Parametric Optimization of Single Cylinder Diesel Engine for Palm Seed Oil Biodiesel and Diesel Blend for Specific Fuel Consumption Using Taguchi Method

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ABSTRACT

An experimental study has been carried out for palm oil blended with diesel used in single cylinder diesel engine. Palm seed oil is obtained from the seeds of palm tree. Blending of Palm seed oil with diesel in maximum possible proportion helps to reduce the consumption of diesel fuel. In this study, the effects of parameters i.e. injection timing, injection pressure, compression ratio, and load are taken as variable for optimization. As the experiment required simultaneously optimization of three parameters with three levels, Taguchi method of optimization is used in this experiment. The results of the Taguchi experiment identify that 16 compression ratios, injection pressure 180 bars and engine load 9kg are optimum parameter setting for highest specific fuel consumption. Engine performance is mostly influenced by engine load and is least influenced by compression ratio. Confirmation experiment was done using an optimum combination showed that the specific fuel consumption was found by experiment is closer to the predicted value.

Keywords: - *Parametric optimization, Diesel engine, Palm seed oil, specific fuel consumption, Taguchi method*

1. INTRODUCTION

Bio-diesel is produced from various sources like plants, animals and is used by blending with diesel. Biodiesel, which can be used as an alternative diesel fuel, is made from renewable biological sources such as vegetable oil and animal fats. It is biodegradable, non-toxic and possesses low emission profiles. Also, the uses of bio-fuels are environmentally beneficial. The name bio-diesel was introduced in the United States during 1992 by the National Soy Diesel Development Board (presently National Bio-diesel Board) which has pioneered the commercialization of biodiesel in the US [1]. The limited (and fast diminishing) resources of fossil fuels, increasing prices of crude oil, and environmental concerns have been the diverse reasons for exploring the use of vegetable oils as alternative to diesel oil [2-5]. Vegetable oils offer almost the same output with slightly lower thermal efficiency when used in diesel engines [6-8]. Reduction of engine emissions is a major research aspect in engine development with the increasing concern over environmental protection and the stringent exhaust gas regulation [9-14]. Among the various possible alternative fuels, hydrogen is found to be most promising due to its clean burning and better combustion properties. There are several reasons for applying hydrogen as an additional fuel to accompany diesel fuel in the internal combustion (IC) compression ignition (CI) engine. Primary; it increases the H/C ratio of the entire fuel. Secondly, injecting small amounts of hydrogen to a diesel engine could decrease heterogeneity of a diesel fuel spray due to the high diffusivity of hydrogen which makes the combustible mixture better premixed with air and more uniform. It could also reduce the combustion duration due to hydrogen's high speed of flame propagation in relation to other fuels [15]. Diesel blended with methanol has been investigated for its performance and emission in the diesel engine by employing Derringers desirability approach [16]. 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. As far as the internal combustion engines are concerned the thermal efficiency and emission is the important parameters for which the other design and operating parameters have to be optimized. The most common optimization techniques used for engine analysis includes Taguchi method [17]. 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. 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 used to find the effect of design and operating parameters on brake power and specific fuel consumption [17]. Taguchi method was applied by taking the parameters injection operating pressure and compression ratio to find the impact on engine performance and heat released and consequently optimal parameters are identified [18].An experimental study has been carried out for palm seed oil blended with diesel used in a single cylinder diesel engine by varying parameters the load, compression ratio and injection pressure. It is found that the engine performance is mostly influenced by engine load and is least influenced by compression ratio [19]. In this investigation, diesel blended with cottonseed oil and inducting the hydrogen during suction stroke, is proposed to be carried out by employing Taguchi methods.

