Optimizing Engine Parameters to Reduce EGT and NOx of CIDI Engine Fueled with Methyl Ester of Jatropha Oil

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***Abstract*— The present work aims to carry-out the optimization process by applying Taguchi on engine parameters to reduce the exhaust gas temperature and NOx emissions released from the diesel engine when fueled with jatropha curcas oil methyl ester as biodiesel. The fuel injection pressure, percentage of biodiesel in the blend and engine load were selected as three influencing engine parameters on the response parameters of EGT and NOx emissions. Taguchi method was employed to investigate the each control parameter influence and to identify the right optimum combination of parameters on each response parameter. The experimental analysis was carried-out based on L16 orthogonal array layout which was designed using Design of Experiments (DoE) methodology. Taguchi's signal-to-noise (S/N) ratio values shown that EGT, and NOx were mainly influenced by the engine load followed by percentage of biodiesel content in blend and least influenced by fuel injection pressure. In addition, the optimized EGT and NOx emissions were found at 220 bar of injection pressure of diesel engine running at 25% of load condition when fueled with B40 jatropha biodiesel blend.**

***Index Terms*— Biodiesel, Optimization, Taguchi Method, Exhaust Emissions, Design of Experiments, Jatropha Biodiesel**

I. INTRODUCTION

The biodiesel is gaining enormous momentum across the globe due to global energy crisis, dwindling fossil fuel reserve and ever increasing fossil fuel prices. It can be a prospective alternative to petro-diesel fuel because plant based biodiesel and their diesel blends have diesel fuel like performance and emission characteristics. The alternative renewable energy sources such as biodiesel are produced from local feedstocks which are biodegradable, less polluting, clean-burning, less toxic, and essentially free of chemical compounds such as sulfur. The production of biodiesel improves the rural economy by increasing the local job opportunities [1]. In the biodiesel preparation the main raw material is feedstock and the past research studies have identified many edible oils such as sunflower, soybean, palm, rapeseed, safflower, and peanut oils etc., as suitable feedstock [2,3]. But, it has raised concerns about deforestation and fear of generating food crisis especially in heavily populated countries such as India and China. Then, researchers have turned their focus toward to utilize the non-edible oils such as karanja, rubberseed, neem, cottonseed, mahua, castor, etc. [4-7] as feedstock of biodiesel. The plants of non-edible oil can be grown on the waste marginal and unfertile lands with less water facility. Moreover it cannot be compete with food products. Since then, the non-edible oils were considered as potential renewable feedstock in biodiesel preparation [8, 9].

Diesel fuel is the single major source for hazardous exhaust gas emissions, which damages the eco-system and eventually harms human health. Recently, biodiesel was identified as suitable alternative renewable fuel, because it emits fewer exhaust gases than diesel fuel. The past research reviews have identified that many engine parameters such as compression ratio, injection timings, injection pressure, percentage of biodiesel content in fuel, diesel additives, and engine operating speed influence the performance and exhaust emissions of the diesel engine. Murthy et.al [58] were used vegetable oil in a conventional diesel engine, which showed the deterioration in the performance, while LHR (Low Heat Rejection) engines showed improved performance, when compared to pure diesel operation on conventional engine. The increase in fuel injection pressure, increased the engine efficiency and decreased emission levels of the engine [10]. Sun Tae et al. (2010) were applied Taguchi method for optimization of process parameters for rapeseed methyl ester production and revealed that 96.7% yield of biodiesel was achieved using Potassium hydroxide as the catalyst and 60°C of reaction temperature as optimized parameters values [63]. Shankar et al., were conducted experiments using Coconut oil to investigate the effect of injection pressure on the performance and emission characteristics of biodiesel blends of B20, B30 and B100 at four different injection pressures of 180, 200, 220 and 160 bar. The investigation results revealed that 200 bar was the optimum injection pressure with B20 and B30 blends, which resulted in better performance and emission characteristics with biodiesel blends as fuel [12]. İsmet Çelikten et al., were investigated the performance and emissions of the diesel engine at different injection pressures such as 200 bar, 300 bar, and 350 bar using Rapeseed methyl ester and Soy bean methyl esters as fuels. The experimental results revealed that performance and emission characteristics of rapeseed oil and soybean oil methyl esters were found to be nearly the same as diesel fuels when injection pressure was increased to 300 bar [13].

In this work, Taguchi optimization technique was employed to investigate the effect and to determine the combined optimum engine parameters to reduce the exhaust gas temperature (EGT) and NOx emissions of single cylinder direct injection diesel engine.

