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Parametric optimization of single cylinder diesel engine for pyrolysis oil & diesel blend for mechanical efficiency using taguchi method

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Abstract

An experimental study has been carried out for pyrolysis oil blended with diesel used in single cylinder diesel engine. Pyrolysis oil is obtained from tire waste by pyrolysis process. Pyrolysis process is a thermo-chemical decomposition of organic matter in absence of oxygen. Blending of 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. load, blend proportion and injection pressure are taken as variable for optimization. As the experiment required simultaneously optimization of three parameters with five levels, taguchi method of optimization is used in this experiment. The results of the taguchi experiment identifies that 5% blend ratio, injection pressure 180 bar and engine load 20kg are optimum parameter setting for highest mechanical 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 mechanical efficiency was found by experiment is closer to the predicated value.

1. Introduction

In present position of the world, energy crisis due to fast depletion of fossil fuel is main problem. Increase in fuel price day by day, continuously growth of automobile industry, rapid growth in individual mobility and improved living standard, continuous accumulation of greenhouse gases are the main causes for development of alternative fuels [1].

In 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 [2].

Considering alternate fuels as a substitute of diesel, Researchers are continuously finding 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 [3]. The various techniques for admission of fuel and mixing of alternate fuel with diesel are required. Recently in this field, the research work is going on to increase maximum portion of alternate fuel in blend with diesel [4].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 maynot be reduced [2].

In such multivariate problem, use of non linear 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 are in the order of 20, 30 etc., like in the case of IC engines. In such situations mathematical modelling 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 on 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[5].

2. Pyrolysis oil

Pyrolysis oil is obtained from tire waste by process which is called pyrolysis process. It is a thermo-chemical decomposition of organic matter in absence of oxygen. Pyrolysis of waste vehicle tires with the purpose of fuel production for the usage 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 [6].

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 NO_x, SO_2, particulate and total unburned hydrocarbons were determined in relation to excess oxygen levels. Throughout the combustion tests, comparison of the emissions was made with 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 [7].

3. Experimental setup

The engine setup is shown in Figure-.1Single cylinder, vertical, water-cooled, self governed diesel engine made by “kilorskar” is used for this experiment. It is capable of developing 5 HP at 1500 rpm. Rope brake dynamometer with spring balances and loading screw is attached to the engine for measuring brake power. For fuel consumption, Calibrated fuel burette measurement was used. The inlet side of engine has anti-pulsating drum which is attached with manometer for measurement of suction pressure of air supplied to the engine. Calorimeter is provided after exhaust from engine which cooled the exhaust gases from engine. Temperature display unit is attached to sense the exhaust gas temperature.

Fig.1 Experimental setup

4. Methodology

Bi-fueling or blending is the simplest technique for admitting mixture of alternate fuel and diesel engines. In this method, the fuel selected for investigation is mixed with standard diesel oil in various proportions on volume basis and its properties such as calorific value was evaluated before admission. The minimum portion of pyrolysis oil is 5%.The other blends have 10%, 15%, 20%, 25% pyrolysis oil with standard diesel fuel. A method called 'Taguchi' was used in the experiment for simultaneous optimization of engine such as injection pressure, blend composition and load condition.

4.1 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 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 .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 five levels and hence, an L25 orthogonal array was used for the construction of experimental layout (Table 2, column -2,3, 4). The L25 has the parameters such as load, injection pressure and blend proportions are arranged in column 2, 3 and 4. (Table -2).

According to this layout, twenty-five (25) 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 higher mechanical 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.

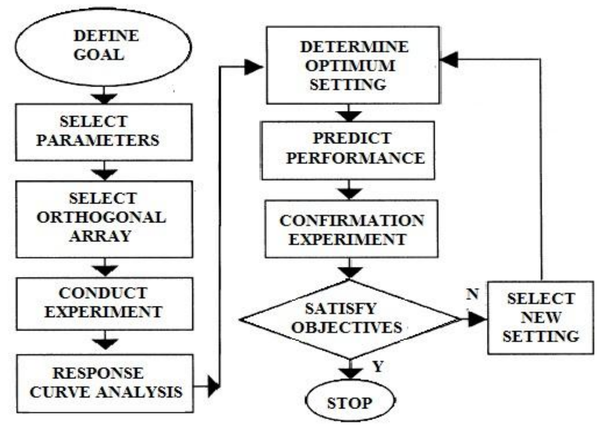

Fig.2 Flow chart of the Taguchi method

Experiment was conducted as per above step as shown in fig.2 in flow chart of taguchi method.

4.2 Selection of factor levels and orthogonal array

In this experiment, three parameters for five levels were considered (table-1). Control parameter and their level are given in table.L_{25} single orthogonal array shown in table-2(column-2, 3 & 4) was selected for the experimental investigation. "Bigger-the-better" is being taken as quality characteristics, since the objective function is to maximize performance.

Table-1 Process parameters and their level

Parameters	Engine load	Injection pressure	Blend ratio
Units	kg	bar	%pyrolysis Oil in diesel
Level 1	4	160	5
Level 2	8	180	10
Level 3	12	200	15
Level 4	16	220	20
Level 5	20	240	25

5. Result and Discussion

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 are given in the table.

