was adjusted by the number of shims in the mounting flange. The emission analysis was done by the AVL 5 gas analyzer. The engine was tested with the diesel fuel and with various blends of refined corn methyl esters at various injection pressures such as 180 bar, 210 bar, and 240 bar and various injection timings of 21^{o} BTDC, 24^{o} BTDC, and 27^{o} BTDC. The experiments were conducted 3 times and the average readings were recorded. The smoke meter AVL 437 C was used to measure the smoke. The emission values are given in Table.3.

The aim of the experiment was to analyze the emission characteristics of the refined corn oil methyl esters. The methyl esters were blended with diesel in different proportions. 10% of methyl esters was blended with 90% of diesel (B10), 20% of methyl ester was blended with 80% of diesel (B25), and 40% of methyl ester was blended with 70% of diesel (B40) on volume basis. The fuel properties are shown in Table.1.

Table.1: Specification Of Fuel Properties

S.No.	Property	Diesel	BIS Standard Bio Diesel	ASTM D – 6751 (IS 15607:2005)	Refined corn oil
1.	Cetane Index (min)	51	51	-	35
2.	Density at 15 ° (C) (kg / $m^{3)}$	820 – 845	860 – 900	860-900	923
3.	Kinematic Viscosity at 40 °(C) cst	2 – 4.5	2.5 – 6	1.9 – 6	5.02
4.	Flash point ° C min	35 ° C	262 ° C	130 ° C	162
5.	Calroific Value kJ/kg	42,000	-	-	36,824

3.0 Response Surface Methodology (RSM):

It is a tool used to study the modeling and to optimize the response parameters of the DI diesel engine. The input parameters are injection pressure, injection timing, and the blend ratio. The responses are CO and HC. The range of injection pressure, injection timing, and blend ratio was varied at 3 levels such as 180 bar, 210 bar, and 240 bar, 21° BTDC, 24° BTDC, 27° BTDC, and B10, B25, and B40. The modification was done to the permissible limit.

The orthogonal array design is shown in Table.3. The Taguchi method was used to design the L27 model. The aim of the response surface methodology was to optimize the model and response. Two degrees of freedom were used for three factors and three levels.

Table.2 : Input Parameters

S.No.	Notataion	Parameter	Levels		
			1	2	3
1.	IP	Injection Pressure (bar)	180	210	240
2.	IT	Injection timing (deg)	21	24	27
3.	BL	Blend Percentage (%)	10	25	40

Table.2 shows input parameters of the DI diesel engine. The injection pressure (IP), injection timing (IT), and the blend ratio (BL) were varied at two levels between (180 bar - 240 bar, 21° BTDC - 27° BTDC) and (B10 – B40). The orthogonal design matrix is given in the Table.3.

Table.3: L27 Orthogonal array Design Matrix

STD	Pi bar	Ti deg	Bl %	CO %	HC ppm
1	1	1	1	0.17	24
2	1	1	2	0.14	32
3	1	1	3	0.14	27
4	1	2	1	0.14	27
5	1	2	2	0.14	32
6	1	2	3	0.16	28
7	1	3	1	0.15	28
8	1	3	2	0.17	29
9	1	3	3	0.21	24
10	2	1	1	0.18	24
11	2	1	2	0.15	30
12	2	1	3	0.14	26
13	2	2	1	0.14	27
14	2	2	2	0.13	30
15	2	2	3	0.15	26
16	2	3	1	0.14	27
17	2	3	2	0.15	30
18	2	3	3	0.19	26
19	3	1	1	0.18	27
20	3	1	2	0.14	31
21	3	1	3	0.13	28
22	3	2	1	0.13	29
23	3	2	2	0.12	30
24	3	2	3	0.13	27
25	3	3	1	0.12	29
26	3	3	2	0.13	24
27	3	3	3	0.16	32

4.0 Results & Discussions

Model Analysis:

The quadratic model of the emissions was analyzed at 99% confidence interval. The results were validated using Analysis of Variance (ANOVA). The analysis of variance of the responses of the engine is given in Table - 4. The value of F is less than 0.05; hence the model is significant. The various response equations have been given in (1) & (2).

