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Parametric Optimization of CI Engine Fuelled with Jatropha Biodiesel - Diesel Blend using Taguchi's DOE Approach

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Abstract- *In this experiment, the outcome of injection pressure, load and blend ratio has been studied. The analysis has been done for SFC (Specific Fuel Consumption), BTHE (Brake Thermal Efficiency) and Mechanical Efficiency with diesel and Jatropha-biodiesel blend. Whole discussion of result has been conveyed out using Taguchi's design experiment. The overall study has stated that SFC will reduce, whereas BTHE, mechanical efficiency will increase at highest injection pressure. Minitab software is useful for analysis and preparing the results for Taguchi method. From that results the optimal set of parameters are generated. By using those parameters set the best results of SFC, BTHE and Mechanical Efficiency will obtain from engine. Jatropha biodiesel has its good effect on its functioning, so it's advantageous to use Jatropha biodiesel instead of diesel.*

Key Words- *Taguchi method; Jatropha Biodiesel; Blend ratio; Injection pressure*

I. INTRODUCTION

In recent scenario, a major research is centralised on the uses of regenerated energy resources. The increase in pollution and increase the need of petroleum reserves are main reason behind usage of biodiesel as an alternate fuel [1]. The increase is because growing population and decrease in fossil fuels. Now a day the crude oil costs are also increasing too high. So the research for the alternate fuel is must. Currently the regenerated energy sources are used up to 15% over the world's primary energy demands [2]. Still 80-85% necessity is fulfilled by the petroleum products [3]. More use of crude oil causes increase in pollution which is harmful for everyone living on earth. However, for reducing the pollution and uses of fossil fuel, it is more appropriate to make the use of the alternate fuels. Such encouraging liquid fuels in current use are ethanol, methanol, vegetable oils, non-edible oils and biodiesels. But biodiesel is reasoned as alternate fuel as its regenerated nature and environment friendly nature. The biodiesel has 12% less energy content than petroleum [4]. The biodiesel has more molecular weight, viscosity, flash point, etc. than diesel fuel. Jatropha a renewable, non-edible plant. The Jatropha oil distilled from its seed which have very similar properties to diesel, but ignition point, flash point, kinematic viscosity is high for Jatropha. It can bring out by chemical process known as 'transesterification' [5]. It's a process in which vegetable oil and/or animal fats reacts with an alcohol such as methanol. This reaction needs a catalyst, and strong acid as sodium or potassium hydroxide. After this process the new chemical compound which is made is known as methyl ester, and is defined as biodiesel [8].

II. LITERATURE REVIEW

Kazi et al. (2010)studied about 50% Jatropha and 50% diesel blend and established that the BTHE and BP are greater than diesel. But, mass of air, fuel consumption, and mass of fuel of biodiesel and air fuel ratio is lesserthan diesel. Also the % of CO_2 of biodiesel is lesser in diesel and also from the blend. The % of O_2 of biodiesel is greater than diesel and near with blend. Percentage of CO is zero in all cases [3]. **Chauhan et al. (2010)** researched on performance and emission of preheated Jatropha oil on diesel engine, this is due to experience that unwarmed Jatropha oil is somewhat lower for the performance than diesel. If the inlet fuel temp of Jatropha oil is increased, the viscosity decreases and engine performance is improved. The NO_X emission is increased with preheated Jatropha oil while HC, Smoke and CO were reduced and CO_2 emission is slightly higher [4].**Jindal et al. (2010)**observed about effect of IP and CR in diesel engine with Jatropha methyl ester at three values of IP and CR and found that at highest IP and highest CR the performance of engine will improves. The BSFC increased by 10% and BTHE by 8.9%. As rise in CR emission of hydro carbon and exhaust temp will also increase while smoke and CO emission will reduce. At highest IP the emission of HC, NOx and smoke were reduced, whereas CO emission and exhaust temp will increase [5].**Chalaton et al. (2011)**experiment about BTHE, BSFC, CO_2 and CO emission of diesel engine by using pure diesel, pure Jatropha, Jatropha and diesel blends. There is no vary in BTHE and BSFC till J20 ration (20% Jatropha oil & 80% diesel), but at higher blends there is decrease in efficiency and specific fuel consumption about 10-25%. At low blend CO_2 emission is less but it will also rise as the blends percentage were more. The emission of CO is much greater than diesel in all blend ratio [6]. **Gumus et al. (2012)**experimented about effects of IP on exhaust emission of diesel engine fuelled with biodiesel and diesel blends and found that as the load on engine increases, the exhaust temperature and emission of gases will increase and SFC will decrease. When the biodiesel and diesel blends were added the CO_2, O_2 and NO_x emission were increased because rise in combustion and CO and UHC emission will decrease [7].**Modi et al. (2014)** experimented about palm seed oil with diesel blend and use that in single cylinder diesel engine with Taguchi's method and found that at 16 CR, 180 bar IP and 10 kg load highest result of break thermal efficiency is noted [14]. **Patel et al. (2013)** studied about IP, injection timing, CR and load with tire waste pyrolysis oil blend with diesel fuel using Taguchi's method for analysis and found that at 22º injection timing, 200 bar IP, 16 compression ratio and 20 kg load. This set will give lowest break specific fuel consumption [15].

