INVESTIGATION ON PERFORMANCE AND EMISSIONS OF A BIODIESEL ENGINE THROUGH OPTIMIZATION TECHNIQUES

by

Sivaramakrishnan KALIAMOORTHY[a]*, and Ravikumar PARAMASIVAM[b]

[a] Department of Mechanical Engineering, Anjalai Ammal Mahalingam Engineering College, Kovilvenni, and Research Scholar Anna University, Chennai, Tamil Nadu, India
[b] Principal St. Joseph College of Engineering and Technology, Thanjavur, Tamil Nadu, India

Original scientific paper
DOI: 10.2298/TSCI120105151K

The study is aimed at investigating the effects of engine parameters on the performance and emission characteristics of a single cylinder 5.2 kW diesel engine. The experiments were designed using a statistical tool known as design of experiments based on Taguchi. Five parameters, namely, power, static injection pressure, injection timing, fuel fraction, and compression ratio were varied at four levels and the responses brake power, fuel economy, and emissions were investigated. The optimum values of the response could be predicted using signal – noise ratio and optimum combination of control parameters were specified. Results of confirmation tests showed good agreement with predicted quantities. A compression ratio of 17.7, blend of 20% karanja biodiesel, an injection pressure of 230 bar, injection timing of 27° before top dead centre and at 70% load were found to be optimal values for the karanja biodiesel blended diesel fuel operation in the test engine.

Key words: *karanja biodiesel, engine parameters, design of experiment*

Introduction

The tremendous growth of vehicular population of the world has led to a steep rise in the demand for petroleum products. Biodiesel such as jatropha, karanja, sunflower, rapeseed, are some of the popular biodiesel currently considered as substitute for diesel. These are clean burning, renewable, non-toxic, biodegradable, and environmentally friendly transportation fuels that can be used in neat form or in blends with petroleum derived in diesel engines. Vegetable oils performance is similar to that obtained with diesel oil as per the experiments carried out by many research workers. Vegetable oil esters particularly karanja appear to be best alternative fuel to diesel.

When biodiesel is used as a substitute for diesel, it is highly essential to understand the parameters that affect the combustion phenomenon which will in turn have direct impact on thermal efficiency and emission. In the present energy scenario lot of efforts is being focused on improving the thermal efficiency of internal combustion (IC) engines with reduction in emissions [1-3].

Direct injection diesel engines occupy an important place in the developing countries since they power agricultural pumps, small power tillers, light surface transport vehicles and other machineries. The problem of increasing demand for high brake power and the fast depletion of the fuels demand severe controls on power and a high level of fuel economy. Many innovative technologies are developed to tackle these problems. Modification is required in the ex-

* Corresponding author; e-mail: sivaporkodi2000@yahoo.co.in

isting engine designs. Some optimization approach has to be followed so that the efficiency of the engine is not comprised. As far as the IC engines are concerned the thermal efficiency and emission is the important parameters for which the other design and operating parameters has to be optimized. The most common optimization techniques used for engine analysis are response surface method, grey relational analysis [4], non-linear regression [5], genetic algorithm [6], and Taguchi method, Taguchi technique has been popular for parameter optimization in design of experiments.

Design of experiments (DOE) has introduced the loss function concept which combines cost, target and variations into one metric. The signal to noise ratio (S/N) is a figure of merit and relates inversely to the loss function. It is defined as the ratio of the amount of energy for intended function to the amount of energy wasted [7].

Orthogonal arrays are significant parts of Taguchi methods. Instead of one factor at a time variation all factors are varied simultaneously as per the design array and the response values are observed. It has the ability to evaluate several factors in a minimum number of tests. DOE approach is cost effective and the parameters are varied simultaneously and then through statistical analysis the contribution of individual parameters towards the response value observed also could be found out. The engine operating parameters play an important role to reduce the emissions the design and operating parameters are the main factors responsible for the engine emissions and fuel economy. The fuel injection parameters like injection valve opening pressure and the compression ratio (CR) also have influence on emissions and fuel economy. In this work DOE approach is used to find the effect of design and operating parameters on brake power and specific fuel consumption (BSFC).

The effect of the parameters – injection pressure (IP), CR, load and engine speed on brake power, and smoke were investigated [8]. An increase in IP contributes to fuel economy by improved mixing [9]. Simultaneous reduction of NO_x and particulate emissions were reported by combining the varying CR and retarded injection timing (IT) [10]. Optimal combination of design and operating parameters were identified that can regulate emissions and improve BSFC. For identifying the optimal combination of injection schedule and fuel spray cone angle, genetic algorithm process was used [11]. The effect of changes in the operating parameters like, piston to head clearance, IP, start of IT on emissions were studied using Taguchi design of experiment methods. This method was found to be useful for simultaneous optimization [12]. It has been observed that among the various factors relevant to diesel combustion, fuel injection plays a major role in the fuel air mixing and combustion process thus determining the exhaust emissions [13]. It was also observed that the IT and injection rate play a major role in brake power advancing the IT by 3° CA for B20 fuel has given better performance and emissions [14]. Using design of experiment method and factorial design the percentage contributions of the effect of parameters-speed, load, IT plunger diameter, nozzle valve opening pressure, nozzle hole diameter, number of nozzle holes, and nozzle tip protrusion were investigated on engine noise, emissions, and BSFC [15].The IT plays an important role in determining engine performance, especially pollutant emissions[16]. Without considering the combustion parameters engine design and operating parameters can be optimized and engine efficiency can be increased by applying Taguchi method [17]. It is known from DOE procedure that for five parameters with four levels, the number of trial runs will be 625. In this present work an attempt is made to carry out an optimization analysis of direct injection diesel engine run by karanja biodiesel using a model in combination with Taguchi method.