II. EXPERIMENTAL SECTION

A. Preparation of Biodiesel

Crude jatropha curcas oil was collected from the local vendor to prepare the biodiesel. The jatropha curcas oil can be used directly in unmodified diesel engine in its pure form, but it generates engine problems such as injector choking, severe carbon deposits, and piston ring sticking in the diesel engine. This is because the higher viscosity, density, and lower cetane number of the jatropha oils. Usually, pyrolysis, dilution, micro-emulsion and transesterification processes are the most commonly used methods to reduce the viscosity and to bring the combustion properties of vegetable oil closer to that of diesel fuel. As shown in Figure 1, in transesterification process, vegetable oil/fat (triglycerides) react with methyl alcohol in the presence of sodium hydroxide as a catalyst. The reaction produces methyl ester of oil/fat, which is called biodiesel.

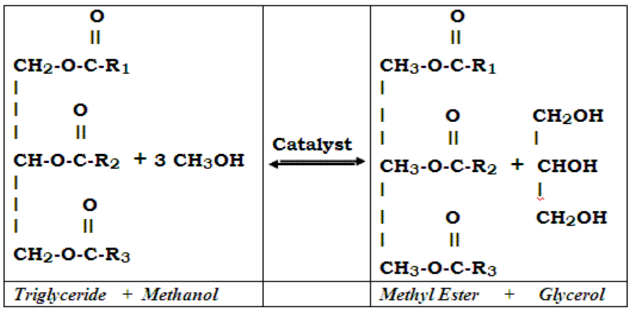

Fig. 1 Transesterification Process

The biodiesel and diesel properties are shown in Table 1.

Table 1: Properties of Diesel and Biodiesel

Fuel Property	Unit	Diesel	Jatropha Biodiesel
Kinematic Viscosity @ 40°C	CST	3.52	5.4
Flash Point	°C	49	169
Density @ 15°C	kg/m³	830	872
Calorific Value	kJ/kg	42850	38500
Cetane Number	--	50	53
Total Sulfur	% by mass	0.01	Nil
Carbon Residue	% w/w	0.1	0.36
Ash Content	% by mass	0.01	0.03

B.Application of Taguchi Method

In all optimization techniques, the Taguchi method has been most widely used in many engineering and biotechnology applications. To apply the Taguchi optimization technique, a selected test data was required. The experimental test data can be designed by using the design of experiments (DOE) of Taguchi. Before this design, the selection of control parameters and their levels are essentially required in the Taguchi analysis. For the present work, engine load, biodiesel content percentage in blend and fuel injection pressure were considered as the factors influencing the objective. The levels of the factors to be included for testing were chosen based on the conclusion of the earlier researchers during their research work with those factors individually.

Table 2: Control Parameters and Levels

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

Using the design of experiments (DoE) of Taguchi, the orthogonal arrays that provides layout for experimentation trials with the various possible combinations of different levels of engine parameters was prepared. In this work, L16 orthogonal array was designed with 16 experimental trials for different combinations of engine parameters to carry out the investigation and presented in Table 3.

Table 3: L16 Orthogonal Array of Taguchi

Trial	Biodiesel Percentage in Blend (%)	Engine Load (%)	Injection Pressure (bar)
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

B.*Experimental Setup*

For the present research work, a single cylinder, four-stroke, water cooled, 3.7 kW compression ignition direct injection engine was used to conduct experimental analysis. The engine was connected to an eddy current dynamometer using coupling for applying the load. As shown in Figure 2 & 3, the major components of the experimental setup are the test diesel engine with fuel tank, dynamometer, exhaust gas line, data acquisition system, computer, exhaust gas temperature measurement system, smoke meter and multi-gas analyzer.

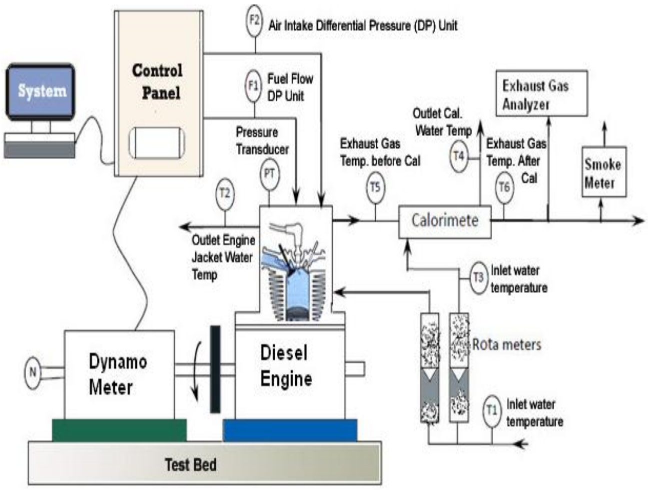

Fig. 2 Schematic Diagram of Test Setup

The technical specifications of the test engine are listed in Table 4.

