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Parametric Optimization of Single Cylinder Diesel Engine for Brake Thermal Efficiency Using Tyre Pyrolysis Oil and Diesel Blend

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Abstract— An experimental study has been carried out for Tyre pyrolysis oil blended with diesel used in a single cylinder diesel engine. Tyre Pyrolysis oil is obtained from tire waste by pyrolysis process. Blending of Tyre pyrolysis 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 four parameters with five levels, Taguchi method of optimization is used in this experiment. The results of the Taguchi experiment identify that 240 Injection Timing, Injection Pressure 140 bar, Compression Ratio 18 and Engine Load 5 kg are optimum parameter setting for highest break thermal efficiency. Engine performance is mostly influenced by Engine load and is least influenced by Injection Pressure. Confirmation experiment was done using optimum combination showed that Brake Thermal Efficiency was found by experiment is closer to the predicated value.

Index Terms— CI Engine, Pyrolysis Oil, Taguchi Method, Brake Thermal Efficiency, S/N ratio

1 Introduction

In the present position of the world, energy crisis due to fast depletion of fossil fuel is the main problem. Increase in fuel price day by day, continuing growth of automobile industry, rapid growth in individual mobility and improved living standard, the continuous accumulation of greenhouse gases are the main causes for development of alternative fuels. In the present situation, there is much possibility of multifold increase in the research in biodiesel, vegetable oils like soybean oil, rapseed oil, sunflower oil, methanol, ethanol and other alternate fuels. Considering alternate fuels as a substitute of diesel, Researchers are continuously finding the best alternative solution, which gives the best performance and fuel characteristics [2]. Most of alternative fuels used today are biodiesel or bio ethanol, which can be used in existing engines. The primary advantage of this kind of fuel is that they are renewable and eco-friendly. The various techniques for admission of fuel and mixing of alternate fuel with diesel are required. Recently in this field, the research work has been going on to increase the maximum portion of alternate fuel in blend with diesel. With the use of alternate fuels, main issue is modification required in IC engines. In order to reduce cost of modification some optimization techniques must be applied. So that efficiency and performance may not be reduced. In such multivariate problem, use of nonlinear techniques like Design of Experiments (DOE), fuzzy logic and neural network are suitable to explore the combined effects of input parameters. The optimum operating parameters for a given system can be determined using experimental techniques, but experimental procedure will be time consuming and expensive when the number of parameters is in the order of 20, 30 etc., like in the case of IC engines. In such situations, mathematical modeling will be a very useful tool for optimizing the parameters. Such a mathematical tool is Design of Experiment. Although few studies were reported using DOE in IC Engine applications, the study of the combined effects between input system parameters such as injection pressure, load, blend proportion on the performance and emission characteristics of CI engine was scarce and offered a scope for this study.

2 Literature Review

Bi-fueling or blending is the simplest technique for admitting low cetane fuels in high compression engines. According to Joshi at el.(2012) 5% blend of Tyre pyrolysis oil with diesel gives best result for the mechanical efficiency. In this experiment the Tyre pyrolysis oil is mixed with standard diesel oil in 5% proportions on volume basis and its properties such as calorific value and viscosity were evaluated before admission [7]. According to Patel at el. (2013) blending of Tyre pyrolysis 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 four parameters with five levels, taguchi method of optimization is used in this experiment. The results of the taguchi experiment identifies that 220 injection timing, injection pressure 200 bar, compression ratio 16 and engine load 20kg are optimum parameter setting for lowest break specific fuel consumption. Engine performance is mostly influenced by engine load and is least influenced by Compression ratio [6].

3 Tyre Pyrolysis Oil

Tyre Pyrolysis oil is obtained from tire waste by process which is called pyrolysis process. It is a thermo-chemical decomposition of organic matter in the absence of oxygen. Pyrolysis of waste vehicle tires with the purpose of fuel production for the used as a fuel in internal combustion engine can be seen as a hygienic, environmentally acceptable and efficient way of disposing them. In an experimental study, it was reported that, cross-section samples of 2–3 cm wide, representative of a whole car tire, have been pyrolysed under nitrogen in a 3.5 dm3 autoclave at 300, 400, 500, 600 and 700 °C. At over 500 °C there is no effect of temperature on gas and liquid yields which were about 17% and 38%, respectively. Besides, catalysts have been applied in several studies for upgrading the quality and quantity of the products obtained from waste tire pyrolysis. Tire pyrolysis oil derived from waste automobile tires was analyzed and compared with the petroleum products and was found that it can also be used as a fuel for compression ignition engine [4].

