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Taguchi Optimization of DI Diesel Engine Parameters to Improve Performance Fueled with Azadirachta Indica Biodiesel

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ABSTRACT

The deterioration of fossil fuel reserves, increased consumption of diesel fuel in automotives and perilous impact environmental pollution caused to find a economically renewable available and eco-friendly biofuel to replace the fossil diesel fuel. Recently, the past research reviews revealed that biodiesel that was prepared from vegetable oil (edible and non-edible) and or animal fats as one of the substitutes of fossil diesel fuel. But the tested diesel engine is not delivering adequate brake power as needed to perform the designated work. For this reason, the present paper is aimed to find the optimized combine engine parameters combination to enhance the engine power of a single cylinder, DI diesel engine using Taguchi method when fueled with Azadirachta indica oil methyl ester (AIOME) and its diesel blends. The research also investigates the effect of fuel injection pressure, AIOME percentage in blend and engine load which were considered as the controlled factors on engine performance characteristics in terms of brake thermal efficiency (BTE) and brake specific energy consumption (BSFC) which were considered as the response variables. The Taguchi's L16 orthogonal array was generated using design of experiments (DoE) methodology and a series of experimental tests were conducted as per designed array with different combination of influencing factors. Taguchi method employed to evaluate the influencing factors and significance of impact on response variables. The Taguchi analysis revealed that that the B20A blend of AIOME at 75% of engine load with 230 bar of fuel injection pressure were optimum parametric combination setting to enhance the BTE and BSFC to the highest possible level and to reduce the BSFC. Engine's performance characteristics are mainly influenced by engine load, followed by percentage of AIOME in blend and is least influenced by injection pressure.

Keywords : Biodiesel, Azadirachta indica oil, Methyl ester, Engine performance, Diesel blends

I. INTRODUCTION

The escalated energy demand due to intense use of fossil diesel fuel in automotives and tremendous demand because of rapid industrial development causing energy crisis in many countries. To resolve this issue and meet the need of energy demand, it has needed to focus on alternative renewable bio-fuels to replace the conventional petroleum fuels. The most probable way to meet this increasing demand and to reduce the hazardous emissions is by using biodiesels as alternative fuels, as shown by previous research reviews. Biodiesels encompasses methanol, plant oils and the methyl esters produced from these vegetable oils [1-4]. Biodiesels are clean burning, non-toxic and eco-friendly [5-7]. Many countries have recognized that the commercial production and usage of biodiesel can provide energy security, rural economic growth, and curb the undesirable impact on climatic changes. Already many nations are using vegetable oils like soybean, sunflower, rapeseed and palm as main feed-stocks as biodiesel [8-9].

In the last century, it was noticed that methyl/ethyl ester based biodiesels that were produced using vegetable oils and animal fat can be used as fuel in compression ignition engine [10,11]. But most of research studies revealed that the performance as well as emissions was reduced from the diesel engine when fuelled with biodiesel and their blends than diesel fuel. Recently, few researchers revealed that miniature changes in the engine design and operating parameters such as fuel injection pressure, fuel injection timings, compression ratio, combustion chamber type, engine speed, load etc., increases the engine performance and also reduces the emissions [12, 13]. Sivaramakrishnan et al. Conducted optimization process using response surface methodology (RSM) to identify the optimum values for engine parameters to increase the performance and to reduce the emissions of a diesel engine. They have identified highest performance and low emissions at 17.9 of compression ratio of B10 biodiesel blend at 3.81 kW of load which were considered as the optimum engine parameter values of the engine [14]. Nigade et al. applied grey relational analysis for optimization of compression ignition direct injection (CIDI) engine performance using Madhuca Indica biodiesel blend as fuel. The optimal combination of input parameters was identified when CR is 18, FIP is 310 bar, injection nozzle geometry is 3H, fuel fraction (FF) is 15% and without additive(s) [15].

II. METHODS AND MATERIAL

A. Preparation of Biodiesel and its Properties

The Azadirachta indica (neem) oil was bought from local vendor and prepared biodiesel using trans-esterification process to reduce its viscosity and density and increase the cetane number. The figure 1 below shows the transesterification chemical reaction to in the production process of methyl ester biodiesel. After completion of transesterification process and the taking apart of the heavy glycerin, the producer is left with a light crude biodiesel phase. This neat biodiesel was filtered and further purified prior to use in diesel engine as fuel. The chemical properties of biodiesel and diesel fuel are presented in Table I.