III. TRANSESTERIFICATION PROCESS FOR PREPARING JATROPHA BIODIESEL

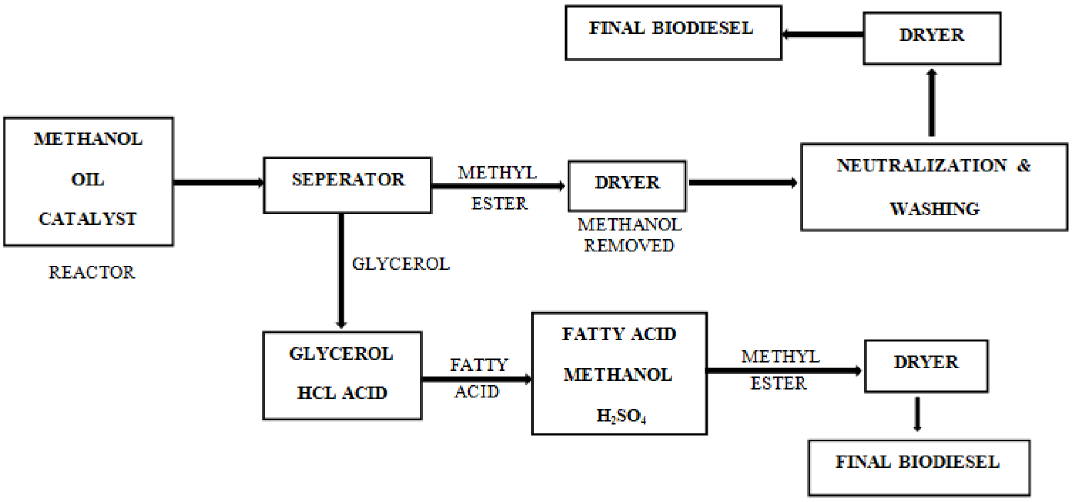

Fig. 1 Schematic diagram of biodiesel production

Figure 1 indicates basic schematic diagram for production of Jatropha biodiesel from the Jatropha oil. In this process three products as methanol, oil and catalyst were mixed in the reactor chamber. In which the oil is Jatropha oil and catalyst is KOH or NAOH. Then that mixer would be forwarded to separator chamber where methyl ester and glycerol will have separated. After that methanol will be removed from methyl ester by drying it and then neutralization and washing process will remove other dust particles and after that drying process will be applied on the cleaner mixture and the last biodiesel will be collected. Same way the HCL acid will added in glycerol which is isolated from separator chamber, the salt will remove and fatty acid were added in it so the mixture is fatty acid, methanol and H_2SO_4. After that adding methyl ester in it and drying the mixture final biodiesel will take in another flask [3].

IV. EXPERIMENTAL SETUP

Figure 2 shows an overview of experiment setup. Which is be formed of single cylinder, four stroke engine. It has multifuel injection system as one for diesel injection and one for petrol. At one side of engine eddy current dynamometer is placed, which is used to control load of engine. The benefit of engine is that the compression ratio can be changed without stopping the engine. The injection pressure as well as spark point will alsochange for research purpose as per requirement.