II. LITERATURE REVIEW

K. Sivaramakrishnan et.al show that there is much possibility of increase research in biodiesel, karanja biodiesel used as a biodiesel with taguchi multiple regression analysis and got better result for performance.[20] Anant Bhaskar Garg et.al used artificial neural network based methodologies for optimization of engine operations.[21] GVNSR Ratnakara Rao et.al done experiment and optimize the compression ratio for diesel engine and got better result for performance.[22] M. Natrajan et.al used variation risk analysis approach for optimizing diesel engine for low emission and got desired result for low emission.[23] N. Balajiganesh et.al used artificial network method for optimizing CI engine parameter.[24] Mr. Krunal B Patel et. Al showed in research paper that taguchi method of optimization is best technique for optimization and got better result for specific fuel consumption for predicted value & experimental value. [25]

III. PALM SEED OIL

The fuel properties like flash point, fire point, kinematic viscosity, density, calorific value. These fuel properties were compared with diesel fuel. Flash point and fire point were higher than diesel this confirmed the safety of biodiesel storage. Kinematic viscosity and density were higher than diesel this may result in improper spray characteristics. Cetane number was higher than diesel and it would have positive impact on combustion quality of biodiesel.

Table-1.The fuel Properties of Palm seed oil and Diesel

Property	Method of Testing	Palm Biodiesel	Diesel
Kinematic viscosity at 40^0C(cSt)	U- tube	4.8	3.0
Density @15^0C (Kg/m^3)	Gravimetry	876	833
Ash content (% m/m)	Gravimetry	0.018	0.006
Carbon Residue (% m/m)	Gravimetry	0.02	0.12
Sulfur content (mg/Kg)	Nephelometry	15	30
Flash point(^{0}C)	Open cup	130^0C	74^0C
Fire point (^{0}C)	Open cup	171^0C	120^0C
Cloud point (^{0}C)	ASTM D2500	13^0C	-16^0C
Pour point(^{0}C)	ASTM D5853	17^0C	-25^0C
Calorific value (KJ/Kg)	BombCalorimeter	38600	42850
Water content (mg/Kg)	KF	411	105
Total contamination (mg/Kg)	Gravimetry	14	10
Copper corrosion 3 hour at 50^0C	DIN EN ISO 2160	Class I	Class I
Ceten no	ISO 5165	62.8	49.0
Acid Value (KOH/g)	Tritrimetry	0.30	0.35

IV. EXPERIMENTAL SET UP

Experiments were conducted with different blend of karanja Bio-diesel and Palm bio-diesel with Diesel (B10,B20,B40,B60,B80,B100) for investigation of performance and emission characteristics of single cylinder four stroke diesel engine. . In this experiment, diesel engine is used and connected with the eddy current dynamometer with the help of dynamometer, varies the load on the engine or load remain constant .Gas analyzer is used to find the emission characteristic of exhaust gas. The reading takes by constant load or by varying the load on the engine using the dynamometer. Engine performance such as specific fuel consumption, brake thermal efficiency, brake specific fuel consumption etc. found from the experiments. First only diesel fuel is used and emission characteristics and engine performance is found. At full load we get minimum Specific fuel consumption(SFC) for P40 blended fuel (Palm biodiesel 40% and diesel 60%).Taguchi optimization approach to determine engine design parameter (compression ration and injection pressure) and operating parameter for P40 blended fuel.L9 orthogonal array was used to collect data for specific fuel consumption related data at full load (9 kg) and different compression ratio and injection pressure.

Table-2: Specification of engine

Engine manufacturer	Apex Innovations (Research Engine test set up)
Software	Engine soft Engine performance analysis software
Engine type	Single cylinder four stroke multi fuel research engine
No. of cylinder	1
Type of cooling	Water cooled
Rated power	3.5 kW @ 1500 rpm
Cylinder diameter	87.5 mm
Orifice diameter	20 mm
Stroke length	110 mm
Connecting rod length	234 mm
Dynamometer	Type: eddy current, water cooled, with loading unit