Implementation of biodiesel in India will lead to many advantages like green cover to waste land, support to agriculture, and rural economy and reduction in dependence on imported crude oil and reduction in air pollution [18].The Karanja plant having advantages namely; effectively yielding oilseeds from the third years onwards, rapid growth, easy propagation, life span of 40 years and suitable for tropical and subtropical countries like India [19].The maximum thermal efficiency for B20 (31.28%) was higher than that of diesel at full load using karanja oil [20]. It has been observed from the literature review, that both bio-diesel-diesel blends and operating parameters have lot of influence on engine performance, and exhaust emissions. But the effects of operating conditions such as IP, IT, CR on the engine performance, and exhaust emissions of a diesel engine using biodiesel have not been clearly studied. Therefore this focus of research is about modification on engine parameters for the best output using optimization techniques.

Experimental details and methodology

Fuel preparation

Pongamia biodiesel was prepared through transesterification process from pongamia oil which was extracted from the seeds of pongamia tree. The formation of methyl esters by transesterification of vegetable oil requires raw oil. 15% of methanol and 5% of sodium or potassium hydroxide on mass basis. However the transesterification process requires excess alcohol to drive the the reaction very close to completion. A reaction time of 45 min to an hour and reaction temperatures of 55-65 °C were required for completion of reaction and formation of esters. The mixture was stirred continuously and then allowed to settle under gravity in a separting funnel. Two distinct layers found after gravity in a settling for 24 hours. The upper layer was of ester and the lower layer was of glycerol. The lower layer was separated out and the separated ester was mixed with some distilled water to remove the catalyst present in ester and allowed to settle under gravity for another 24 hours. The catalyst not dissolved in water, which was separated and removed the moisture. The biodiesel thus produced through the above process was blended with diesel. The fuel blend was prepared just before commencing the experiments to ensure the mixture homogeneity. The properties of the fuel blend and diesel have been determined as per the ASTM standards in an analytical lab. The fatty acid composition and fuels properties were tested using standard measuring devices shown in tabs. 1, 2, and results are shown in tab. 3.

Table 1. Fatty acid composition of akranja oil

Fatty acid	Percentage
Palmitic acid	11.65
Stearic acid	7.50
Oleic acid	51.59
Linoleic acid	16.64
Eicosanic acid	1.35
Docosanoic acid	4.45
Tetracosanoic acid	1.09

Table 2. Measuring devices and test methods for measuring fuel properties

Properties	Measurement apparatus	Standard test method
Density	Hydrometer	ASTM D941
Flash & fire point	Penksy-Martens apparatus	ASTM D93
Calorific value	Bomb calorimeter	ASTM D240
Viscosity	Red wood viscometer	ASTM D445
Cetane number	Ignition quality tester	ASTM D613

Table 3. Properties of biodiesel-blends-karanja

Biodiesel	Kinematic viscosity [mm^{2}s^{-1}] ν	Heating value [MJkg^{-1}] HV	Flash point [°C] FP	Density [kgl^{-1}] ρ	Cetane number
B0	2.71	42.5	55	0.836	51.00
B20	4.01	41.5	65	0.849	51.70
B40	5.23	39.9	77	0.858	52.82
B60	6.72	38.7	88	0.862	53.15
B80	8.19	37.0	101	0.878	53.86
B100	9.60	35.9	114	0.900	54.53

Experimental set-up

The experimental set-up consists of a direct injection single cylinder four stroke cycle diesel engine connected to an eddy current type dynamometer for loading. It is provided with necessary instruments for pressure and CA measurements. These signals are interfaced to computer through engine indicator for P-θ and PV diagrams. Provision is also made for interfacing air flow, fuel flow, temperatures, and load measurements. This set-up has stand-alone panel box consisting of air-flow, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement details of the engine specification are shown in tab. 4. The signals from the combustion pressure sensor and the CA encoder are interfaced to a computer for data acquisition. The control module system was used to control the engine load, monitor the engine speed, and measure the fuel consumption. Windows based engine performance analysis software package "Engine soft" is provided for online performance evaluation. HC, CO, CO_2, and K (air surplus rate) NO_x emissions were measured with an infra red gas analyzer with an accuracy shown in tabs. 5 and 6.

Table 4. Engine specification

Make and model	Kirloskar model TV 1
Engine type	Single cylinder four stroke direct injection
Bore × stroke	87.5 × 110 mm
Maximum power output	5.2.kW at 1500 rpm
Displacement	661 cc
CR	17.5
Loading	Eddy current dynamometer, water cooling
Fuel injection	23 bTDC
Engine speed	1500 rpm
Software used	Engine soft
Governor type	Mechanical centrifugal type
Eddy current dynamometer	
Model	AG-10
Type	Eddy current
Maximum	7.5 kW at 1500-3000 rpm

Procedure

CR is altered by adding different number of gaskets between the cylinder head and the block since this method does not need major modification in the engine. In this study the number of gaskets has been increased from the original one to maximum modification of four gaskets.