Fig. 2 Experiment setup [12]

There are sensors used for measuring values of different parameters, those values can be taken from computer device which is connected with engine set up. The setup has combination of air box, pressure indicators, two fuel flow measurements in single box panel. Rotameters are also provided with setup for cooling of water flow and calorimeter water flow measurement. For analysing performance of engine and for taking values of different parameters on computer a software package named 'Engine soft' is provided. Table 1 indicates engine specifications of model on which experiments have done.

Table 1 Engine specification [12]

Number of cylinder	Single Cylinder
Number of Stroke	4
Swept Volume	552.64 cc
Cylinder diameter	80 mm
Stroke length	110 mm
Connecting rod length	234 mm
Orifice Diameter	20 mm
Dynamometer Rotor Radius	141 mm
Fuel	Diesel
Power	5.2 kw
Speed	1500 rpm
Compression ratio range	12 to 18
Injection point variation	0 to 25 Before TDC

V. METHODOLOGY

Taguchi derived a method for reducing number of experiments and increasing speed of experiment process. By using this method, the effective solutions will be generated. Orthogonal Array (OA) are substantial parts of Taguchi method. The OA is an alternate solution for factorial design and has ability to evaluate some factors in a minimal number of tests. This method is reasoned as an effective technique as much result were obtained from a few trials. The Signal-Noise ratio of Taguchi method is a troupe of virtue and relates inversely to the loss function. It is identified as the ratio of amount of energy for specified function to amount of energy squandered [9]. With the concept of SN (Signal-Noise) ratio the various quality characteristics can be analysed using the method to accomplish high quality products [8].

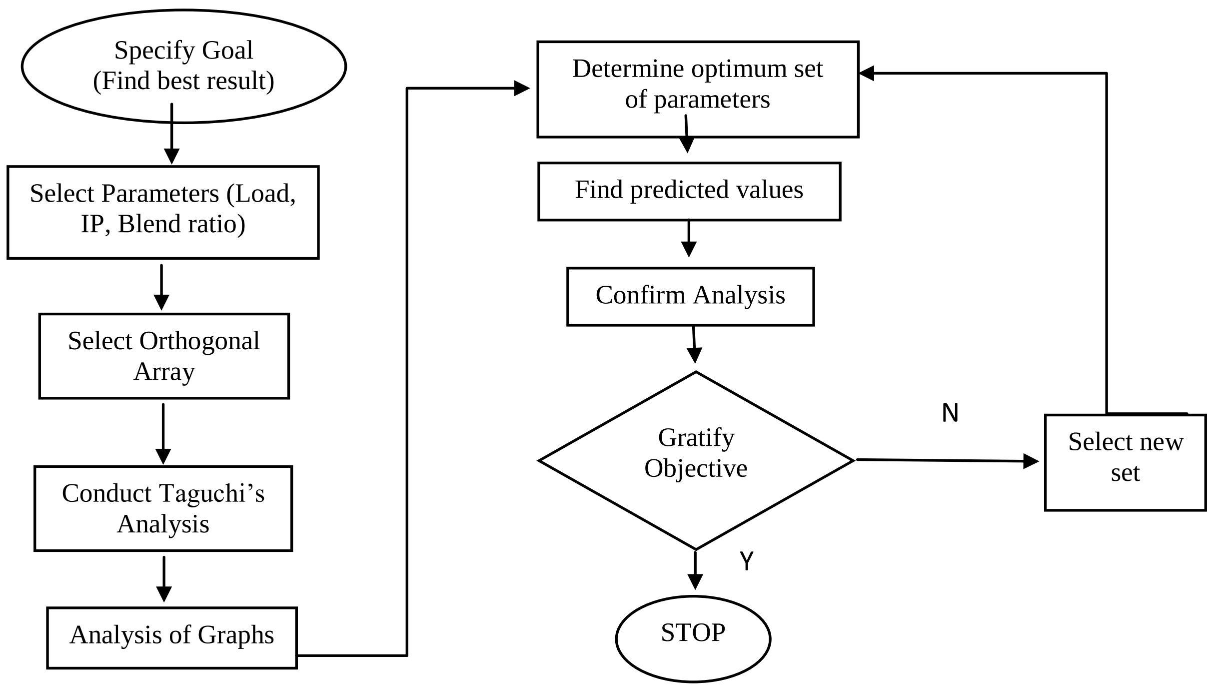

Fig. 3 Flow chart for methodology

Figure 3 shows basic flow chart for methodology. By following this steps optimum set of parameters will be found out and based on that result final conclusion will give optimum set.
The steps convoluted in Taguchi's DOE (Design of Experiment) method are [8],

- Discovering the response function and control parametric quantity to be measured.