V. TAGUCHI METHOD OF OPTIMISATION

Taguchi method is a simplest method of optimising experimental parameters in less number of trials. The number of parameters involved in the experiment determines the number of trials required for the experiment. More number of parameters led to more number of trials and consumes more time to complete the experiment. Hence, this was tried in the experiment to optimise the levels of the parameter involved in the experiment. This method uses an orthogonal array to study the entire parameter space with only a small number of experiments .To select an appropriate orthogonal array for the experiments, the total degrees of freedom need to be computed. The degrees of freedom are defined as the number of comparisons between design parameters that need to be made. The present study uses three factors at three levels and hence, an L9 orthogonal array was used for the construction of experimental layout (Table 3, column -1, 2, 3). The L9 has the parameters such as compression ratio, injection pressure and load arranged in column 1, 2 and 3. (Table 4). According to this layout, nine (09) experiments were designed and trials were selected at random, to avoid systematic error creeping into the experimental procedure. For each trial the mechanical efficiency was calculated and used as a response parameter. Taguchi method uses a parameter called signal to noise ratio (S/N) for measuring the quality characteristics. There are three kinds of signal to noise ratios are in practice of which, the higher-the-better S/N ratio was used in this experiment because this optimisation is based on brake thermal efficiency. The taguchi method used in the investigation was designed by statistical software called „Minitab 16" to simplify the taguchi procedure and results. A confirmation experiment for the optimum set of parameters was also conducted for validation of the predicated value obtained by minitab software. This is mainly to compare the mechanical efficiency of predicated value and experimental value of optimum set of parameters.

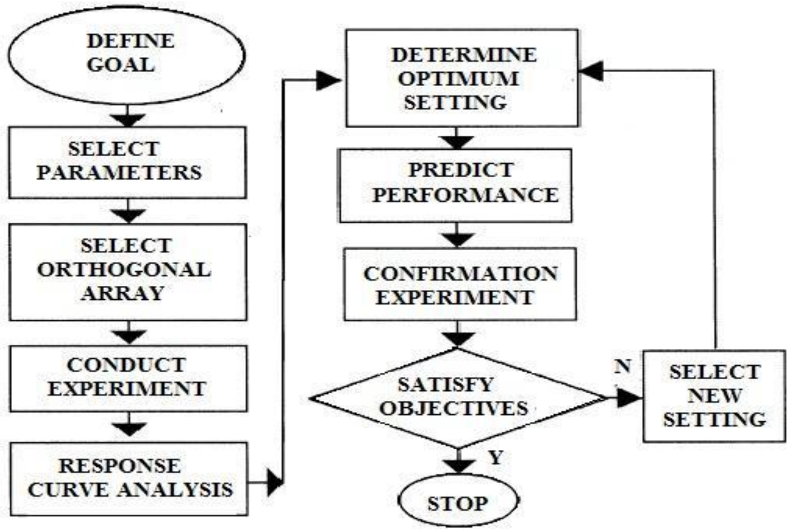

Fig.1 Flow chart of the Taguchi method

Experiment was conducted as per above step as shown in fig.5.4.1 in flow chart of taguchi method. Following Step are taken in Minitab software for Design of Experiment By taguchi

Minitab 17
↓
State
↓
DOE
↓
Taguchi
Create Taguchi Design
(i)Select 03 Level Design
(ii)Select No. Of Factor =02
↓
Display Available design
Select(L9)- (3 Level)-(2-4)
Design
Select L9 Array
Factor
Factor A:- compression Ratio:-14 16 18
Factor B:-Ignition pressure:-120 160 200
Ok
Data Sheet

Selection of factor levels and orthogonal array

In this experiment, three parameters for three levels were considered (table-3). Control parameter and their level are given in table. L9 single orthogonal array shown in table-4 (column-2, 3) was selected for the experimental investigation. “smaller-the-better” is being taken as quality characteristics, since the objective function is to maximize performance.

Table-3 Process parameters and their level

Parameter	Compression ratio	Injection pressure
Unit	---	bar
Level 1	14	120
Level 2	16	160
Level 3	18	200

VI. RESULT AND ANALYSIS FOR RESPONSE CURVE

Experiment was done for selected sets of parameters by Minitab software and find mechanical efficiency for those sets of parameters. Mechanical efficiency for those sets is given in the table.