It was reported that pyrolysis of scrap tyres produced oil similar in properties to a light fuel oil, with similar calorific value, and sulphur and nitrogen contents. The oil was found to contain 1.4% sulphur and 0.45% nitrogen by mass, and had similar properties to diesel fuel. The oil contained a significant concentration of polycyclic aromatic hydrocarbons, some of which had been shown to be carcinogenic and/or mutagenic. A single oil droplet combustion study was carried out and also the oil was analyzed in detail for its content of polycyclic aromatic hydrocarbons (PAH). The derived oil was combusted in a 18.3 kW ceramic-lined, oil-fired, spray burner furnace, 1.6 m in length and 0.5 m internal diameter. The emissions of NOx, SO2, particulate and total unburned hydrocarbons were determined in relation to excess oxygen levels. Throughout the combustion tests, comparison of the emissions was made to the combustion of diesel. The oil was found to contain 1.4% sulphur and 0.45% nitrogen on mass basis and have similar fuel properties to those of DF.

Table 1 shows the properties of Diesel and Tyre Pyrolysis Oil [1].

TABLE 1

Property Of Diesel And Tyre Pyrolysis Oil

Properties	Diesel	Tyre Pyrolysis oil
Density (kg/m3)	830	923
Calorific value (kj/kg)	43800	38000
Kinematic Viscosity (cst)	2.58	3.77
Flash Point (0c)	50	43
Fire Point(0c)	56	50

4 Experimental Setup

The setup consists of single cylinder, four stroke, multi-fuel, research engine connected to eddy type dynamometer for loading. The operation mode of the engine can be changed from diesel to Petrol of from Petrol to Diesel with some necessary changes. In both modes the compression ration can be varied without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. The injection point and spark point can be changed for research tests. Setup is provided with necessary instruments for combustion pressure, Diesel line pressure and crank-angle measurements. These signals interface with computer for pressure crank-angle diagrams. Instruments are provided to interface airflow, fuel flow, temperatures and load measurements. The set up has stand-alone panel box consisting of air box, two fuel flow measurements, process indicator and hardware interface. Rota meters are provided for cooling water and calorimeter water flow measurement. A battery, starter and battery charger is provided for engine electric start arrangement. Fig.1 shows the experimental setup for experiment [6].

Fig.1 Experimental Setup

The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio, heat balance and combustion analysis. Lab view based Engine Performance Analysis software package "Engine soft" is provided for on line performance evaluation. Table 2 shows the Technical Specification of Experimental Setup.

TABLE 2

Technical Specifications Of Experimental Setup

Sr. No	Item	Specification
1	Model	TV1
2	Make	Kirlosker Oil Engines
3	Type	Four stroke, Water cooled, Diesel
4	No. of cylinder	One
5	Bore	87.5 mm
6	Stroke	110 mm
7	Compression ratio	12 to 18
8	Power rating	7.5 HP
9	Injection timing	≤ 250 BTDC

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5 Methodology

In this study, the effects of parameters` i.e. injection timing, injection pressure, compression ratio, and load are taken as variable for optimization. A method called 'Taguchi' was used in the experiment for simultaneous optimization of engine parameters such as injection timing, injection pressure, compression ratio, and load etc.

5.1 Taguchi Method of Optimization

Taguchi method is a simplest method of optimizing 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 [5]. Hence, a method called 'Taguchi' was tried in the experiment to optimize 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. The present study uses four factors at five levels and hence, an L_{25} orthogonal array with four columns and twenty five rows were used for the construction of experimental layout (Table 3). The L_{25} has four columns and nine rows and the parameters such as injection timing, injection pressure and compression ratio and load are arranged in column 1, 2, 3 and 4. According to this layout, twenty five experiments were designed and trials were selected at random, to avoid systematic error creeping into the experimental procedure. For each trial the brake thermal 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 lower-the-better S/N ratio was used in this experiment because this optimization is based on lower SFC. The taguchi method used in the investigation was designed by statistical software called 'Minitab Release 16' to simplify the taguchi procedure and results. A full range experiment for the selected blend was also conducted for after modifying the engine operating parameters. This is mainly to optimize the performance characteristics of pyrolysis oil-diesel blend [3].