- Deciding number of stages of control parameter.
- Choosing the advantageous orthogonal array, assigning the parameters to the array and directing the experiment.
- Analysing the experiment results and taking the optimal levels of control parameter.
- Validating the optimal control parameter through a compliance experiment.

VI. RESULTS AND DISCUSSION

The results of experiments are being calculated by using Minitab software. It provides four types of methods as: response surface method, full factorial method, mixture method and Taguchi method (robust method) [11]. After the analysis process, software offers some analytical and graphing techniques for understanding results and plotting the graphs. Table shows experiment results of different parameters which has been measured and analysed.

Table 2 Experiment result table

Sr. No	Blend Ratio (%)	Injection Pressure (bar)	Load (kg)	SFC (kg/kWh)	BTH Efficiency (%)	Mechanical Efficiency (%)
1	100D0B	L	2	0.38	22.50	16.64
2	100D0B	M	7	0.16	53.73	39.40
3	100D0B	H	12	0.14	61.59	52.59
4	50D50B	L	7	0.14	61.86	52.92
5	50D50B	M	12	0.39	21.84	16.37
6	50D50B	H	2	0.16	52.42	39.23
7	0D100B	L	12	0.16	52.04	39.94
8	0D100B	M	2	0.12	69.08	51.95
9	0D100B	H	7	0.33	25.85	15.89

Table 2 shows experiment result table which will indicates the results taken by doing experiment and it includes three different parameters as specific fuel consumption, break thermal efficiency and mechanical efficiency of single cylinder 4 stroke diesel engine. This results were taken for different blend ratios as 100D0B, 50D50B and 0D100B for different injection pressure as Low (160 bar), Medium (180 bar) and High (200 bar) at three different load as 2 kg, 7 kg and 12 kg. Whole analysis is done by using Taguchi's design of experiment.

Taguchi analysis for SFC with different blend ratio, IP and LOAD

Figure 4 shows that smaller value in means graph will give optimal result. In which optimum set of parameter is 0D100B blend ratio, medium IPi.e 180 bar and 12 kg load. This set of parameter will give best result.

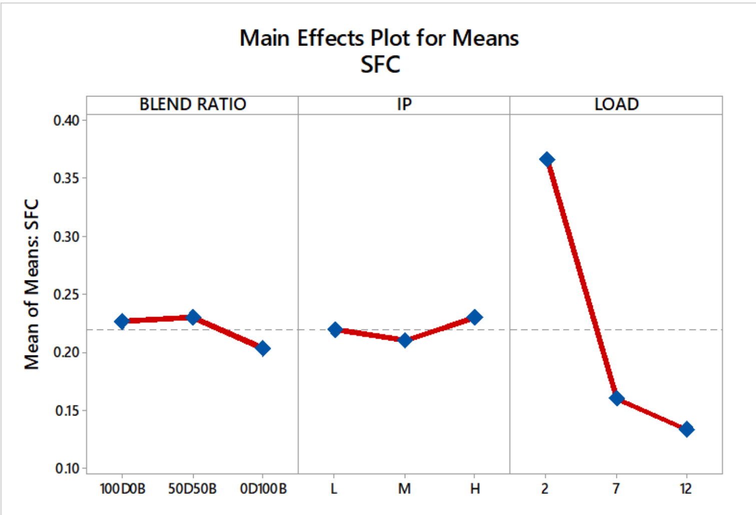

Fig. 4 Main effects plot for means: SFC

Table 3 shows effect of means for SFC in which the maximum delta value is 0.2333 it is of load and minimum delta value is 0.0200 it is of injection pressure. This result means that load will affect more on SFC and IP will affect less on SFC.