Table 5. Exhaust gas analyzer specification

Measuring item	Measuring method	Measuring range	Resolution
CO	NDIR	0-9.99%	0.01%
HC	NDIR	0-5000 ppm	1 ppm
NO_x	Electrochemical	0-5000 ppm	1 ppm

Table 6. Accuracies of the measurements and the uncertainties in the calculated results

Fuel [g]	Accuracy = ±1 g
Time [s]	Accuracy = ±0.5%
Torque [Nm]	Uncertainty = ±1%
P [kW]	Uncertainty = ±1.41%

The static IT was altered by adjusting the number of shims under the seat of the mounting flange of the fuel pump. When the number of shims was added timing was retarded and *vice versa*. Procedure of measurement of static IT as follows: The tank is filled with the fuel in the tank is about 10 cm above the testing device. The TDC position is marked on the flywheel by bringing the position to the top most position of the cylinder .Then the flywheel is turned in anticlockwise direction till the fuel reaches the testing device. This operation is repeated to note down exactly the movement at which the fuel moves through the testing device hole by slowly rotating the flywheel and stopped immediately. Then the flywheel is brought back by 5 mm. This position is marked on the flywheel and that position is called as static IT, thus the static IT of the engine can be checked with the manufactures set value. Similar procedure is adopted to measure the static IT when the shims are added or removed to vary the timing in comparison with the original IT. The curvilinear distances on the flywheel are measured by using thread then the IT angle was calculated in relation with the original IT angle the accuracy of measurement will be 1°. Thickness of one shim, located in connection place between engine and fuel pump, is 0.20 mm and adding or removing one shim changes the IT 2°, this exercise was repeated five times to get the correct timings in terms of CA [21].

Variation of static IP is achieved by altering the spring stiffness of the nozzle. A provision is made with a bolt arrangement to alter the spring stiffness.

A separate loading unit is provided in the experimental set-up which controls the opposing current to the eddy current developed in the eddy current dynamometer. A dimmer stat is provided which varies the current and thus different load could be applied. As the test engine used is a constant speed engine the load test could be conducted from no load to full load only by varying the load torque. Hence it is considered as a test parameter.

Taguchi procedure

The Taguchi method provides simple and effective solutions for investigating the effect of parameters on the performance as well as in the experimental planning [22]. In this method, (*S/N*) ratio is used to represent a performance characteristic and the largest value of the *S/N* ratio is required. There are three types of *S/N* ratios: the-lower-the-better, the-higher-the better, and more-the-nominal-the-better.

The criteria for optimization of the response parameters was based on the smaller the better *S/N* ratio:

$$\frac{S}{N} = -10\log\left[\frac{1}{r}\sum_{i=1}^{r} y_i^2\right] \tag{1}$$

where y_i represents the measured value of the response variable *i*.

The *S/N* ratio with the higher – the-better characteristic can be expressed as:

$$\frac{S}{N} = -10\log\left[\frac{1}{r}\sum_{i=1}^{r} \frac{1}{y_i^2}\right] \tag{2}$$

where y_i represents the measured value of the response variable.

The negative sign is used to ensure that the largest value gives an optimum value for the response variable and therefore robust design.

Experimentation and analysis

Selection of control parameters

The following control parameters as given in tab. 7. Were selected for the investigation since they have influence on the objectives of improving brake power and fuel economy. More parameters are related to the fuel injection and these parameters were found to be suitable for the experiment and could be done with available engine configuration. Four levels were chosen for this investigation.

Table 7. Setting levels for design parameters

Controlled factors	Level 1	Level 2	Level 3	Level 4
A: compression ratio	17.5	17.7	17.9	18.1
B: Static injection pressure [bar]	230	220	210	190
C: Injection timing [bTDC]	23	25	27	29
D: Fuel fraction [%]	10	20	30	50
E: Power [kW]	3.64	4.16	4.68	5.2

Selection of orthogonal array

Orthogonal array (OA) is selected based on the minimum number of test runs to be conducted, which in turn depends on the degrees of freedom. The minimum of experiments can be found out using the relation $N = (L–1) P + 1$ where N is the total number of test runs, L – the number of levels, and P – the number of design and control parameters chosen. The OA facilities the experimental design process by assigning parameters to the appropriate columns. In this investigation there are five 4-level parameters and these arbitrarily called as parameters A, B, C, D, and E, to the columns 1, 2, 3, 4, and 5, respectively, for an L16 array. Sixteen trials of experiments are to be conducted, with the level of each parameter for each trial run as indicated on the array. The L16 orthogonal array is shown in tab. 8.

Setting optimum conditions and prediction of response variables

The next step in DOE analysis is determining optimal conditions of the control parameters to give the optimum responses. In this work the response variables to be optimized were brake thermal efficiency (BTHE) has to be maximized and BSFC and emissions to be reduced as much as possible. Hence the optimum parameter settings will be those that give maximum values of the BTHE and minimum values of BSFC, HC, and NO_x. The optimum settings of the parameters were achieved from the *S/N* tables of the control parameters.

The optimum value of response variable can be predicted using the additivity law:

$$OPT = T + \sum_{i=1}^{n}(X_i - T) \tag{3}$$

where T is the overall mean value of the output response variable for the test runs conducted and X_i – the design and control parameter value for the i level of the parameter X.

Results and discussions

Sixteen experiments, following the plan shown in tab. 8, were performed on the engine and the results were shown in tab. 9 and *S/N* ratio is calculated and shown in tab. 10.

Table 8. L16 OA

Run number	(A)	(B)	(C)	(D)	(E)
1	1	1	1	1	1
2	1	2	2	2	2
3	1	3	3	3	3
4	1	4	4	4	4
5	2	1	2	3	4
6	2	2	1	4	3
7	2	3	4	1	2
8	2	4	3	2	1
9	3	1	3	4	2
10	3	2	4	3	1
11	3	3	1	2	4
12	3	4	2	1	3
13	4	1	4	2	3
14	4	2	3	1	4
15	4	3	2	4	1
16	4	4	1	3	2