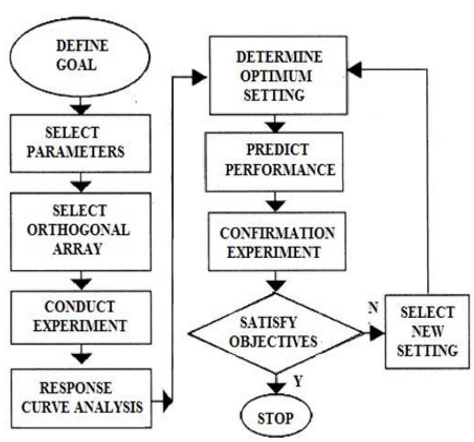

Fig. 2 Flow chart of the Taguchi method

6 Results And Discussion

Experiment was done for selected sets of parameters by Minitab software and find Break thermal efficiency (BTHE) for those sets of parameters. Break thermal efficiency for those sets are given in the Table 3.

TABLE 3
L_{25} ORTHOGONAL ARRAY

Sr. No	Injection Timing (Degree BTDC)	C.R	Injection pressure (bar)	Load (kg)	BTHE %
1	21	14.00	140	1	4.57
2	21	15.00	160	2	4.04
3	21	16.00	180	3	6.58
4	21	17.00	200	4	8.26
5	21	18.00	220	5	10.45
6	22	14.00	160	3	9.54
7	22	15.00	180	4	11.93
8	22	16.00	200	5	13.55
9	22	17.00	220	1	3.7
10	22	18.00	140	2	6.86
11	23	14.00	180	5	13.56
12	23	15.00	200	1	3.39
13	23	16.00	220	2	7.82
14	23	17.00	140	3	11.76
15	23	18.00	160	4	15.64
16	24	14.00	200	2	6.16
17	24	15.00	220	3	11.34
18	24	16.00	140	4	13.58
19	24	17.00	160	5	15.8
20	24	18.00	180	1	5.21
21	25	14.00	220	4	6.6
22	25	15.00	140	5	8.67
23	25	16.00	160	1	1.75
24	25	17.00	180	2	7.42
25	25	18.00	200	3	11.56

6.1 Response Curve Analysis

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. 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 largest S/N ratio corresponds to the parameters setting indicates highest performance.

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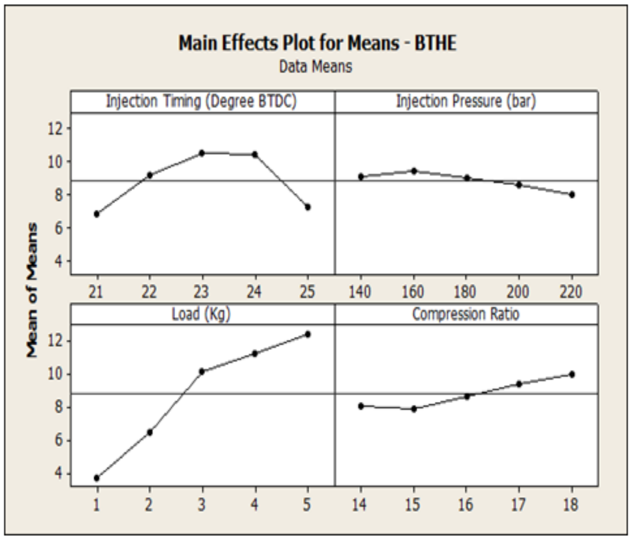

Fig. 3 Main effects plot for Means-BTHE

From above Fig. 3 mean is average value for reading taken for particular parameter. From graph, mean value is maximum (10.434) for 230 BTDC injection timing and minimum (6.780) for 210 BTDC injection timing. Mean value is maximum (9.354) for 160 bar injection pressure and minimum (7.982) for 220 bar injection pressure. Mean value is maximum (9.944) for 18 compression ratio and minimum (7.874) for 15 compression ratio. Mean value is maximum (12.406) for 5 kg engine load and minimum (3.724) for 1 kg engine load.