Table 3 Main effects plot for means: SFC

Level	BR %	IP	Load
1	0.2267	0.2200	0.3667
2	0.2300	0.2100	0.1600
3	0.2033	0.2300	0.1333
Delta	0.0267	0.0200	0.2333
Rank	2	3	1

Figure 5 shows effect for SN ratio of SFC (Specific Fuel Consumption), which indicates smaller is better which means the lowest values plotted on SN ratio graph will give optimum set of parameters. That optimum set of parameter will give best result as that setoff parameters will be used for engine as at that set of parameter the SFC will be less.

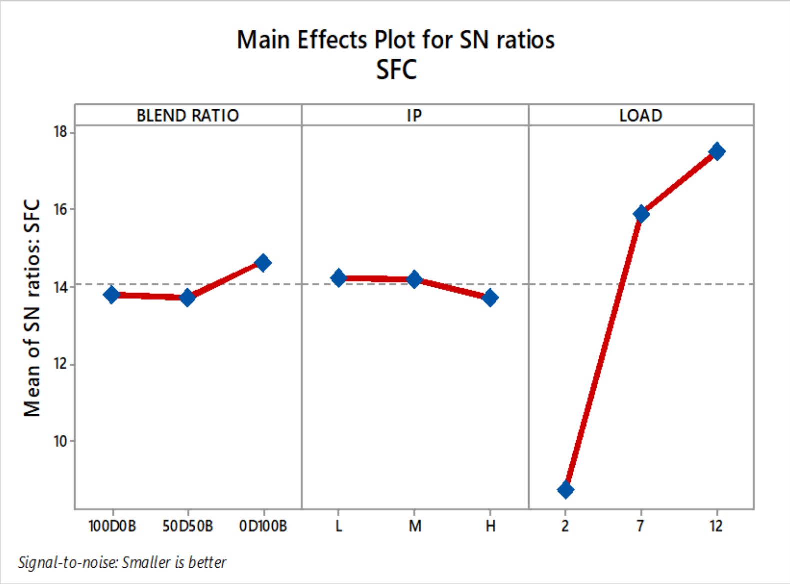

Fig. 5 Main effects plot for SN ratio: SFC

Table 4 shows effect of SN ratio in which the maximum delta value is 8.786 and minimum value is 0.930. From this values it is shown that load will affect more and blend ratio will affect less on the SN ratio for SFC.

Table 4 Main effects plot for SN ratio: SFC

Level	BR %	IP	Load
1	13.800	14.246	8.738
2	13.725	14.208	15.918
3	14.655	13.725	17.524
Delta	0.930	0.522	8.786
Rank	2	3	1

Table 5 demonstrates optimum set of parameter which is created from SN ratio graph. So the optimum result will be generated by using blend ratio 0% diesel and 100% Jatropha biodiesel, medium IPi.e 160 bar and load 12 kg. For this set of parameter foreseen value is 0.0.11667.

Table 5 Optimum set of parameters: SFC

BR %	IP	Load	Predicted Value
0D100B	L	12	0.116667

Taguchi analysis for Mechanical Efficiency

Fig. 6 Main effects plot for means: Mechanical efficiency

Figure 6 shows maximum value in graph which will give best result for the means of mechanical efficiency. As larger the values plotted on graph higher the performance is.

Table 6 Main effects plot for means: Mechanical efficiency

Level	BR %	IP	Load
1	36.21	35.94	16.30
2	36.17	36.07	39.52
3	35.93	36.30	52.49
Delta	0.28	0.36	36.19
Rank	3	2	1

Table 6 demonstrates effect of means for mechanical efficiency in which the maximum delta value is 36.19 which is of load and minimum delta value is 0.28 which is of blend ratio. So load will affect more on mechanical efficiency and blend ratio will affect less on it.

