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Parametric Optimization of Single Cylinder Diesel Engine for Jatropha Biodiesel and Diesel Blend for Mechanical Efficiency Using Taguchi Method

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Abstract: *An experimental study has been carried out for Jatropha biodiesel blended with diesel used in single cylinder diesel engine. Jatropha biodiesel is obtained from Jatropha oil by tranesterification process. Blending of Jatropha biodiesel 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 compression ratio 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 identifies that 50% blend ratio, compression ratio 16 and engine load 10kg are optimum parameter setting for highest mechanical efficiency. Engine performance is mostly influenced by engine load and is least influenced by blend ratio. Confirmation experiment was done using optimum combination showed that mechanical efficiency was found by experiment is closer to the predicated value.*
Keywords: *Blend ratio, Compression ratio, Mechanical efficiency, Taguchi, Jatropha*

I. Introduction

According to statistical review of world energy published by British Petroleum the increase of oil reserves in world from 2012 to 2013 is 0.60% whereas oil consumption increases from 2012 to 2013 is 1.40%. [1] Due to the increasing awareness of the depletion of fossil fuel resources and environmental issues, biodiesel became more attractive in the recent years. Biodiesel production is a promising and important field of research because the relevance it gains from the rising petroleum price and its environmental advantages. [2]

In present situation, there is much possibility of multifold increase in the research in biodiesel, vegetable oils like soybean oil, rapeseeds oil, sunflower oil, methanol, ethanol and other alternate fuels.

Considering alternate fuels as a substitute of diesel, Researchers are continuously finding best alternative solution, which gives the best performance and fuel characteristics. [3]

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 by using experimental techniques but it 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 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 on combined effects between input system parameters such as injection pressure, load, blend proportion on the performance characteristics of CI engine was scarce and offered a scope for this study. [4]

II. Jatropha Biodiesel

Jatropha biodiesel is obtained from Jatropha oil. It is reported that a dry seed of Jatropha curcas contains about 55% of oil. Following are the steps to be followed to extract oil from seeds:

1. Shelling: This is to remove the seed coat.
2. Milling: The unshelled seeds were milled into dough using the corn mill machine.
3. Moisture content: If moisture is less than 12% w.b. add water or else remove water to achieve 12% moisture content.
4. Rolling: Dough rolled into balls of about 1kg by weight.
5. Heating: Raise the temperature of the rolled dough to 75-80$0^0$ C by placing them in an oven.
6. Pressing: Rolled heated dough was pressed using the ram-press.
7. Filtration: The oil was collected and filtered. [5]

However, the maximum amount of oil that can be extracted from a given sample of the seed depends on the method of extraction and thus the quality of the feedstock. Two main methods of extracting the oil have been identified. They are the chemical extraction method using solvent extraction with n-hexane and the mechanical extraction method using either a manual ram-press or an engine driven-expeller. [5] The process of converting vegetable oil into biodiesel fuel is called Transesterification.

2.1 Transesterification Process

Table 1 Transesterification Process [5]

Vegetable Oil	Alcohol	Catalyst	Glycerin	Biodiesel
100 gm	12 gm	1 gm	11 gm	95 gm

It is the displacement of alcohol from an ester by another alcohol in a similar process to hydrolysis. Vegetable oil i.e. the triglyceride can be easily trans-esterified in the presence of alkaline catalyst at atmospheric pressure and at temperature of approximately 60 to 700C with an excess of methanol. If 100 gm of vegetable oil is taken, 1 gm of the alkaline catalyst (Potassium Hydroxide), and 12 gm of methanol would be required. As a first step, the alkaline catalyst is mixed with methanol and the mixture is stirred for half an hour for its homogenization. This mixture is mixed with vegetable oil and the resultant mixture is made to pass through reflux condensation at 650C. The mixture at the end is allowed to settle. The lower layer will be of glycerin and it is drained off. The upper layer of bio-diesel (a methyl ester) is washed to remove entrained glycerin. The excess methanol recycled by distillation. This reaction works well with high quality oil. If the oil contains 1% Free Fatty Acid (FFA), then difficulty arises because of soap formation. If FFA content is more than2% the reaction becomes unworkable. Methanol is inflammable and potassium hydroxide is caustic, hence proper and safe handling of these chemicals is must. [5]