$$CO = +0.77488 + 4.68519E\text{-}003 * ip - 0.080093 * IT - 0.012160 * BL - 1.11111E\text{-}004 * ip * IT - 1.11111E\text{-}005 * ip * BL + 5.00000E\text{-}004 * IT * BL - 4.93827E\text{-}006 * ip^2 + 1.91358E\text{-}003 * IT^2 + 5.43210E\text{-}005 * BL^2 \quad (1)$$

$$HC = +3.24383 - 0.47315 * ip + 7.06481 * IT - 1.27840 * BL - 6.48148E\text{-}003 * ip * IT + 1.66667E\text{-}003 * ip * BL + 0.011111 * IT * BL + 1.41975E\text{-}003 * ip^2 - 0.11728 * IT^2 + 0.010864 * BL^2 \quad (2)$$

Table.4: Analysis Of Variance (ANOVA) for CO and HC:

Source	Sum of Squares		Df		Mean Square		F- Value		P-Value, PROB > 1		
	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	
Model	0.0125	144.5	9	9	0.0013	16.06	307.4	300.79	< 0.0001	< 0.0001	significant
A-ip	0.0018	1.388	1	1	0.0018	1.389	398.2	26.02	< 0.0001	< 0.0001	
B-B	0.0001	20.05	1	1	0.0001	20.06	30.72	375.73	< 0.0001	< 0.0001	
C-E	0.0002	56.88	1	1	0.0002	56.89	44.24	1065.79	< 0.0001	< 0.0001	
AB	0.0012	4.083	1	1	0.0012	4.083	265.4	76.5	< 0.0001	< 0.0001	
AC	0.0003	6.75	1	1	0.0003	6.75	66.36	126.45	< 0.0001	< 0.0001	
BC	0.0060	3	1	1	0.0060	3	1344	56.20	< 0.0001	< 0.0001	
A2	0.0001	9.7963	1	1	0.0001	9.796	26.22	183.53	< 0.0001	< 0.0001	
B2	0.0017	6.6852	1	1	0.0017	6.685	393.7	125.2449	< 0.0001	< 0.0001	
C2	0.000896	35.852	1	1	0.0008	35.85	198.3	671.6735	< 0.0001	< 0.0001	
Residual	7.69E-05	0.9074	17	17	4.52E-06	0.053					
Cor Total	0.0125	145.41	26	26							

Table.5: Response surface method of evaluation:

Model	F- value	Mean	Std. dev.	Model degree	R^2	Adj R^2	Pred R^2	Adeq Precision
CO	206.05	9.32E-04	2.13-03	Quadratic	0.9939	0.9907	0.9907	71.915
HC	326.8163	1.74E+01	0.23103	Quadratic	0.9938	0.9905	0.9854	59.269

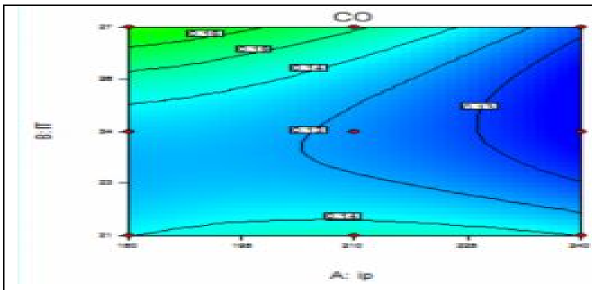


Fig – 1(a) Contour Plot of CO between Injection Pressure and InjectionTiming

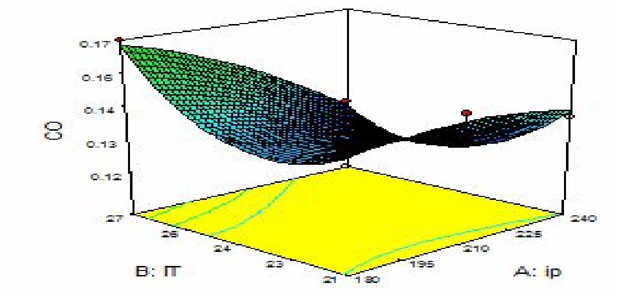


Fig – 2(a) 3D Surface Plot Variation of CO between Injection Pressure and InjectionTiming