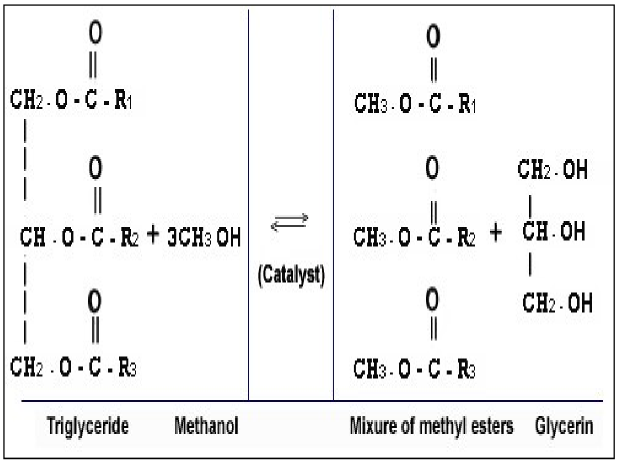

Figure. 1 Chemical Reaction of Transesterification Process

TABLE I

FUEL PROPERTIES OF DIESEL AND BIODIESEL BLENDS

Property	Diesel	AIOME
Kinematic Viscosity at 40^0 C (Cst)	3.58	4.6
Density at 15^0 C (Kg/m^3)	830	868
Flash Point (^{0}C)	51	152
Cetane Number	50	54
Calorific Value (KJ/kg)	42000	39500
Total Sulphur (% by	0.01	Nil

B. Orthogonal Array of Taguchi

In this work, three factors and four levels were chosen to study the effect of these three factors on objective parameter which is engine exhaust emissions. The parameters of diesel engine: fuel injection pressure, percentage of AIOME in biodiesel blend, and engine load were considered as the factors that influencing the brake thermal efficiency (BTE) and brake specific energy consumption (BSFC) that are considered as responsive parameters. The list of control parameters and levels are presented in table II.

TABLE II

FUEL PROPERTIES OF DIESEL AND BIODIESEL BLENDS

Control Parameters	Level 1	Level 2	Level 3	Level 4
A. Engine Load	25	50	75	100
B. AIOME Percentage in Blend	20	40	60	100
C. Injection Pressure	210	220	230	240

In order to determine the optimized parametric values to reduce the emissions, quiet number of experimental tests should conducted when the number of process parameters and levels increases. To reduce the number of experimental tests to be conducted, a special design of orthogonal arrays of Taguchi to study the entire parameter space with only a small number of experiments. To solve this problem, the Taguchi method uses L16Orthogonal array for the present research analysis using design of experiments (DoE) and presented the orthogonal array in table III.

Taguchi has four different types of categorization of response variables for S/N ratio and are Larger-is-better to maximize the response, Nominal-is-best when the goal is to target the response and S/N ratio on standard deviations are required, Nominal is best when the goal is to target the response, the S/N ratio on means and standard deviations are required, and smaller is better when the S/N ratio should be selected that best meets the objective of the optimization. In this research study, the goal is to maximize the response variables of BTE and minimize the BSFC, and hence Larger-is-Better was selected to maximize the BTE and Smaller-is-Better to reduce the engine emissions when fuelled with AIOME biodiesel.

TABLE IIII

TAGUCHI'S L16 ORTHOGONAL ARRAY

Experiment Number	AIOME Percentage in Blend (A)	Engine Load (%) (B)	Injection Pressure (bar) (C)
1	1	1	1
2	2	1	2
3	3	1	3
4	4	1	4
5	1	2	2
6	2	2	1
7	3	2	4
8	4	2	3
9	1	3	3
10	2	3	4
11	3	3	1
12	4	3	2
13	1	4	4
14	2	4	3
15	3	4	2
16	4	4	1

C. Experimental Setup

For the present research analysis of Taguchi optimization, a single cylinder, 4-stroke water cooled compression ignition direct injection (CIDI) engine was used when it is fueled with AIOME. The specifications of the test engine are presented in Table II. The experiment setup is illustrated as schematic diagram below at figure 2 and photographic view is presented in figure 3. The setup consists of 3.7 KW diesel engine, eddy current dynamometer, smoke meter, and exhaust gas analyser. The dynamometer was coupled with engine shaft.