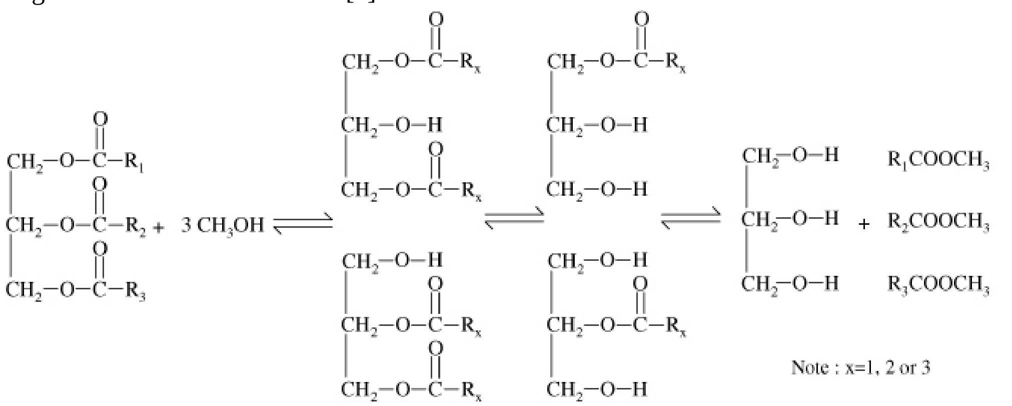

Figure 1 chemical process of Transesterification [6]

Table 2 Comparison of properties

Sr. No.	PROPERTIES	JATROPHA BIODIESEL	DIESEL
1	Colour	Golden Yellow	Orange
2	Specific Gravity at 30 °C	0.886	0.84 to 0.88
3	Gross Calorific Value (MJ/kg)	41	42
4	Kinematic Viscosity, Cst @ 40°C	4.20	2.0
5	Cetane number	57-62	55
7	Boiling point ºC	286	248
8	Solidifying point ºC	-10	-14

III. 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 and 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 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.

3.1 Technical Specifications

Model	TV1
Make	Kirlosker Oil Engines
Type	Four stroke, Water cooled, Diesel
No. of cylinder	One
Bore	87.5 mm
Stroke	110 mm
Combustion principle	Compression ignition
Cubic capacity	0.661 litres
Compression ratio 3 port	18:1
Peak pressure	77.5 kg/cm^2
Fuel timing for std. engine	0 to 25 BTDC
Power	3.5 kW @ 1500 rpm
Valve timing	
Inlet opens BTDC	4.5
Inlet closes ABDC	35.5
Exhaust opens BBDC	35.5
Exhaust closes ATDC	4.5
Lub. Oil pump delivery	6.50 lit/min.
Sump capacity	2.70 litre
Lub. Oil consumption	1.5% normally exceed of fuel
Connecting rod length	234 mm

Figure 2 Diesel engine setup

3.2 Compression Ratio adjustments:

- Slightly loosen 6 Allen bolts provide for clamping the tilting block.
- Loosen the lock nut on the adjuster and rotate the adjuster so that the compression ratio is set to "maximum". Refer the marking on the CR indicator.
- Lock the adjuster by the lock nut.
- Tighten all the 6 Allen bolts gently.
- You may measure and note the centre distance between two pivot pins of the CR indicator. After changing the compression ratio the difference can be used to know new CR.

IV. Methodology

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 diesel on volume basis. We used 50% blend and pure biodiesel. A method called 'Taguchi' was used in the experiment for simultaneous optimization of engine such as compression ratio, blend composition and load condition.

4.1Taguchi Method of Optimisation

Taguchi method is one of the simplest methods of optimising experimental parameters in less number of trials. The number of parameters involved in the experiment determines the number of trials required in the experiment. This method uses an orthogonal array to study the entire parameter space with only less number of experiments. To select an appropriate orthogonal array for the experiments, the total degrees of freedom have to be computed. The present study uses three factors at three levels and hence, L9 orthogonal array was used for the construction of experimental layout. The L9 has the parameters such as load, compression ratio and blend proportions. According to this layout, nine (9) 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 uses as a response parameter.

Taguchi method uses a parameter called signal to noise ratio (S/N) to measure the quality characteristics. There are three kinds of S/N are in practice. Of which, 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 its results. A confirmation experiment for the optimum set of parameters was also conducted for validation of the predicted value obtained by Minitab software. This is mainly used to compare the mechanical efficiency of predicted value and experimental value of optimum set of parameters.