Table 9. Experimental results

Factors	Compression ratio	Static injection pressure [bar]	Injection timing	Fuel fraction [%]	Power [kW]	BSFC [kgkW^{-1}h^{-1}]	BTHE [%]	HC [ppm]	NO_x [ppm]
Run number	(A)	(B)	(C)	(D)	(E)				
1	17.5	230	23	10	3.64	0.25	34	30	1572
2	17.5	220	25	20	4.16	0.275	33	60	1300
3	17.5	210	27	30	4.68	0.31	28	74	1057
4	17.5	190	29	50	5.2	0.34	27	200	690
5	17.7	230	25	30	5.2	0.39	24	45	1606
6	17.7	220	23	50	4.68	0.31	29	46	1300
7	17.7	210	29	10	4.16	0.26	34	92	1122
8	17.7	190	27	20	3.64	0.27	33	73	627
9	17.9	230	27	50	4.16	0.31	30	40	1258
10	17.9	220	29	30	3.64	0.37	26	50	1100
11	17.9	210	23	20	5.2	0.27	34	123	1133

Table 9. (continuation)

Factors	Compression ratio	Static injection pressure [bar]	Injection timing	Fuel fraction [%]	Power [kW]	BSFC [kgkW^{-1}h^{-1}]	BTHE [%]	HC [ppm]	NO_x [ppm]
Run number	(A)	(B)	(C)	(D)	(E)				
12	17.9	190	25	10	4.16	0.26	35	134	662
13	18.1	230	29	20	4.16	0.3	30	33	1720
14	18.1	220	27	10	5.2	0.3	31	100	1300
15	18.1	210	25	50	3.64	0.32	29	41	800
16	18.1	190	23	30	4.68	0.35	27	260	625

Table 10. Calculated S/N ratio

Factors	BTHE	BSFC	HC	NO_x
Run number	*S/N* ratio			
1	30.63	12	–29.54	–63.90
2	30.37	11.37	–35.56	–62.27
3	28.94	10.17	–37.38	–60.48
4	28.63	9.37	–46.02	–56.77
5	27.60	8.17	–33.06	–64.11
6	29.25	10.17	–33.25	–62.27
7	30.63	11.70	–39.27	–60.99
8	30.37	11.37	–37.26	–55.95
9	29.54	10.17	–32.04	–61.99
10	28.30	8.63	–33.97	–60.83
11	30.63	11.37	–41.80	–61.08
12	30.88	11.70	–42.54	–56.41
13	29.54	10.45	–30.37	–64.71
14	29.83	10.45	–40.00	–62.27
15	29.25	9.89	–32.25	–58.06
16	28.63	9.11	–48.30	–55.91

Engine performance

Brake specific fuel consumption

Effect of CR. The variation in the BSFC of the engine is shown in fig. 1. As shown in the fig. 1 the BSFC increases with increase in biodiesel content in the blends. The best results were obtained at increased CR. The maximum percentage increase of BSFC from the overall mean is 4.9% when the CR is 18.1. This shows that increasing the CR had more benefits with biodiesel than with high speed diesel. Due to their low volatility and higher viscosity, biodiesel might be performing relatively better at higher CR.

Effect of IT. Retarding the start of the fuel delivery yields a reduction in peak combustion pressure and temperature. It can be seen when IT has been advanced from 23° to 29° bTDC of which 23° gives the best value. An increase in BSFC by 2.3%. Advancing the IT meant the combustion occurred earlier in the cycle and more fuel burnt bTDC and the peak pressure move closer to TDC. If the IT is advanced too much a 2% decrease from the overall mean value is observed .This is due to pressure and temperature in the cylinder might be too low to cause auto ignition.

Effect of nozzle pressure. The IP 230, 220, 210, and 190 bar were chosen to investigate their influence on BSFC. At high IP, the fuel coming out of the nozzle undergoes a throttling process and droplets end up almost in the vapour phase aiding very good combustion. There is

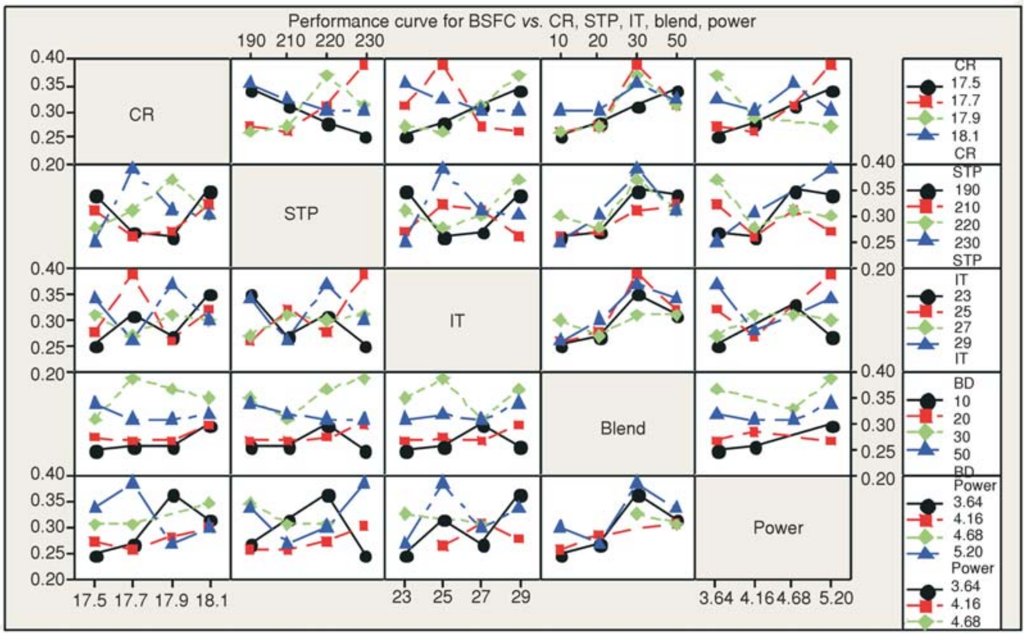

Figure 1. Performance curve for BSFC

an improvement in the BSFC. Thus it can be concluded that 210 bar has a little effect in improving fuel economy.