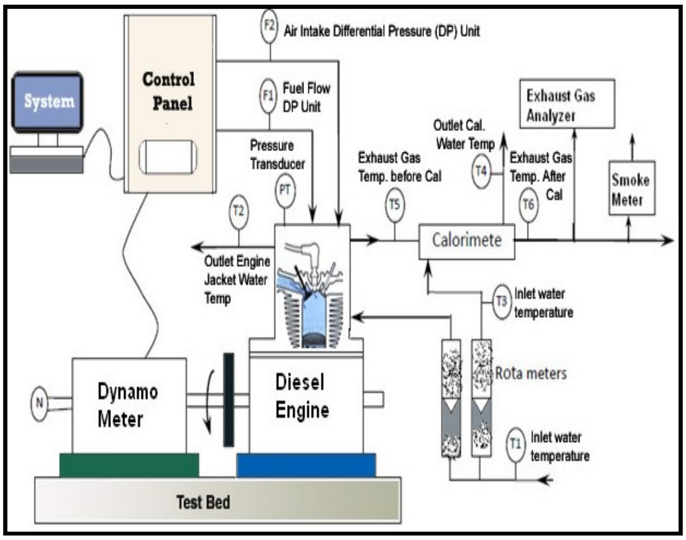

Figure 2. schematic diagram of experimental setup

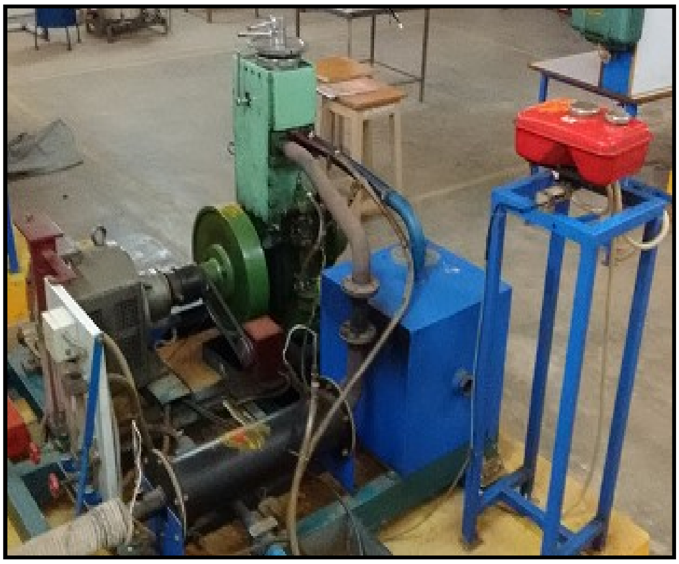

Figure 3. Photographic view of experimental setup

TABLE IIIV
SPECIFICATIONS OF TEST ENGINE

Engine Make	Kirloskar AV1, India
No. of Cylinders	One
Engine Details	Four stroke, Water cooled
Injection Type	Direct Injection
Bore & Stroke	80 × 110 mm
Rated Power	3.7 KW (5 HP) at 1500 rpm
Speed	1500 rpm
Injection Pressure	200 bar
Compression Ratio	16.5:1
Dynamometer	Eddy Current

III. RESULTS AND DISCUSSION

The Taguchi optimization was applied to identify the parametric optimization combination of the selected 3 three process parameters of diesel engine. The three input control variables: fuel injection pressure, AIOME percentage in blend, and engine load were chosen to evaluate the effect on two output response parameters: BTE and BSFC.

A. Brake Thermal Efficiency (BTE)

The signal-to-noise (S/N) ratios for the output response parameter: brake thermal efficiency (BTE) was estimated using sing Minitab software and the calculated S/N ratios are shown in Table V. The Figure 4 shows the effect of the three influencing control factors on the S/N ratios of BTE. From the main effects plot of BTE, it is evident that B20 blend of AIOME at engine load of 75% with 230 bar of injection pressure combination has the highest degree of inclination with parallel plan and highest S/N ratio of 29.3271 for BTE. It means the test engine delivers maximum BTE at this parametric combination.