Delta is difference of maximum value and minimum value. Delta value is maximum for load (8.682) and minimum (1.372) for Injection Pressure. Delta value for Injection timing and Compression Ratio is between other two parameters. So that effect of load is maximum and effect of Injection Pressure is minimum on Break Thermal Efficiency (BTHE).

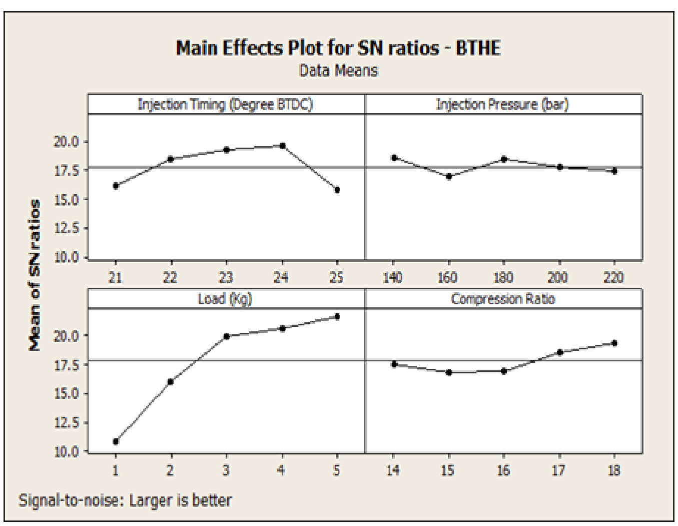

Fig. 4 Main Effect plot for SN ratio-BTHE

Fig. 4 shows the response curve for S/N ratio, the largest S/N ratio was observed at injection timing (240 BTDC), injection pressure(140bar) and compression ratio (18), load (5 kg), which are optimum parameter setting for largest Break thermal efficiency (BTHE). From delta values as mention above, maximum (10.8100) for engine load and minimum (1.66) for Injection Pressure. Parameter engine load is most significant parameter and Injection Pressure is least significant for Break thermal efficiency (BTHE).

6.2 Optimum Combination of Parameter Level

The term optimum set of parameters is reflects only optimal combination of the parameters defined by this experiment for highest Break thermal efficiency (BTHE). The optimum setting is determined by choosing the level with the highest S/N ratio. Referring Fig.4 and Table 4, the response curve for S/N ratio, the highest performance at set 240 BTDC injection timing, engine load 5 kg, injection pressure 140 bar and compression ratio 18 which is optimum parameter setting for Highest Break thermal efficiency (BTHE).

TABLE 4
RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS

Level	Injection Timing BTDC	Injection Pressure (bar)	Load (Kg)	Compression Ratio
1	16.08	18.55	10.87	17.52
2	18.37	16.89	15.98	16.82
3	19.28	18.46	19.94	16.88
4	19.57	17.73	20.56	18.50
5	15.74	17.42	21.68	19.32
Delta	3.83	1.66	10.81	2.49
Rank	2	4	1	3

6.3 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 Break thermal efficiency (BTHE) 15.4872 and S/N ratio was 25.6942 for optimum set of parameter as shown in Table 5.

TABLE 5
PREDICTED PERFORMANCE

S/N Ratio	BTHE (%)
25.6942	15.4872

6.4 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. Table 6 shows performance was compared with predicated performance and was found that the experimental value was nearer to the predicated value.

TABLE 6
COMPARISON BETWEEN PREDICATED VALUE AND EXPERIMENTAL VALUE

Brake Thermal Efficiency (BTHE)	
Predicated Value	Experimental Value
15.4872	15.1586

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7 Conclusion

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 results of the Taguchi experiment identify that 240 Injection Timing, Injection Pressure 140 bar, Compression Ratio 18 and Engine Load 5 kg are optimum parameter setting for highest break thermal efficiency. Engine performance is mostly influenced by Engine load and is least influenced by Injection Pressure. Confirmation experiment was done using optimum combination showed that Brake Thermal Efficiency was found by experiment also closer to the predicated value.

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