Table-4 Result for specific fuel consumption

Sr. No.	Compression Ratio	Injection pressure (bar)	SFC (Kg/Kwh)
1	14	120	0.36
2	14	160	0.33
3	14	200	0.32
4	16	120	0.34
5	16	160	0.36
6	16	200	0.34
7	18	120	0.27
8	18	160	0.26
9	18	200	0.32

Response curve analysis is aimed at determining influential parameters and their optimum levels. It is graphical representations of change in performance characteristics with the variation in process parameter. The curve give a pictorial view of variation of each factor and describe what the effect on the system performance would be when a parameter shifts from one level to another. Figure-3 shows significant effects for each factor for three levels. The S/N ratio for the performance curve were calculated at each factor level and average effects were determined by taking the total of each factor level and dividing by the number of data points in the total. The greater difference between levels, the parametric level having the highest S/N ratio corresponds to the parameters setting indicates highest performance

Steps in Minitab software for Analysis of Taguchi design
Minitab 17
↓
State –DOE--Taguchi
↓
Define custom Taguchi design
↓
Select Factor
C1:-Compression Ratio
C2:- Injection pressure

OK
↓
State –DOE—Taguchi-- Analysis Taguchi design
↓
Response Data:- SFC(kg/Kwh)--- Analyse
↓
Select response for
Signal to noise ratio
Mean
Ok

↓
Tearms
Available Terms:- AB
Select Both AB terms
OK
↓
Option → Select Smaller is Better
↓
Storage
↓
Welcome to Minitab, press F1 for help.

Taguchi Design

Taguchi Orthogonal Array Design
L9 (3^2)
Factors: 2
Runs: 9
Columns of L9 (3^4) Array
1 2
Analysis P40 Blend for SFC.MPJ'

Taguchi Analysis: SFC (Kg/Kwh) versus compression Ratio, Injection pressure (bar)

- **Main effect for mean curve (minimum mean is better performance)**

Fig 4.24 illustrate main effect plot for means

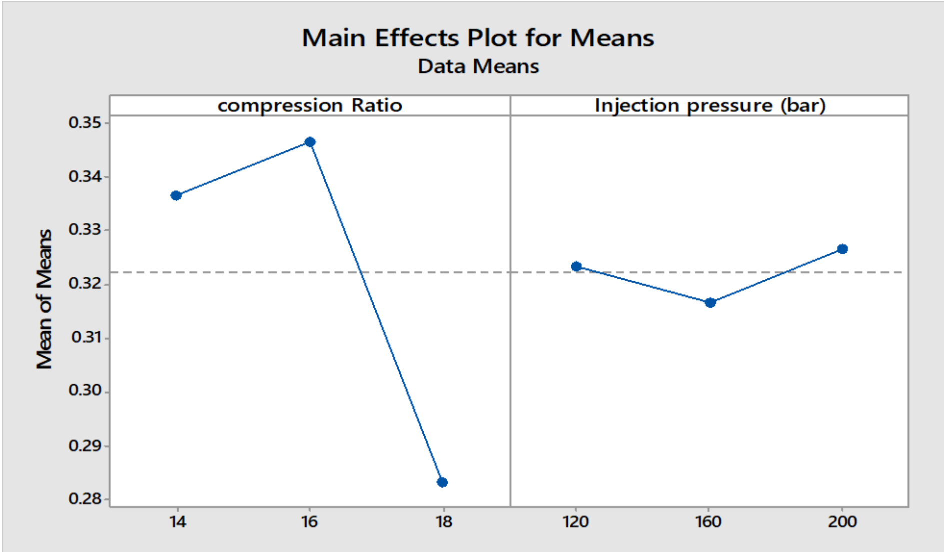

Fig 2 Main Effects Plot for Means

From above figure-2 mean is average value for reading taken for particular parameter. From graph, mean value is maximum (0.3467) for 16 compression ratio and minimum (0.2837) for 18 compression ratio. Mean value is maximum (0.3267) for 200 bar injection pressure and minimum (0.3167) for 160bar injection pressure..Delta is difference of maximum value and minimum value. Delta value is maximum for Compression ratio parameter (0.0633) and minimum (0.0100) for injection pressure parameter. .So that effect of compression ratio is maximum and effect of injection pressure is minimum on Specific fuel consumption. As shown in figure 2 and Table 5