TABLE V EXPERIMENTAL RESULTS – S/N RATIO

AIOME Percentage in Blend (%)	Engine Load (%)	Injection Pressure (bar)	S/N Ratio-BTE (%)	S/N Ratio-BSFC (kg/kW-h)
20	25	210	24.2278	-4.58296
20	50	220	26.7811	-7.53501
20	75	230	29.3271	-3.29888
20	100	240	29.1030	-7.82948
40	25	220	23.2333	-4.26497
40	50	210	26.4527	-7.13095
40	75	240	28.3325	-9.31948
40	100	230	28.7455	-8.77797
60	25	230	22.4649	-4.26497
60	50	240	25.5116	-4.58296
60	75	210	28.0736	-8.971
60	100	220	29.0938	-8.94664
100	25	240	23.6163	-5.19275
100	50	230	25.5516	-6.30309
100	75	220	28.5998	-9.29412
100	100	210	28.7105	-9.11864

The Table VI displays the computed delta values of each control parameter. From the delta values, it was noticed that engine load has the most significant influence on BTE with delta value of 5.53, followed by biodiesel content percentage in the blend with delta value of 1.07 and the injection pressure has least influence on BTE with delta value of 0.4 among all three control factors.

B. Brake Specific Fuel Consumption (BSFC)

The effect of three input control parameters on BSFC is depicted in Figure 5. Based on the angle of inclination of curves in the main effects plot for S/N Ratios for BSFC and the highest S/N ratios of the BSFC, it was noticed that the B20 blend of AIOME at engine load of 75% with 230 bar of injection pressure has the optimum process parametric combination corresponding to lower the BSFC. The response table for signal-to-noise ratios for BSFC is presented in Table VI. From the data, it has been noticed that engine load has the major significant effect on BSFC, followed by biodiesel content percentage in the blend and the least influenced by injection pressure.