Table 4: Test Engine Specifications

Engine Type:	Kirloskar AV1, India,
Engine Details:	Single Cylinder, Four Stroke, Water Cooled, Direct Injection Engine
Bore & Stroke:	80 × 110 mm
Rated Power :	3.7 KW (5 HP) at 1500 rpm
Rated Speed:	1500 rpm
Injection Pressure:	200 bar
Compression Ratio:	16.5:1
Dynamometer:	Eddy Current

The experimental runs were carried out as stated in L16 orthogonal array for the four different injection pressures from quarter load to full load conditions using the diesel and jatropha biodiesel blends. The smoke meter and gas analyzer readings of emissions were recorded for 16 test conditions.

Fig. 3 Photographic View of Test Setup

III. RESULTS AND ANALYSIS

In Taguchi optimization approach, the signal-to-noise (S/N) ratio plays a major role and used to determine the effect of input control parameters on each response variable. The S/N ratios of response parameters were computed using Minitab software (v17.1) and are listed in Table 5.

Table 5: S/N Ratios of Output Response Parameters

Trial	Biodiesel Percentage in Blend	Engine Load (%)	Injection Pressure (bar)	S/N Ratio for EGT	S/N Ratio for NOx Emissions
1	20	25	210	-44.609	-32.0412
2	20	50	220	-45.1536	-36.6502
3	20	75	230	-47.0822	-41.2892
4	20	100	240	-49.8552	-42.7976
5	40	25	220	-44.5577	-31.364
6	40	50	210	-46.107	-37.5012
7	40	75	240	-47.6403	-41.5109
8	40	100	230	-50.103	-43.4052
9	60	25	230	-45.4368	-32.2557
10	60	50	240	-46.4856	-38.2763
11	60	75	210	-47.8539	-42.1442
12	60	100	220	-50.1571	-43.6369
13	100	25	240	-45.7111	-33.2552
14	100	50	230	-46.6083	-38.3816
15	100	75	220	-47.924	-42.5421
16	100	100	210	-50.4749	-43.918

A .EXHAUST GAS TEMPERATURE (EGT)

The exhaust gas temperature (EGT) released from the diesel engine indicates the utilization level of the heat energy. The lower exhaust gas temperature is preferred for best utilization of energy by the engine, which in turn represents higher thermal efficiency. Hence, the lower value of EGT is preferred and hence the *Smaller-is-better* of S/N ratio criteria for optimization of the engine parameters was selected to minimize the EGT. The S/N ratios for EGT were computed using Minitab software and the response table for signal-to-noise (S/N) ratios is presented in Table 6 with delta statistics.

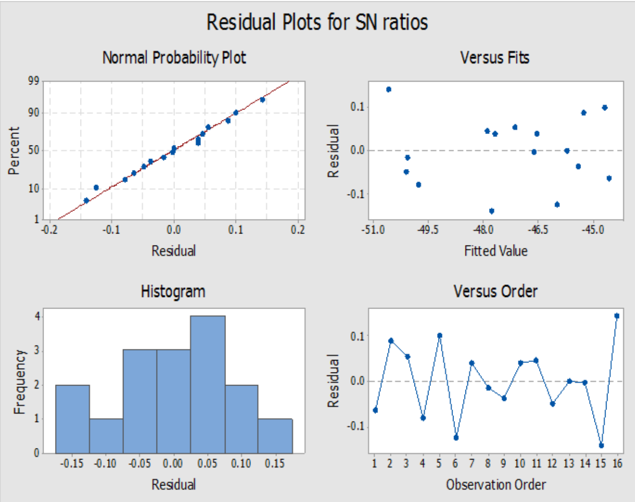

Fig. 4 Residual Plots for S/N Ratio – EGT

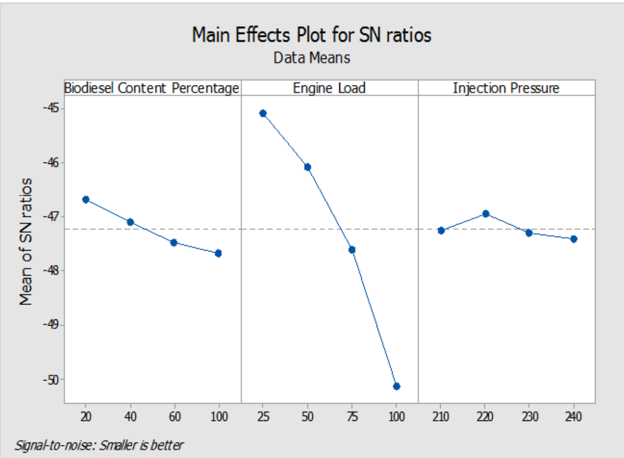

Fig. 5 Main Effects Plot for S/N Ratio – EGT

Table 6: Response Table for S/N Ratios – EGT

Level	Biodiesel Percentage in Blend	Engine Load	Injection Pressure
1	222.0	179.8	238.3
2	233.0	202.0	230.3
3	241.8	240.8	236.8
4	247.5	321.8	239.0
Delta	25.5	142.0	8.8
Rank	2	1	3

The cyclical/repeating pattern of order vs. residual graph in Figure 4 revealed that residuals may not be independent and instead dependent on other factors. The delta values and the maximum angle of interaction plots as shown in Figure 5 confirms that the engine load is most influencing factor in all 3 control parameters followed by the biodiesel content percentage in blend, then injection pressure.