Table-5 Response table for mean

Level	Compression ratio	Injection pressure
1	0.03367	0.03233
2	0.3467	**0.3167**
3	**0.2833**	0.3267
Delta	0.0633	0.0100
Rank	1	2

- **Main effect for S/N ratio (highest ratio is better performance)**
- Fig 3 illustrate main effect plot for S/N ratio

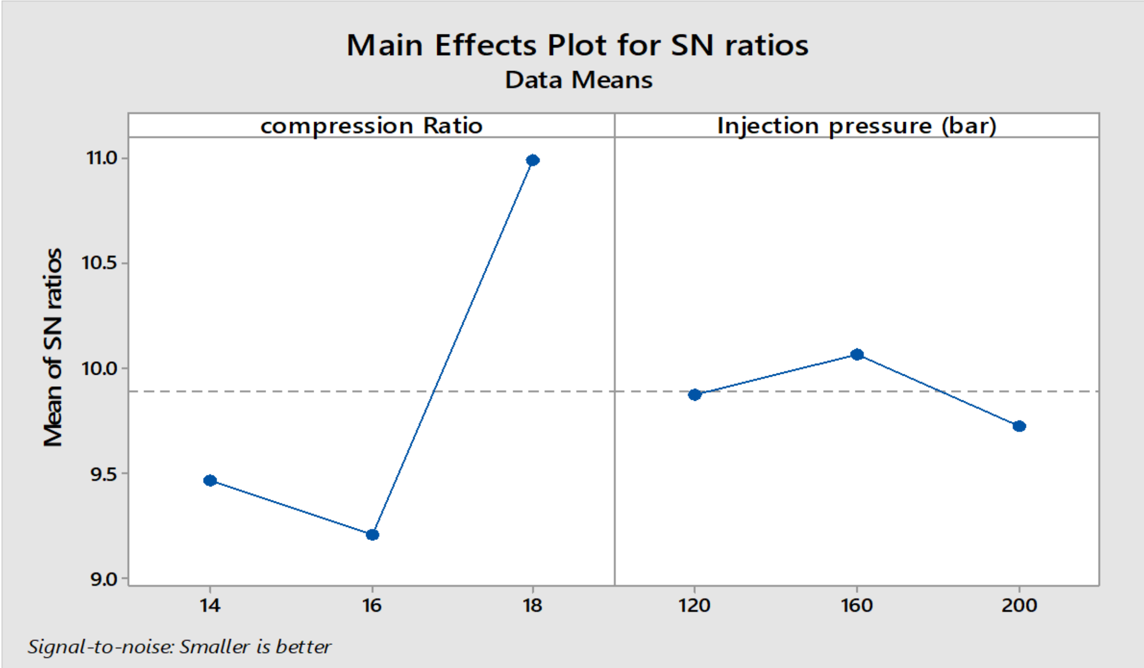

Fig 3 Main Effects Plot for SN ratios

Referring Figure- 3 the response curve for S/N ratio, the highest S/N ratio was observed at 18 compression ratio (10.99) ,160 Injection pressure(10.068) which are optimum parameter setting for Lowest Specific fuel. From delta values as mention above, maximum (1.785) for compression ratio and minimum (0.347) for Injection pressure . Parameter Compression ratio is most significant parameter and injection pressure is least significant for Specific fuel consumption. As shown in figure 3 and Table 6

Table 6 Response table for signal to nose ratio

Level	Compression ratio	Injection pressure
1	9.467	9.872
2	9.205	**10.068**
3	**10.990**	9.721
Delta	1.785	0.347
Rank	1	2

- **Choosing optimum combination of parameter level**

The term optimum set of parameters is reflects only optimal combination of the parameters defined by this experiment for Lowest Specific fuel consumption. The optimum setting is determined by choosing the level with the highest S/N ratio. Referring figure-3 and table-6, the response curve for S/N ratio, the highest performance at set 18 compression ratio , engine load 9kg, and injection pressure160 bar, which is optimum parameter setting for lowest Specific Fuel consumption.