Brake thermal efficiency (BTHE)

Effect of CR. In general increasing the CR improved the efficiency of the engine. The mean BTHE of the engine increased by more than 6% when CR was raised from 17.5 to 18.1. This improved performance of the engine at higher CR may be due to reduced ignition delay. The CR 17.9 was to be best.

Effect of IT. It can be seen that BTHE increased with increase in IT in most cases. The mean BTHE was found to increase by 10% when IT was advanced from 23° to 29°. This improvement in thermal efficiency with injection advances could be due to the allowances provided by such advanced timings to the fuel quantities for proper combustion. Thus injection advance was found to have more effect on improvement of BTHE for the higher percentage of biodiesels in the blends.

Effect of nozzle pressure. The BTHE was found to decrease at maximum pressure 230 bar whereas at 210 bar it gives the maximum efficiency as shown in fig. 2. Compared to diesel fuel, the changes in BTHE of the engine for all fuel blends at different IP are depicted in fig. 2, it is minimum at 230 bar.

Hydro carbon

It is seen from fig. 3. There is a significant decrease in the HC emission level blends of methyl ester of karanja oil as compared to pure diesel. These reductions indicate that more complete combustion of the fuels and thus HC level decreases significantly. The reduction in HC emission was linear with the addition of biodiesel for the blends. Advanced injection and com-

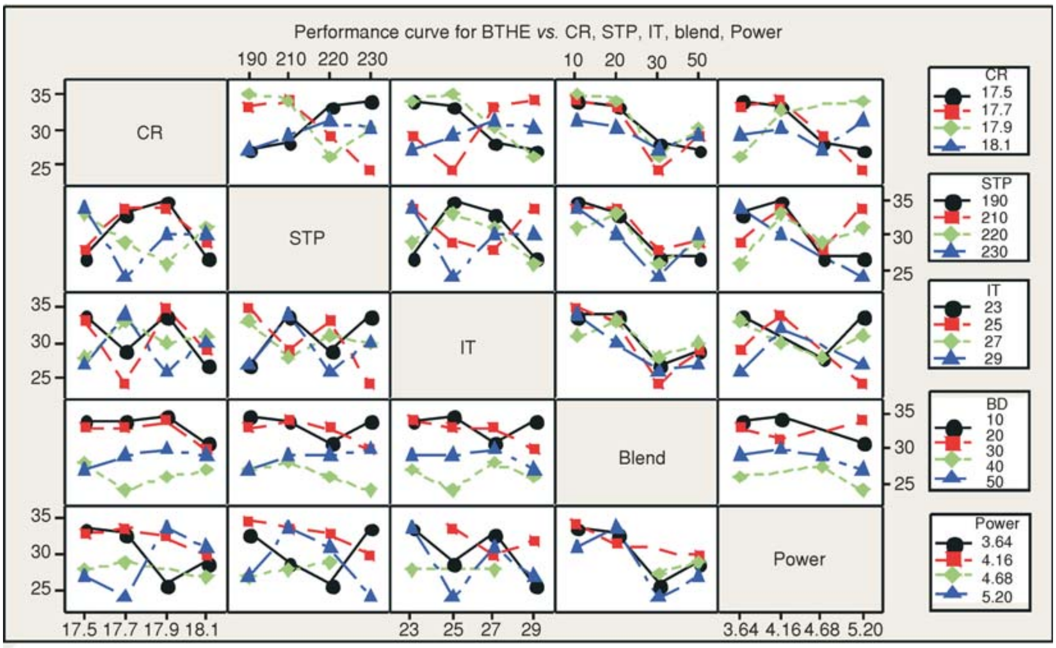

Figure 2. Performance curve for BTHE

bustion timing lower the HC emissions this is due to higher cetane number of biodiesel reduces the combustion delay and such a reduction has been related to decrease in HC emissions.