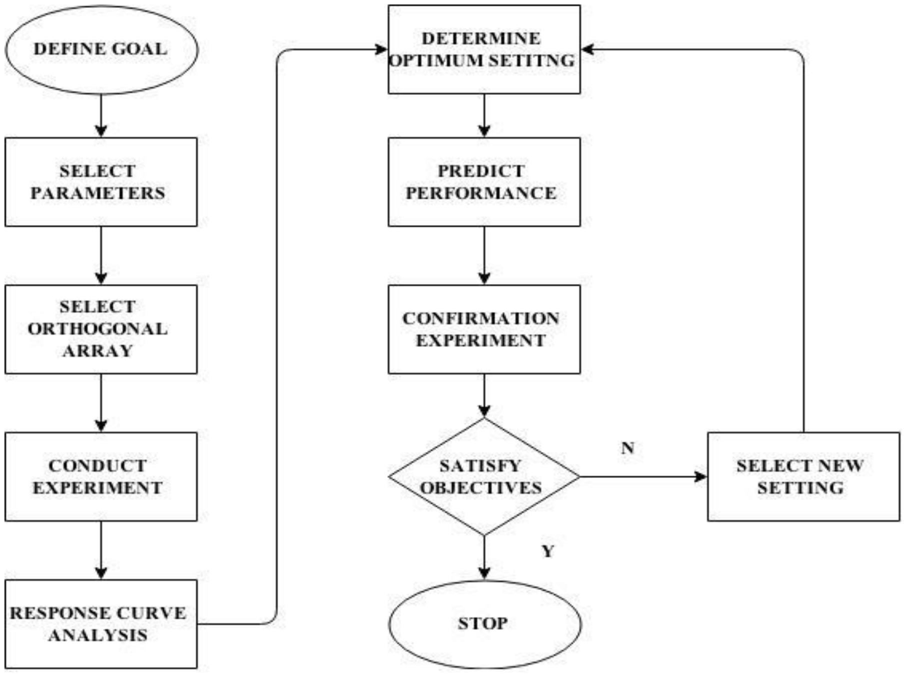

Figure 3 Flow chart of the Taguchi method.

Experiment was conducted as per above steps in Fig. 3 in flow chart of Taguchi method.

4.2 Selection of factor levels and orthogonal array

In this experiment, three parameters for three levels were considered. Control parameter and their levels are given in the table L9 single orthogonal array as shown in the table. Bigger-the-better is being taken as quality characteristics, since the objective function is to maximise performance.

Table 3 Process parameters and their levels

Parameters	Blend Ratio	Compression Ratio	Engine Load(kg)
Level 1	0	18	1
Level 2	50	17	5
Level 3	100	16	10

V. Result And Discussion

Experiment was done for selected sets of parameters by Minitab software and find mechanical efficiency for those sets of parameters.

Table 4 Result table for mechanical efficiency

Sr. No.	BR V/V	CR	load(kg)	Mech. Eff. (%)
1	100D0B	18	1	10.09
2	100D0B	17	5	37.02
3	100D0B	16	10	54.86
4	50D50B	18	5	36.15
5	50D50B	17	10	54.75
6	50D50B	16	1	11.49
7	0D100B	18	10	53.65
8	0D100B	17	1	10.21
9	0D100B	16	5	37.21

5.1 Response Curve analysis

Response curve analysis is aimed at determining influential parameters and their optimum levels. It is the graphical representations of change in performance characteristics with the variation in process parameter. The curves gives 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. Fig.4 shows significant effects for each factor for three levels.

The S/N ratio for performance curve were calculated at each factor level and average effects were determined by taking the total of each factor level and dividing by 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.

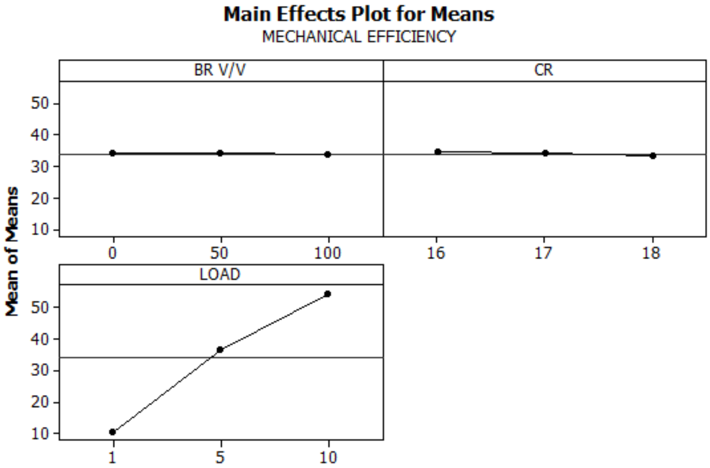

Figure 4 Main effects plot for means of mechanical efficiency

From above figure, mean is average value for reading taken for particular parameter. For blend parameter, mean value is maximum (33.99) for 0% blend and minimum (33.69) for 100% blend. For C.R., mean value is maximum (33.52) for 16 C.R. and minimum (33.3) for C.R 16. For load parameter, mean value is maximum (54.42) for 10 kg engine load and minimum (10.6) for 1 kg engine load.