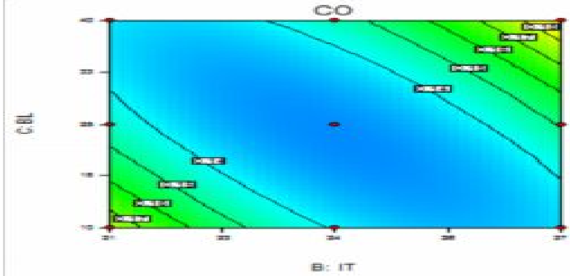


Fig – 1 (b) Contour Plot of CO between Injection Timing and Blend

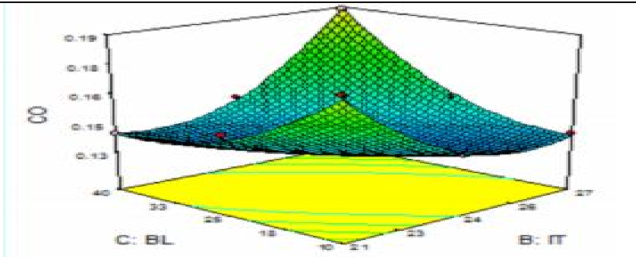


Fig – 2(b) 3D Surface Plot Variation of CO between Blend and InjectionTiming

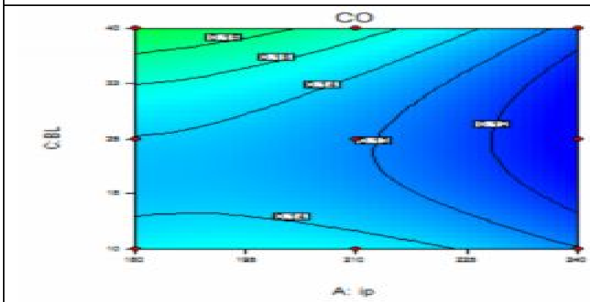
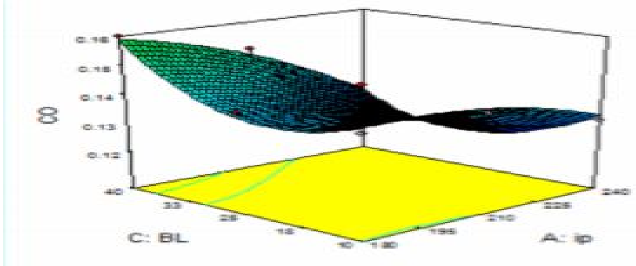


Fig – 1(c) Contour Plot of CO between Injection Pressure and Blend



FFig – 2(c) 3D Surface Plot Variation of CO between Injection Pressure and InjectionTiming

Fig.1 and Fig. 2: 2D Contour Plot and Surface Plot Variation for CO between Injection Pressure, Injection Timing, and Blend

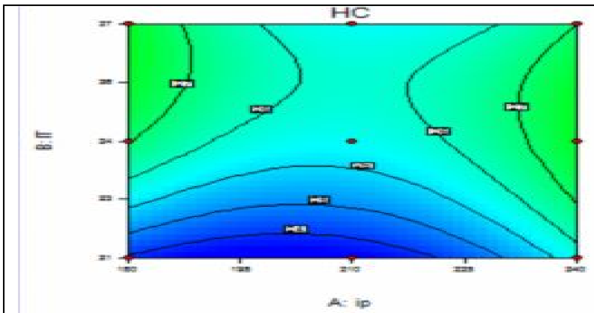


Fig – 3 (a) Contour Plot of HC between Injection Pressure and Injection Timing

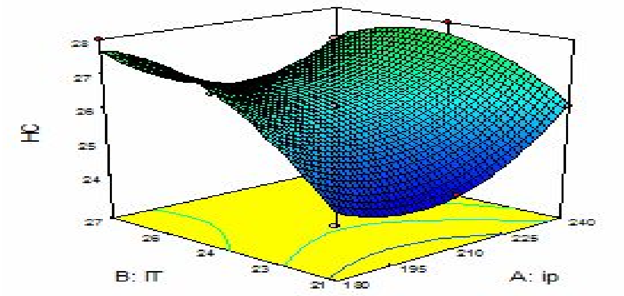


Fig – 4 (a) 3D Surface Plot Variation of HC between Injection Pressure and Injection Timing