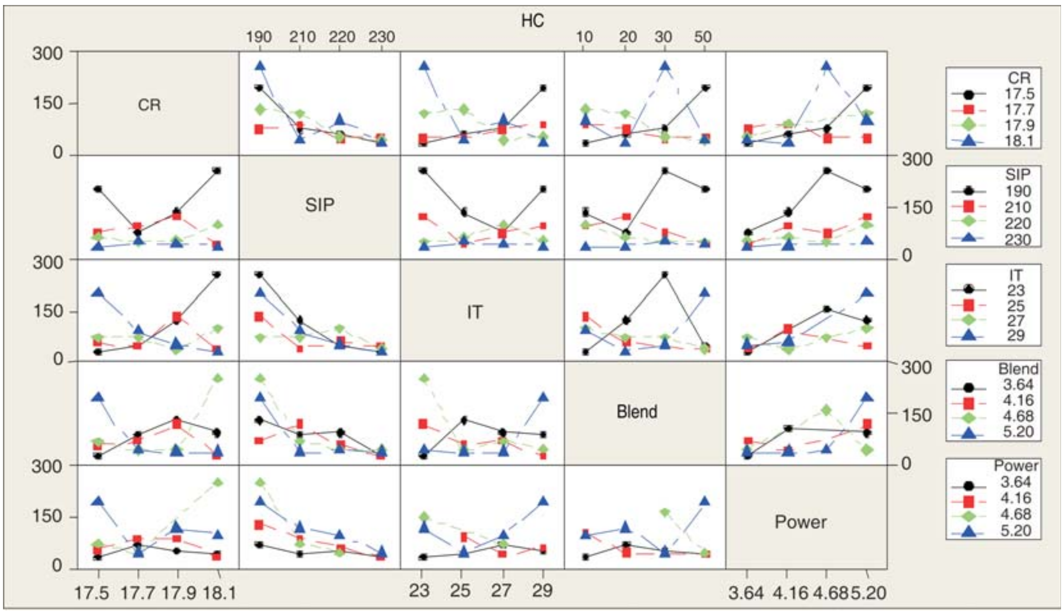

Figure 3. Hydro carbon emissions

Nitrogen oxides

The NO_x values for different fuel blends are shown in fig. 4. The amount of NO_x produced for B10 to B50 is in the range of 627-1730 ppm. It can been seen that the increasing proportion of biodiesel in the blends increases NO_x emissions as compared with diesel. This could be attributed to the increased exhaust gas temperatures and the fact that biodiesel had some oxygen content in it which promotes NO_x formation. In general the NO_x concentration varies linearly with the load of the engine. As the load increases the overall fuel –air ratio increases resulting in an increase in the average gas temperature in the combustion chamber and hence NO_x formation, which is sensitive to the temperature increase. During advancement of IT from 23° to 29° bTDC the NO_x emissions increased. This could be due to the following fact: in-cylinder charge temperature and pressure decreased with an advancement of the IT resulting in extended ignition delay of the injected fuel. Increasing the IP from 190-230 bar increases the NO_x formation.

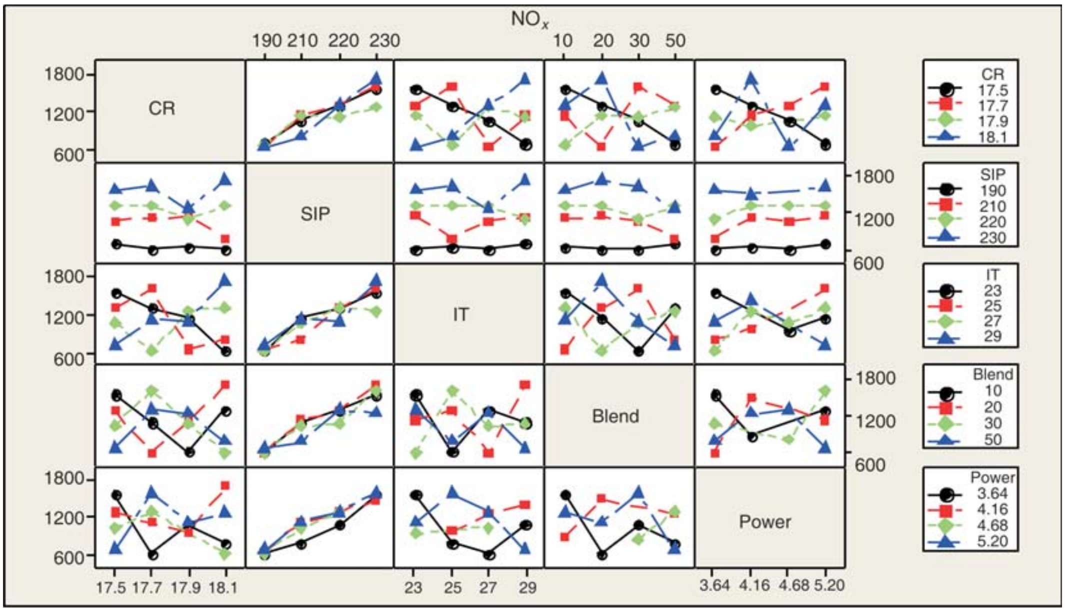

Figure 4. NO_x emissions

Optimal combination of engine performance parameters

BTHE

For the engine performance, the response variable BTHE was higher-the-better. The criteria for optimization of the response parameters was based on the Higher the better *S/N* ratio.

The experimental results were substituted in eq. (1). to calculate the *S/N* ratios for all response variables and it is shown in fig. 5.

From the value the optimization the engine parameters were obtained. CR-17.9, IP-210 bar, IT-23° bTDC, Blend –B10, Power –4.16 kW. From the eq. (3) the value of BTHE is calculated OPT BTHE = Ybar + (Abar3- Ybar) + (Bbar3- Ybar) + (Cbar1- Ybar) + (Dbar1- Ybar) + (Ebar2-Ybar). The value of BTHE is 37%.