Table 4 Response table of means

Level	Blend Ratio	Compression Ratio	Engine Load(kg)
1	33.99	34.52	10.60
2	34.13	33.99	36.79
3	33.69	33.30	54.42
Delta	0.44	1.22	43.82
Rank	3	2	1

Delta is difference of maximum value and minimum value. Delta value is maximum for load parameter (43.82) and minimum (0.44) for blend ratio parameter. Delta value for C.R. is between other two parameter and it is (1.22).So that effect of load is maximum and effect of blend ratio is minimum on mechanical efficiency.

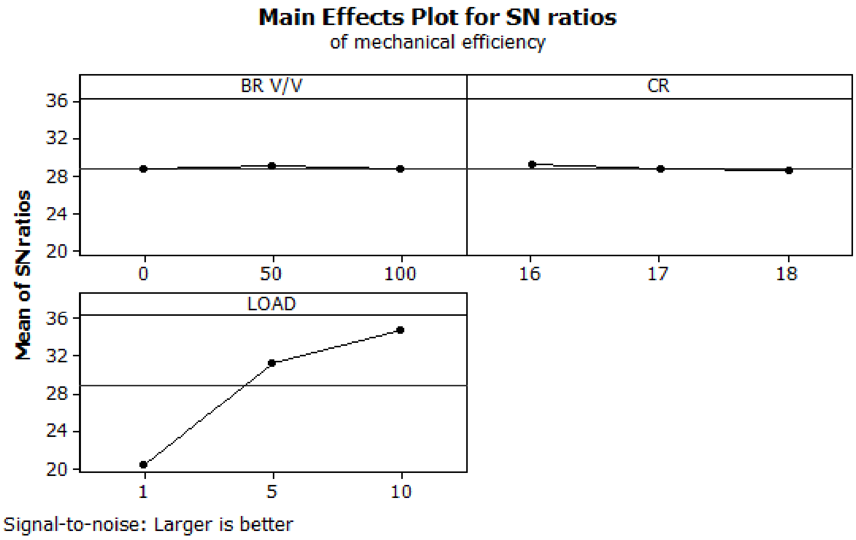

Figure 5 Main effects for SN ratio of mechanical efficiency

Referring (Figure-4) the response curve for S/N ratio, the highest S/N ratio was observed at 50% blend ratio, engine load (10kg) and C.R. (16), which are optimum parameters setting for highest mechanical efficiency. From delta values, maximum (14.23) is for engine load and minimum (0.32) is for blend ratio. Parameter engine load is most significant parameter and blend ratio is least significant for mechanical efficiency.

Table 5 Response table for signal to noise ratio

Level	Blend Ratio	Compression Ratio	Engine Load(kg)
1	28.74	29.13	20.49
2	29.05	28.77	31.31
3	28.73	28.61	34.71
Delta	0.32	0.52	14.23
Rank	3	2	1

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 and table, the response curve for S/N ratio, the highest performance at set 50% blend ratio, engine load 10kg, and compression ratio 16, which is optimum parameter setting for highest mechanical efficiency.

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 55.1967 % and S/N ratio was 35.2166 for optimum set of parameter as shown in table.

Table 6 Predicted Value for Mechanical Efficiency

Mechanical Efficiency	S/N Ratio
55.1967	35.2166

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, this performance was compared with predicated performance and was found that the experimental value was nearer to the predicated value.

Table 7 Validation of experiment

Mechanical Efficiency	
Predicted value	Experimental value
55.1967	54.20

VI. 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 50% blend ratio, engine load 10kg, and compression ratio 16, which are optimum parameter setting for highest mechanical efficiency.
3) Engine performance is mostly influenced by engine load and is least influenced by blend ratio.
4) Performance results obtained from the confirmation experiment using optimum combination showed excellent agreement with the predicated result.

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Appendix

Nomenclatures

bsfc	Brake specific fuel consumption
BR V/V	Blend ratio by volume
100D0B	100% diesel 0% biodiesel
50D50B	50% diesel 50% biodiesel
0D100B	0% diesel 100% biodiesel