- **Prediction of Taguchi Result :-**

Step for prediction of taguchi result in minitab 17 software Minitab

↓

State →DOE→Taguchi→ Predict Taguchi result

↓

Select

(1)Mean (2)signal noise Ratio

↓

Available Terms:- AB, Select Both AB terms, OK

↓

Level

↓

Specify New level Factor in:-Unicode Units

↓

Method Of Specify new factor Level:- Select level from List

↓

OK

- **Predict performance at optimum setting**

Using optimum set of parameters, which was achieved by response curve analysis was used for prediction by Minitab software. Minitab software for taguchi method of optimization was suggested minimum specific fuel consumption 0.27 778 and S/N ratio was 11.1709 for optimum set of parameter as shown in table 7

Table 7 Predicted value for Specific fuel consumption

Specific fuel consumption (Kg/kwh)	S/N ratio
0.277778	11.1709

Factor levels for predictions

Table 8 Factor levels for predictions

Compression ratio	Injection pressure (bar)
18	160

Confirmation Experiment

In this step of the process was to run confirmation experiments to verify the engine parameter setting really produce optimum performance and to evaluate the predictive capability of the taguchi method for diesel engine performance. The optimum parameters were settled in the diesel engine and performance was measured for that set of parameter. As shown in table-9, this performance was compared with predicated performance and was found that the experimental value was nearer to the predicated value

Table 9 Predicted value and experimental value of SFC

Specific Fuel consumption (Kg/Kwh)	
Predicted value	**Experiment value**
0.27	0.26

VI. CONCLUSIONS

The feasibility of using taguchi method to optimize selected diesel engine parameter for highest performance was investigated using single cylinder, 4-stroke diesel engine. The conclusions from this work are summarized as follow:

1. The taguchi method was found to be an efficient technique for quantifying the effect of control parameter.
2. The highest performance at set 40% blend ratio, engine load 9kg, compression ratio 18 and injection pressure160 bar, which are optimum parameter setting for Lowest specific fuel consumption
3. Engine performance is mostly influenced by compression ratio and is least influenced by injection pressure.

Performance results obtained from the confirmation experiment using optimum combination showed excellent agreement with the predicated result.

References

1. J. Xue, T. E. Grift, and H. C. Alan, "Effect of biodiesel on engine performances and emissions," Renewable and Sustainable Energy, 2011.
2. Ramadhas A.S., Jayaraj S. and C. Muraleedharan. 2004. Use of vegetable oils as I.C. engine fuels- A review. Journal of Renewable Energy. 29: 727-742.
3. Muralidharan M., Thariyan M.P., Roy S., Subrahmanyam J.P. and P.M.V. Subbarao. 2004. Use of pongamia bio-diesel in CI engines for rural application. SAE Paper No. 28-0030.
4. Recep Selim C. and S.Y. Huseyin. 2000. The potential of using vegetable oil fuels as fuel for diesel engines. International Journal of Energy Conversion Management. 42: 529-538.
5. Vellguth G. 1983. Performance of vegetable oils and their monoesters as fuels for diesel engines. SAE Paper No. 831358.
6. Agarwal D. and A.K. Agarwal. 2007. Performance and emission characteristics of a Jatropha oil (preheated and blends) in a direct injection compression ignition engine. Journal of Applied Thermal Engineering. 27: 2314-2323.
7. Barsic N.J. and A.C. Humke. 1981. Performance and emission characteristics of a naturally aspirated diesel engine with vegetable oil fuels. SAE Paper No. 810262.
8. Moneym A and J.H. Gerpen. 2001. The effect of bio-diesel production on engine performance and emissions. Journal of Biomass and Bio energy. 20: 317-325.
9. Lee Pedkey R and C.H. Hobbs. 1998. Fuel quality impact on heavy duty diesel emissions- A literature review. SAE Paper No. 982649.
10. Akasaka Y., Suzuki T. and Y. Sakurai. 1997. Exhaust emissions of a DI diesel engine fueled with blends of bio-diesel and low sulphur diesel fuel. SAE Paper No. 972998.
11. Owen K. and T. Coley. 1995. Automotive fuels reference book. Society of Automotive Engineers, USA.