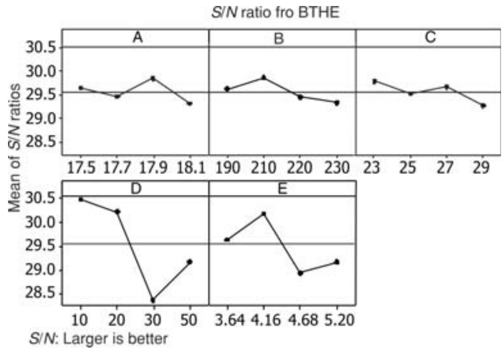

Figure 5. Shows the value of *S/N* ratio for BTHE

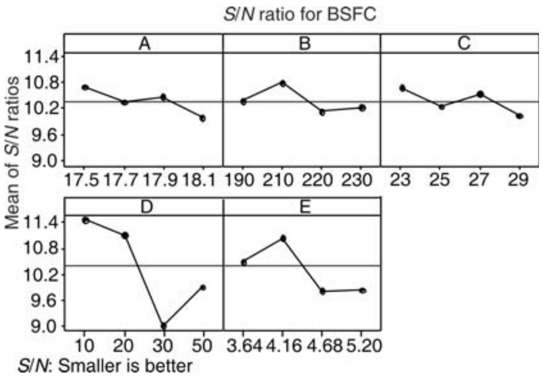

Figure 6. Shows the value of *S/N* ratio for BSFC

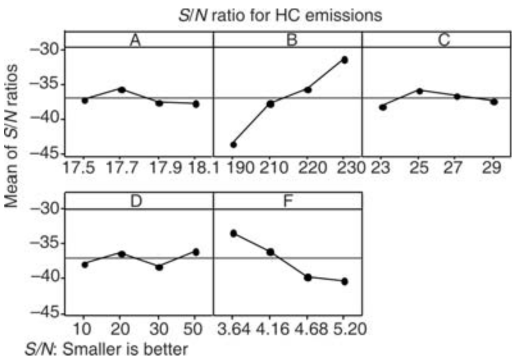

Figure 7. Shows the value of *S/N* ratio for HC

BSFC

The experimental results were substituted in eq. (2). To calculate the *S/N* ratios for all response variables and it is shown in fig. 6. From the value of optimization the engine parameters were obtained. CR-18.1, IP-220 bar, IT-29° bTDC, Blend –B30, Power –5.2 kW. From the eq. (3) the value of BSFC is calculated BSFC = Ybar + (Abar3-Ybar) + (Bbar1-Ybar) + (Cbar3--Ybar) + (Dbar4- Ybar) + (Ebar1-Ybar). The value of BSFC is 0.3107 kg/kWh.

Emissions HC

The experimental results were substituted in eq. (2). To calculate the *S/N* ratios for all response variables shown in fig 7. From the value the optimization of engine parameters were obtained CR-18.1, IP-190 bar, IT-23° bTDC, Blend –B30, Power 5.2 kW. The value of HC is 45 ppm.

Emissions NO_x

The experimental results were substituted in eq. (2). to calculate the *S/N* ratios for all response variables shown in fig. 8. From the value of optimization the engine parameters were obtained. CR-17.5, IP-230 bar, IT-29° bTDC, Blend –B20, Power 4.16 kW. The value of NO_x is 318 ppm.

Multi-optimization techniques

The single objective optimization gives different results and shown in tab. 11. To obtain an optimal combinations of engine parameters considering performance and emissions multi-optimization techniques is used. The weighting factor (*W*) of each response variable is given in tab. 12.

The sum of the *W* for all the response variables should be unity and the weighing factor for all of the response variables should be unity and the *W* assigned to each particular response variable is determined on the basis of its relative importance. In this present experimental work the *W* for each response variable assumed as given in tab. 12. The *W* plays a very important role in this type of analysis. For the output performance variables there are two parameters of engine performance and emissions. Equal weights were given to performance and emissions *i. e.* 0.5. The BTHE was more critical parameter therefore a *W* of 0.3 was assigned and a value of 0.2 for BSFC amongst the two emission vari-

ables a (W) of 0.25 for NO_x and HC. The experimental results were used to calculate S/N ratios for all the response variables.
The S/N ratios is calculated using the equation:

$$S/N = W1\ SN1 + W2\ SN2 + W3\ SN3 + W4\ SN4 \quad (4)$$

Using eq. (4) it can be observed that A2, B1, C3, D2, and E1, *i. e.* CR – 17.7, IP – 230 bar, IT – 27° bTDC, B20, and BP – 3.64 kW is the optimal combination which achieves multiple – performance characteristics of the engine. The values of response variable are shown in tab. 13.

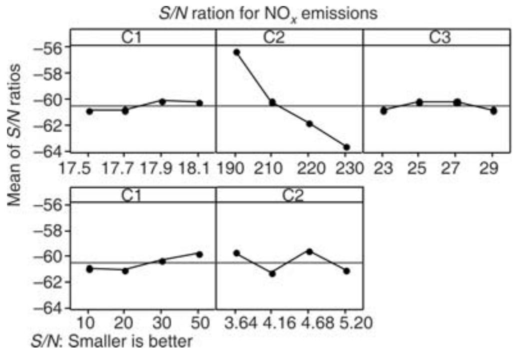

Figure 8. Shows the values of S/N ratio of NO_x

Table 11. Optimum parameter for each response variable

Controlled factors	BTHE	BSFC	HC	NO_x
A: Compression ratio	17.9	18.1	18.1	17.5
B: Static injection pressure [bar]	210	220	190	230
C: Injection timing [bTDC]	23	29	23	29
D. Fuel fraction [%]	10	30	30	20
E. Power [kW]	4.16	5.2	5.2	4.16

Table 12. Weighing factor of single objective optimization

S. no.	Response variable	Weighing factor
1	BTHE	0.30
2	BSFC	0.20
3	NO_x	0.25
4	HC	0.25

Table 13. Values of response variable

S. no.	Responsevariable	Values
1	BTHE	32%
2	BSFC	0.298 kg/kWh
3	NO_x	1249 ppm
4	HC	24 ppm

Confirmatory test

After selecting the optimal levels of the engine, the final step is to verify the results using the optimum design parameter levels in comparison with standard engine parameters with biodiesel fuel. A confirmation test for the combined objective is conducted by choosing the five design and control parameters as found in multi objective optimization. Thus for the engine the optimum set for conditions may be stated as A2, B1, C3, D2, and E1 which is the optimum for the combined objective of minimizing both the fuel consumption and emissions. The confirmation test was conducted with optimized parameters given in tab. 14.

Table 14. The comparison of the prediction and confirmation between the initial and the optimal conditions

S. no.	Response variable	Predicted value at optimum condition using Taguchi	Confirmation test value at optimum condition
1	BTHE	32%	31%
2	BSFC	0.298 kg/kWh	0.30 kg/kWh
3	NO_x	1249 ppm	1300 ppm
4	HC	24 ppm	28 ppm

Nomenclatures

P	– power, [kW]	BSFC	– brake specific fuel consumption, [$kgkW^{-1}h^{-1}$]
IP	– injection pressure, [bar]	bTDC	– before top dead center, [–]
IT	– injection timing, [degrees]	*S*/*N*	– signal to noise ratio, [–]
B	– fuel fraction, [%]	OA	– orthogonal array, [–]
CR	– compression ratio, [–]	W	– weighing factor, [–]
BTHE	– brake thermal efficiency, [–]		

Conclusions

The Taguchi's approach analysis has been carried out for optimizing the performance of karanja biodiesels engine. The various input parameters have been optimized using SNR.The higher-the-better quality characteristic has been been used for maximizing the BTHE and lower-the-better has been used to minimize the BSFC and emissions. The CR was found to be the most significant parameter followed by IT. Based on this study, it can be concluded that BTHE, BSFC, and emissions of diesel engine depend upon biodiesel blend, CR, nozzle pressure, and IT. It was found that a diesel engine operating at a CR –17.7, pressure 230 bar, IT of 27° bTDC, biodiesel – diesel blend B20, and brake power –3.64 kW achieves the optimum engine performance. The results are well supported by the findings of our confirmatory test.