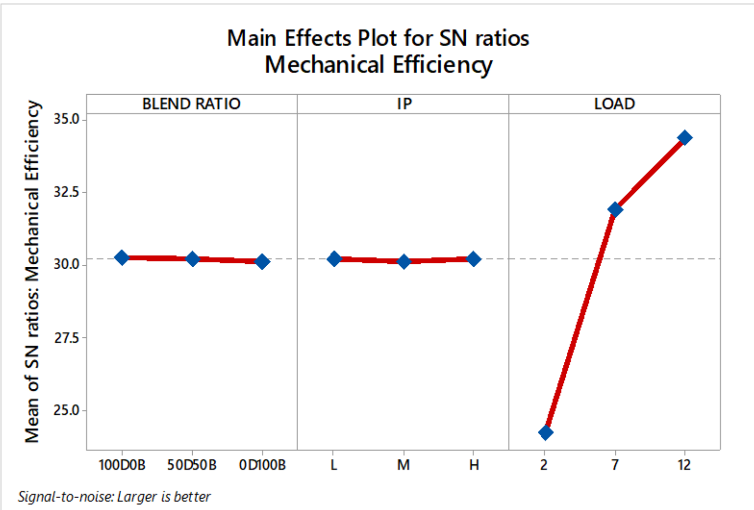

Fig. 7 Main effects plot for SN ratio: Mechanical efficiency

Figure 7 shows effect of Sn ratio for mechanical efficiency of engine. Larger the efficiency better the engine performance. The highest values on the graph will give optimal set of parameters, optimum set of parameters are defined in the table below.

Table 7 Main effects plot for SN ratio: Mechanical efficiency

Level	BR %	IP	Load
1	30.25	30.20	24.24
2	30.21	30.13	31.94
3	30.12	30.24	34.40
Delta	0.13	0.11	10.16
Rank	2	3	1

Table 7 shows delta value of SN ratio for mechanical efficiency in which the larger value is 10.16 which is of load and smaller value is of 0.11 which is of injection pressure. So it is stated that load will affect more and IP will affect less on the SN ratio graph.

Table 8 Optimum set of parameter: Mechanical efficiency

BR %	IP	Load	Predicted value
100D0B	H	12	52.79

From table 8 it is clear that optimum set of parameter for mechanical efficiency is, blend ration of 100% diesel and 0% biodiesel, high pressure i.e. 200 bar and load of 12kg. For this set of parameters, the highest mechanical efficiency will generate, which is to be preferred while designing the engine. For this set the predictive value is 52.79 while experiment value is 52.59 from which it is clear that this set of parameter will definitely give a good performance.

Taguchi analysis for Brake thermal efficiency

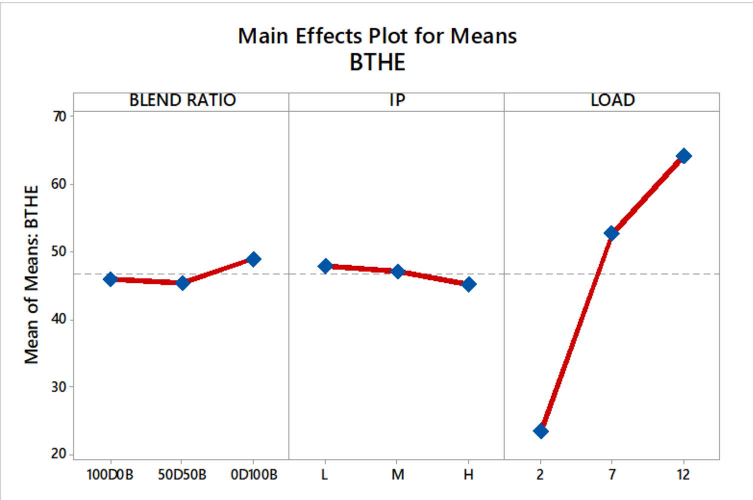

Fig. 8 Main effects plotfor means: BTHE

Figure 8 indicates effect of means for brake thermal efficiency in which the larger value gives optimum result. By using those set of parameters better result will be generated for brake thermal efficiency.

Table 9 Main effects plot for means: BTHE

Level	BR %	IP	Load
1	45.94	48.00	23.40
2	45.37	47.15	52.73
3	48.99	45.16	64.18
Delta	3.62	2.84	40.78
Rank	2	3	1

Table 9 shows effect of means for brake thermal efficiency in which maximum value is 40.78 which is of load and minimum value is 2.84 which is of injection pressure. So load will affect more on BTHE and IP will affect less.