12. Szybist J. 2003. Potential methods for NOx reduction from bio-diesel. SAE Paper No. 01-3205.
13. NabiMdN, AkhterMdS, MhiaMd and S. Zaglul. 2006. Improvement of engine emissions with conventional diesel-bio-diesel blends. Journal of Bioresource Technology. 97: 372-378.
14. Sarath M., Ravi Kumar P., and Prashanth Reddy K. 2009. Performance characteristics of a diesel engine operating with animal tallow oil blended with diesel.
15. Quadri S. A. P., Masood M., and Ravi Kumar P., 2015. Effect of pilot fuel injection operating pressure in hydrogen blended compression ignition en-gine : An experimental analysis, Fuel; V 157, pp-279-284
16. Y. D. Bharadwaz, B. G. Rao, V. D. Rao and C. Anusha, Improvement of biodiesel methanol blends performance in a variable compression ratio engine using response surface methodology, Alexandria Engineering Journal,55, 2016, pp. 1201-1209.
17. K. Sivaramakrishnan and P. Ravikumar, “Performance Optimization of karanja bio-diesel engine using Taguchi approach and multiple regressions,” ARPN J., vol. 4, pp. 506–516, April 2012.
18. Quadri S.A.P, M. Masood, T. Wahidi, M. S. Ghouse, M. Wajid, “Doe applied to multi response optimization study on performance, combustion and emission characteristics of a VCR diesel engine,” Int. J. of Ambient Energy, Taylor & Francis, July 2016.
19. M. A. Modi, T. M. Patel, G. P. Rathod., “Parametric Optimization Of Single Cylinder Diesel Engine For Palm Seed Oil & Diesel Blend For Brake Thermal Efficiency Using Taguchi Method”. IOSR Journal of Engineering., Vol.5, pp.49-54, 2014.
20. K. Sivaramakrishnan & P. Ravikumar, "Performance optimization of karanja biodiesel engine using taguchi approach and multiple regressions‟‟ ARPN Journal of Engineering and Applied Sciences, April-2012, Vol.7.No.4,PP. 506-516.
21. Anant Bhaskar Garg, Parag Diwan, Mukesh Saxena, "Artificial Neural Networks based Methodologies for Optimization of Engine Operations‟‟ International Journal of Scientific & Engineering Research, May-2012, Vol.3 No.5,
22. GVNSR Ratnakara Rao1, V. Ramachandra Raju2 and M. Muralidhara Rao3, "Optimising the Compression Ratio of Diesel Fuelled C.I Engine‟‟ ARPN Journal of Engineering and Applied Sciences, April-2008, Vol.3,No.2
23. M.Natarajan, V P Arunachalam, N Dhandapani, "Optimizing diesel engine parameters for low emissions using Taguchi method: Variaton Risk Analysis Approach part-1‟‟, International Journal of Engineering and MS, June-2005, Vol.12, PP.169-181.
24. N. Balajiganesh & B. Chandra Mohan Reddy, "Optimization of C.I Engine Parameters Using Artificial Neural‟‟ International Journal of Mechanical and Industrial Engineering (IJMIE),2011, Vol.1.No.2,
25. Mr. Krunal B Patel1, Prof. Tushar M Patel2, Mr. Saumil C Patel3, "Parametric Optimization of Single Cylinder Diesel Engine for Pyrolysis Oil and Diesel Blend for Specific Fuel Consumption Using Taguchi Method‟‟ IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE),Mar-April-2013, Vol.6.No.1,PP 83-88.