B. NOx EMISSIONS

Nitrogen oxides (NOx) causes damage to the ozone layer and acid rains that leads to adverse effects on human health and should be reduced as much as possible. Hence the S/N ratio of *Smaller-is-Better* is selected for the optimization of response parameter of NOx emission.

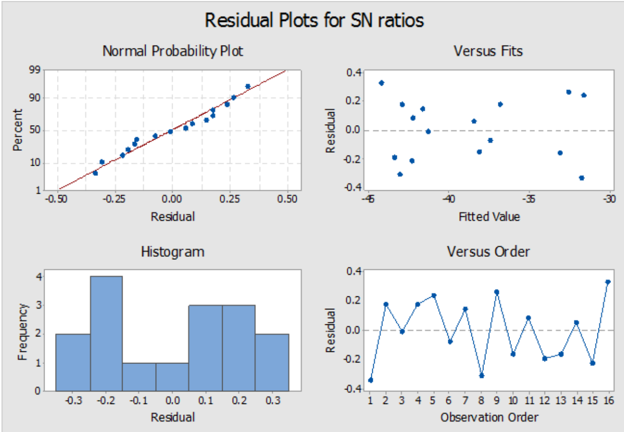

Fig. 6 Residual Plots for S/N Ratio – NOx

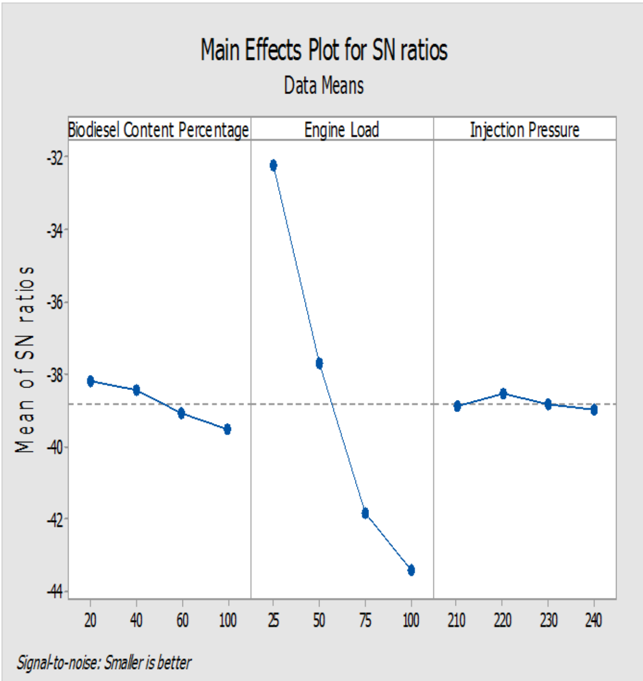

Fig. 7 Main Effects Plot for S/N Ratio – NOx

Based on the delta statistics, it was noticed that engine load is most influential factor followed by the biodiesel content percentage in blend percentage and lastly fuel injection pressure.

Table 7: Response Table for S/N Ratios – NOx

Level	Biodiesel Percentage in Blend	Engine Load	Injection Pressure
1	90.50	41.00	100.00
2	94.75	77.00	97.75
3	100.75	124.25	97.00
4	105.00	148.75	96.25
Delta	14.50	107.75	3.75
Rank	2	1	3

The pattern exhibited in Figure 6 shows that residuals are dependent on engine parameters. The main effects plot for S/N Ratio plots as shown in Figure 7 and delta values of Table 7 confirm that the engine load is the primary parameter that influences the NOx emission, then the biodiesel content percentage in blend, followed by injection pressure.

IV. CONCLUSION

The experimental analysis was carried out using single cylinder CIDI engine as outlined in L16 orthogonal array to optimize the engine parameters. In this study, engine load, biodiesel content percentage in blend and fuel injection pressure were considered as control engine parameters to reduce the EGT and NOx emissions of the engine when fueled with jatropha biodiesel and its diesel blends. The signal-to-noise (S/N) ratios of Taguchi were employed to determine effect of each control parameter and optimal response conditions that reduced the EGT and NOx emissions. The analysis identified that the selected response parameters were primarily influenced by the engine load, followed by the biodiesel content percentage in blend and is least influenced by fuel injection pressure. The lowest value of response parameters were found at to be at 220 bar of injection pressure of the engine when it is fueled with B40J blend of jatropha biodiesel, at 25% of engine load condition.

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