Table- 2 Result table for Mechanical efficiency

Sr. No.	blend ratio(% of pyrolysis oil in diesel	Injection pressure	load	mechanical efficiency
1	5	160	4	39.59
2	5	180	8	56.73
3	5	200	12	66.29
4	5	220	16	72.39
5	5	240	20	76.62
6	10	160	8	51.67
7	10	180	12	61.59
8	10	200	16	68.13
9	10	220	20	72.77
10	10	240	4	34.83
11	15	160	12	61.59
12	15	180	16	68.13
13	15	200	20	72.77
14	15	220	4	34.83
15	15	240	8	51.67
16	20	160	16	63.03
17	20	180	20	68.06
18	20	200	4	29.89
19	20	220	8	46.02
20	20	240	12	56.12
21	25	160	20	74.32
22	25	180	4	36.67
23	25	200	8	53.66
24	25	220	12	63.46
25	25	240	16	69.84

5.1 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. Figure-4 shows significant effects for each factor for five 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.

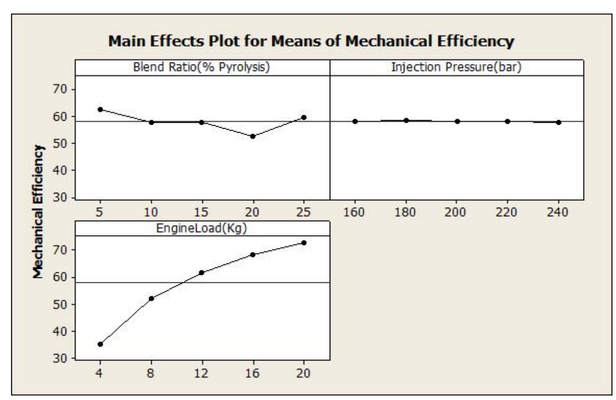

Fig.3 Main Effects Plot for Means of Mechanical Efficiency

From above figure-3, mean is average value for reading taken for particular parameter. From graph, mean value is maximum (62.33) for 5% blend and minimum (52.63) for 20% blend. Mean value is maximum (58.24) for 180 bar injection pressure and minimum (57.82) for 240bar injection pressure. Mean value is maximum (72.91) for 20 kg engine load and minimum (35.17) for 4 kg engine load.

Delta is difference of maximum value and minimum value. Delta value is maximum for load parameter (37.75) and minimum (0.42) for injection pressure parameter. Delta value for blend ratio is between other two parameter and it is (9.70).So that effect of load is maximum and effect of injection pressure is minimum on mechanical efficiency.

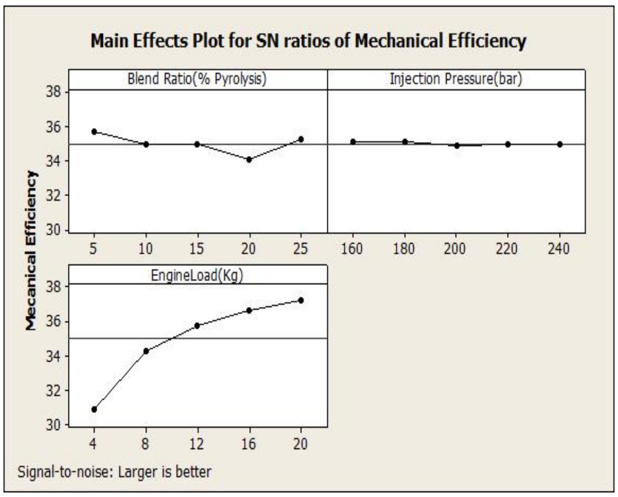

Fig.4 Main Effects Plot for SN ratios of Mechanical Efficiency

Referring (Figure-4) the response curve for S/N ratio, the highest S/N ratio was observed at 5% blend ratio(35.67),engine load(20kg) and injection pressure(180 bar),which are optimum parameter setting for highest mechanical efficiency.From delta values as mention above, maximum (6.36) for engine load and minimum (0.21). Parameter engine load is most significant parameter and injection pressure is least significant for mechanical efficiency.

5.2 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 highest mechanical efficiency. The optimum setting is determined by choosing the level with the highest S/N ratio. Referring figure-4 and table-3, the response curve for S/N ratio, the highest performance at set 5% blend ratio, engine load 20kg, and injection pressure180 bar, which is optimum parameter setting for highest mechanical efficiency.

Table 3 Response table for signal to noise ratio

Level	Blend Ratio	Injection Pressure	Load
1	35.67	35.08	30.89
2	34.96	35.10	34.29
3	34.96	34.89	35.81
4	34.08	34.92	36.68
5	35.25	34.93	37.25
Delta	1.59	0.21	6.36
Rank	2	3	1

5.3 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 maximum mechanical efficiency 77.42 % and S/N ratio was 38.0469 for optimum set of parameter as shown in table 4.

Table-4 Predicted Value for Mechanical Efficiency

Mechanical Efficiency	S/N Ratio
77.42	38.0469

5.4 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. As shown in table-5, this performance was compared with predicated performance and was found that the experimental value was nearer to the predicated value.

Table:5 Comparison between predicated value and experimental value

Mechanical Efficiency	
Predicated Value	Experimental Value
77.42	76.62

6. 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 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 5% blend ratio, engine load 20kg, and injection pressure180 bar, which are optimum parameter setting for highest mechanical efficiency.

3) Engine performance is mostly influenced by engine load and is least influenced by injection pressure.

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

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