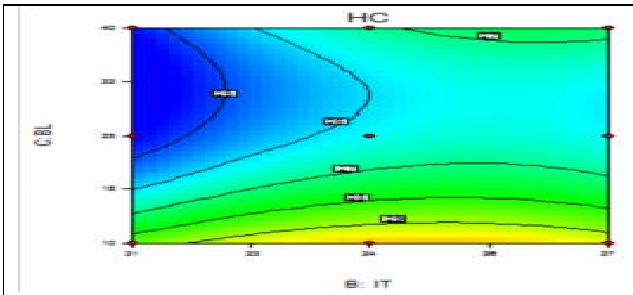


Fig – 3(b) Contour Plot of of HC between Injection Pressure and blend

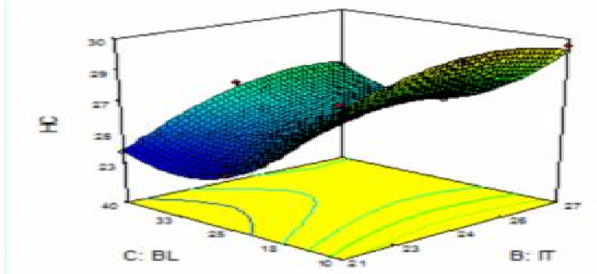


Fig – 4(b) 3D Surface Plot Variation of HC between Injection Timing and Blend

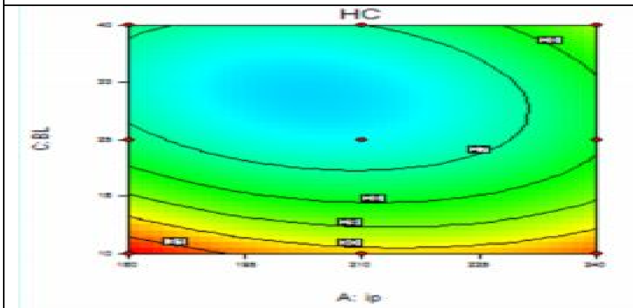


Fig – 4(c) Contour Plot of of HC between Injection Pressure and blend

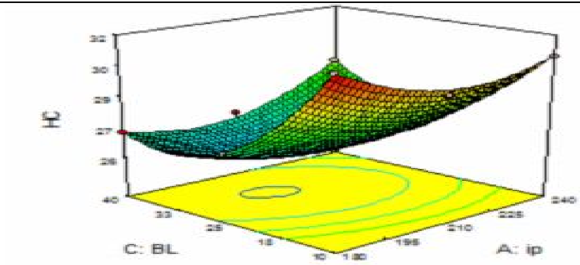
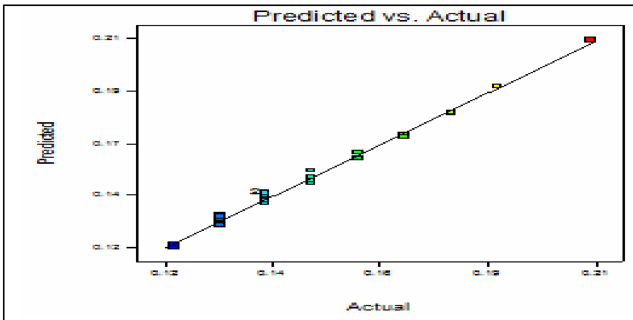
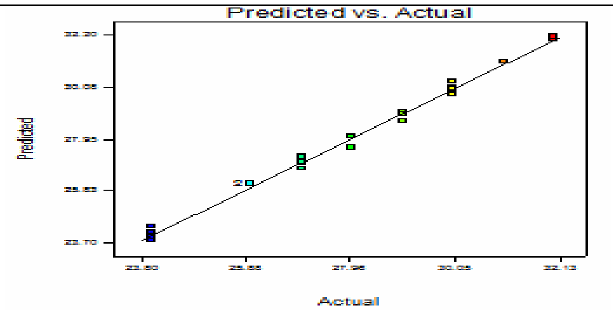


Fig – 4(c) 3D Surface Plot Variation of HC between Injection Pressure and blend

Fig. 3 and Fig – 4: 2D Contour Plot and 3D Surface Plot Variation for BSFC and BTE between Injection Pressure and Blend



CO



HC

Fig – 5: Predicted Vs Actual values of CO and HC for Injection Pressure, Injection Timing, and Blend