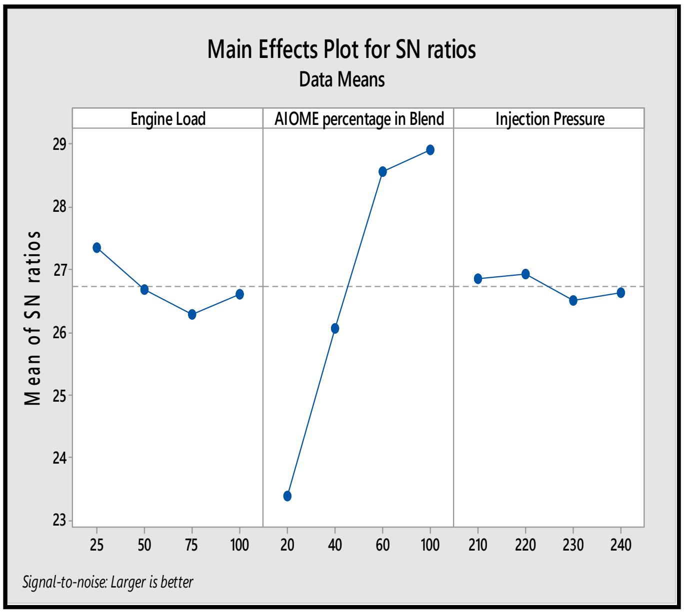

Figure 4: Main Effects Plot for S/N Ratios of BTE

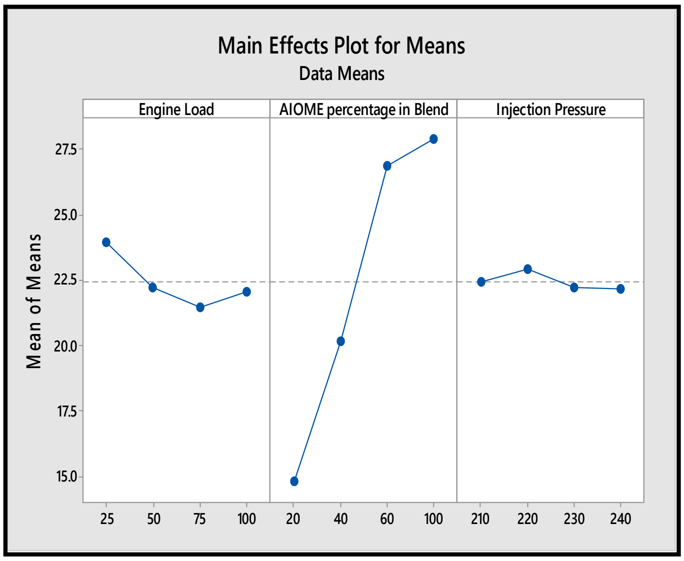

Figure 5: Main Effects Plot for Mean of BTE

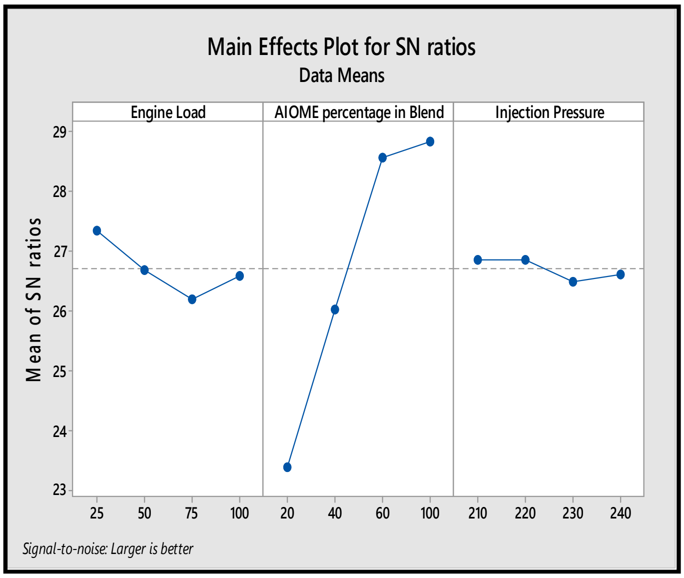

Figure 6: Main Effects Plot for S/N Ratios of BSFC

TABLE V

RESPONSE TABLE FOR S/N RATIOS OF BTE

Level	AIOME Percentage in Blend	Engine Load	Injection Pressure
1	27.36	23.39	26.87
2	26.69	26.07	26.93
3	26.29	28.58	26.52
4	26.62	28.91	26.64
Delta	1.07	5.53	0.40
Rank	2	1	3

(larger is better)

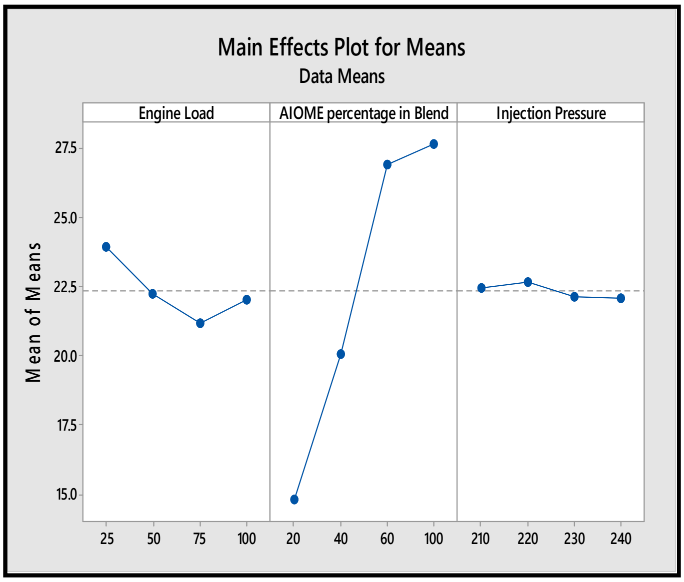

Figure 7: Main Effects Plot for Mean of SBFC

TABLE VI
RESPONSE TABLE FOR S/N RATIOS OF BSFC

Level	AIOME Percentage in Blend	Engine Load	Injection Pressure
1	-6.053	-4.414	-7.451
2	-7.453	-6.388	-7.590
3	-6.450	-7.962	-5.661
4	-7.477	-8.668	-6.731
Delta	1.424	4.254	1.228
Rank	2	1	3

(smaller is better)

IV.CONCLUSION

In this research work, the Taguchi analysis was employed in order to establish the optimum combination of control parameters and effect of the engine parameters such as engine load, AIOME biodiesel percentage in blend and fuel injection pressure of diesel engine on brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC). The experimental trials were carried-out using a single cylinder, 4-stroke compression ignition direct injection engine fuelled with different blends (B20A, B40A, B60A and B100A) of Azadirachta indica oil methyl ester (AIOME) as biodiesel. The results of Taguchi analysis revealed that that Injection pressure 230 bar, blend B20A of AIOME at 75% of engine load are optimum parametric combination to achieve higher engine performance in terms higher BTE and lower BSFC.

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