References

[1] Babu, A. K., *et al*., Vegetable Oils and Their Derivates as Fuels for CI Engines, SAE paper 2003-01-0767, 2003

[2] Demirbas, A., Biodiesel Production from Vegetable Oils Via Catalytic and Non-Catalytic Supercritical Methanol Transesterification Methods, *Int Journal Energy Combustion Science Direct, 31* (2005), 5-6, pp. 466-487

[3] Agarwal, D., Agarwal, A. K., Performance and Emission Characteristics of a Jatropha Oil, *Preheated and Blend in a Direct Injection Compression Ignition Engine Applied Thermal Engineering Eng., 27* (2007), 13, pp. 2314-2323

[4] Karnwal, A., *et al*., Multi- Response Optimization of Diesel Engine Performance Parameters Using Thumba Biodiesel –Diesel Blends by Applying the Taguchi Method and Grey Relational Analysis, *International Journal of Automotive Technology, 12* (2011), 4, pp. 599-610

[5] Maheshwari, N., *et al*., A Nonlinear Regression Based Multi-Objective Optimization of Parameters Based on Experimental Data from an IC Engine Fueled with Biodiesel Blends-Biomass and Bioenergy, *35* (2011), 5, pp. 2171-2183

[6] Alonso, J. M., *et al*., Combining Neural Networks and Genetic Algorithms to Predict and Reduce Diesel Engine Emission, *IEEE Trans Evol, 11* (2007), 1, pp. 46-55

[7] Ganapathy, T., *et al*., Performance Optimization of Jatropha Engine Model Using Taguchi Approach, *Applied Energy, 86* (2009), 11, pp. 2476-2486

[8] Cenk, S., Metin Gumus-Impact of Compression Ratio and Injection Parameters on the Performance and Emissions of a DI Diesel Engine Fueled with Bio-Diesel-Blended Fuel, *Applied Thermal Engineering, 31* (2011), 3, pp. 182-3188

[9] Xue, J., *et al*., Effect of Biodiesel on Engine Performances and Emissions, *Renewable and Sustainable Energy Reviews, 15* (2011) 2, pp. 1098-1116

[10] Raheman, H., *et al*., Performance of Diesel Engine with Biodiesel at Varying Compression and Ignition Timing, *Fuel, 87* (2008), 12, pp. 2659-2666

[11] Nataraj, M., Optimizing Diesel Engine Parameters for Low Emissions Using Taguchi Method: Variation Risk Analysis Approach Part I, *Indian Journal of Engineering and Material Sciences, 12* (2005), 6, pp. 169-181

[12] Anand, G., Karthikeyan, B., An Investigation and Engine Optimization of a Spark Ignition Engine with Gaseous Fuels, Gas Turbine Conference, Germany, Munich, Germany, 2005

[13] Yang, B., *et al*., Multiple Injections with EGR Effects on NO_x Emissions for DI Diesel Engines Analyzed Using an Engineering Model, SAE paper 2002-01-2774, 2002

[14] Doddayaraganalu, *et al*., Combustion Characteristics of Diesel Engine Operating on Jatropha Oil Methyl Ester, *Thermal Sciences, 14* (2010), 4, pp. 965-977
[15] Win, Z., *et al*., Investigation of Diesel Engine Operating and Injection System Parameters for Low Noise, Emissions and Fuel Consumption Using Taguchi Methods, *Proceedings*, Institute of Mechanical Engineers part D, *Jurnal of Automobile Engineering, 211* (2005), 10, pp. 1237-1291
[16] Cenk, S., *et al*., Effect of Fuel Injection Timing on the Emissions of a Direct-Injection (DI) Diesel Engine Fueled with Canola Oil Methyl Ester- Diesel Fuel, *Energy and Fuels, 24* (2010), 4, pp. 2675-2682
[17] Wincent, H. W., *et al* , Simulation and Modeling of Fuel Injection System of a Diesel Engine, *Proceedings*, International Conference on Mechanical Engineering, 2003, Dhaka, Bangladesh, pp. 24-29
[18] Agarwal, A. K., Das, L. M., Biodiesel Development and Characterization for the Use as a Fuel in Compression Ignition Engine, *J. Engineering for Gas Turbine and Power, 123* (2001), 3, pp. 440-447
[19] Patil, V., Singh, K., Oil Gloom to Oil Boom, Jatropha Curcas a Promising Agro Forestry Crop, Shree Offset Press, Nashik, India, 1991
[20] Sharanappa, K., *et al*., The Effect of Karanja Oil Methyl Ester on Kirlosar HA394DI Diesel Engine Performance and Exhaust Emissions, *Thermal Science, 14* (2010), 4, pp. 957-964
[21] Pandian, M., *et al*., Investigation on the Effect of Injection System Parameters on the 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, 88* (2011), 8, pp. 2663-2676
[22] Ross, P. J., Taguchi Techniques for Quality Engineering, McGraw-Hill, New York, 11, USA, 1988

Paper submitted: January 5, 2012
Paper revised: May 27, 2012
Paper accepted: July 16, 2012