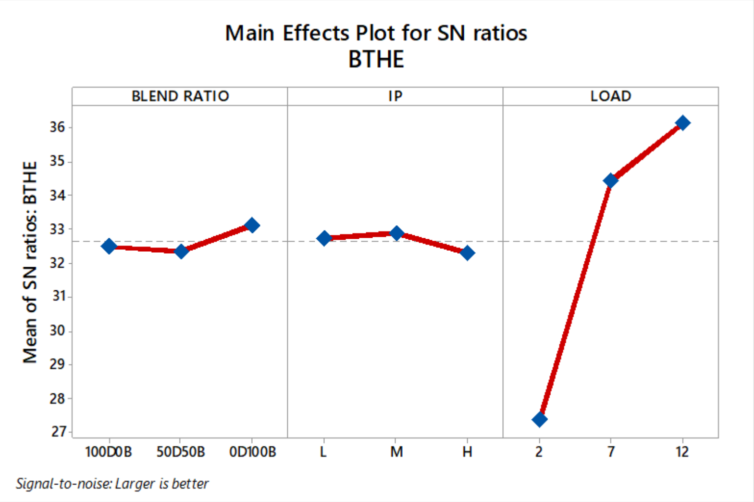

Fig. 9 Main effects plot for SN ratio: BTHE

Figure 9 shows effect of SN ratio for brake thermal efficiency of engine. Engine performance will increase as increase in brake thermal efficiency of engine. So higher the BTHE better the engine performance.

Table 10 Main effects plot for SN ratio: BTHE

Level	BR %	IP	Load
1	32.48	32.74	27.36
2	32.33	32.89	34.44
3	33.12	32.30	36.14
Delta	0.79	0.59	8.78
Rank	2	3	1

Table 10 shows effect of SN ratio for brake thermal efficiency in which the load has maximum value of 8.78 and IP has minimum value of 0.59. So it is clear that load will affect more and injection pressure will affect less on SN ratio result.

Table 11 Optimum set of parameters

BR %	IP	Load	Predicted value
0D100B	M	12	66.7778

Table 11 shows optimum set of parameters which will give a better result of BTHE for engine and they are, blend ratio of 0%diesel and 100% biodiesel, medium injection pressure i.e 180 bar and load of 12kg. For this set of parameters predictive value is 66.7778 and experiment value is 65.9542 which is lower than predictive value. So this set of parameters will give good performance result of brake thermal efficiency.

Validation of experiment

Table 12 Validation table of experiments

Response	BR %	IP	Load	Predicted value	Experimented value	Difference
SFC	0D100B	L	12	0.116667	0.12	0.003333
Mechanical Efficiency	100D0B	H	12	52.79	52.59	0.2
BTHE	0D100B	M	12	66.7778	66.4254	0.3524

Table 12 shows different predicted values, experiment values difference of two. Which tells that predictive value of optimum set for SFC is 0.116667 and for same experiment value is 0.12, difference of that two is very near as 0.003333 is very minor. Predictive value for Mechanical Efficiency is 52.79 and for experiment it is 52.59 and difference is 0.2. Predictive value for BTHE is 66.7778 and experiment value is 66.4254 and difference for that is 0.3524. This whole differences indicates that optimal set of parameters give better result in engine performance.

VII. CONCLUSIONS

From the experiment the conclusion derived is as follows

- Taguchi method is best method for analysis of experiments. It is less time consuming method. The results were easy to understand. The graph which are generated will also easily explainable.
- From result and discussion, it is found that Jatropha is useful biodiesel instead of diesel. As some results generated are in fever of Jatropha biodiesel. So it will appropriate to use Jatropha biodiesel.
- The result and discussion chapter tells that there are optimum set of parameters for SFC, Mechanical Efficiency and Brake Thermal Efficiency.
- Optimum set for SFC is 0D100B blend, low injection pressure and load of12kg. This set of parameters will give less specific fuel consumption.
- Optimum set for Mechanical efficiency of engine is 100D0B blend, high injection pressure and load of 12 kg. This parameterwill give highest mechanical efficiency for engine.
- Optimum set for Brake thermal efficiency is 0D100B blend, medium injection pressure and load of 12kg. This set of parameters will give highest brake thermal efficiency for engine.
- From all graphs it is clear that load is affecting more to the result and injection pressure will affect less.

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