4.1 Carbon mono oxide emission model (CO):

Table.4 gives the most significant model terms of injection pressure, injection timing and the blend ratio. The interaction between the injection pressure, injection timing and the blend ratio for the CO in contour plot and surface plot is shown in Fig -1 and Fig. 2. The predicted R^2 of 0.9939 is close to adjusted R^2 0.9907 as given in Table.5. Hence the model is valid. Figs.1 (a-c) and Figs.2 (a-c) show the contour and response surface plot of CO emission model for injection pressure and injection timing, injection pressure and blend, and injection timing and blend. It is observed from the plot that the advance in injection timing and increase in injection pressure cause decrease in CO at 240 bar, 27° BTDC and at B25 blend. This could be due to the oxygen content in the fuel and good spray characteristics that improve combustion.

4.2 Hydrocarbon model (HC):

The response surface plot of the HC is shown in Fig. 3. The interaction between the injection pressure, injection timing, and blend ratio for HC is shown in Figs. 3(a-c) and Figs. 4(a-c). From Table.4 it is observed that the predicted R^2 (0.9938) is close to Adjusted R^2 value (0.9905) implying that the validation of the model is correct. It is observed from Figs.3 (a-c) and Figs. 4 (a-c) shows that the HC increases at higher blends when the injection pressure and the injection timing advance. The HC decreases at B25 blend at higher injection pressure and injection timing. This may be due to the higher calorific value in the fuel. The predicted and actual values are shown in Fig.5.

5.0 Conclusion:

The empirical model has been developed to analyze the factors of CO and HC which have influence on the diesel engine.

1. The Mathematical model has been developed using ANOVA to predict the effects of emissions in the diesel engine.
2. The predicted values of the CO and HC at any combination are in the range of variables. Hence the model is good.

6.0 References

1. Rajesh MG, Latha MS. Priliminary evaluation of the antihepatoprotective activity of Kamilari, a polyherbal formulation. J Ethnopharmacol., 2004, 91; 99-104
2. McCarthy .P, Rasul. M.G, Moazzem.S, Analysis and comparison of performance and emissions of an internal combustion engine fuelled with petroleum diesel and different bio-diesels. Fuel, 2011, 90, 1-11.
3. Qi D.H, Geng L.M., Chen .H, Bian .Y.ZH, Liu.J, Ren X.CH. Combustion and performance evaluation of a diesel engine fueled with biodiesel produced from soybean crude oil. Renewable Energy, 2009, 34, 1-8.
4. Yousef Haik, Mohamed Y.E. Selim, Tahir Abdulrehman. Combustion of Algae oil methyl ester in an indirect injection diesel engine. Energy, 2011, 36; 1-9.
5. Sukumar Puhan, A. Gopinath, G. Nagarajan.. Combustion, performance and emission characteristics of a DI CI engine using biodiesel with varied fatty acid composition. Int. J. Renewable Energy Technology, 2009, 1, 1-20.
6. Ismet Celikten, Atilla Koca, Mehmet Ali Arslan, Comparison of performance and emissions of diesel fuel, rapeseed and soybean oil methyl esters injected at different pressures. Renewable Energy, 2010, 35; 1-7
7. Jinlin Xue, Tony E. Grift, Alan C. Hansen. Effect of biodiesel on engine performances and emissions, Renewable Energy, 2011, 15; 1-19.
8. Marcelo J. Colaco, Claudio V. Teixeira, Luciana M. Dutra, Thermal analysis of a diesel engine operating with diesel-biodiesel blends. Fuel, 2010, 89, 1-11.
9. Osmano Souza Valente, Marcio Jose da Silva, Vanya Marcia Duarte Pasa, Carlos Rodrigues Pereira Belchior, Jose Ricardo Sodre. Consumption and emissions from a diesel power generator fuelled with castor oil and soybean biodiesel. Fuel, 2010, 89; 1-6
10. Hemanandh .J and Narayanan K.V. Performance Modeling of Refined Corn Oil in Direct Ignition Diesel Engine Using Response Surface Methodology, American-Eurasian J. Agric. & Environ. Sci., 2015,15, 497-503.
11. Sivaramakrishnan Kaliamoorthy, and Ravikumar Paramasivam, Investigation on performance and emissions of a biodiesel engine through optimization techniques. Thermal Science, 2013, 17, 179-193.

*****

****