



Optimization of Engine Parameters to Reduce the Emissions of CIDI Engine Fueled with Transesterified Jatropha Curcas Oil

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Abstract: Continuously raising global fuel consumption, diminishing fossil fuel reserves and perilous environmental pollution from diesel engines are the raising concerns of energy security for the future generation and led to search for alternative renewable energy sources. Initially ethanol and methanol were used as alternative fuels and also to reduce the emissions in many countries especially agro-based countries like Brazil. In the last few decades, plant based oils, waste cooking oils, and animal fats and its biodiesels became a promised feasible alternative fuels. Previous research studies revealed that the engine has lower thermal efficiency, but higher NO_x emissions. The present research study is aimed to identify the optimized engine parameters in order to reduce the exhaust emissions of DI diesel engine when fuelled with Jatropha curcas oil methyl ester (JCOME). In this investigation, fuel injection pressure (FIP), percentage of JCOME in blend and engine load were considered as the affecting factors for the objective and CO, smoke opacity and NO_x emissions were considered as output response variables. Using design of experiments (DoE), the L16 orthogonal array was designed and series of experiments were conducted as per the designed array with different combination of influencing control factors. Taguchi optimization technique was applied to appraise the effect of control factors on response variables. The results of Taguchi analysis revealed that that fuel injection pressure 220 bar, blend BJ40 at 25% of engine load were optimum parameter setting for lowest CO, smoke opacity and NO_x emissions. Engine's emissions were mostly influenced by engine load, percentage of JCOME in blend and least influenced by fuel injection pressure.

Keywords: Taguchi Method; Optimization; Jatropha Curcas Oil; Methyl Ester, Biodiesel Emission Analysis; Transesterification.

I. Introduction

Volatile and unpredictable prices of fossil fuel, global energy insecurity due to production reduction, dependence on few OPEC countries, and environmental changes due to exhaust emissions put together a high priority to research for low-emission alternative renewable fuel sources. The biodiesel is prepared using vegetable oil or animal fat or some times waste cooking oil also [1-3]. The usage of biodiesel will make the economy secure, enhances the rural economy and moreover environmental friendly [3,11,12]. Lahane et al. were conducted analysis using diesel engine when fuelled with different blends of biodiesel-diesel and noticed that there is no significant change in torque with biodiesel-diesel blends up to 20% (B20). Conversely, it was noticed that there is about 2.7% reduction in torque with B100 at the rated load condition. Also observed that engine has exhausted a considerable less emissions such as CO, hydrocarbon (HC) and smoke emissions with all biodiesel-diesel blends. But oxides of nitrogen (NO_x) emission increased in the range of 1.4–22.8% with all biodiesel-diesel blends at rated load due to oxygenated fuel, automatic advance in dynamic injection timing (DIT), higher penetration and higher in-cylinder temperature [4]. Sahoo et al. evaluated the performance and emission characteristics of a diesel engine fueled with biodiesel blends (B10, B20, B30, B50 and B100). The experimental results shown that CO, HC, PM, smoke emission and Poly-Aromatic Hydrocarbon (PAH) emissions decreased with the biodiesel-diesel blends whereas brake specific fuel consumption (BSFC) and NO_x emission were increased extensively [5,6]. Similarly most of the researchers experimental studies revealed that the engine performance is less and also emissions except NO_x from the diesel engine when fuelled with biodiesel than diesel fuel. In order to further reduce the emissions and improve the performance, a quiet few number of research studies revealed that small changes in the engine design parameters such as fuel injection timings, fuel injection pressure, CR, combustion chamber design, combustion chamber type, etc., increases the engine performance and also reduces the exhaust emissions [7–9]. Jaichandar et al. carried-out different experimental tests to identify the optimized the combination of injection timing and combustion chamber geometry to achieve maximum performance and reduce exhaust emissions of Aa single cylinder, DI diesel engine when fueled with a blend of 20% by vol. pongamia oil methyl ester (POME) in diesel fuel (B20). The test engine

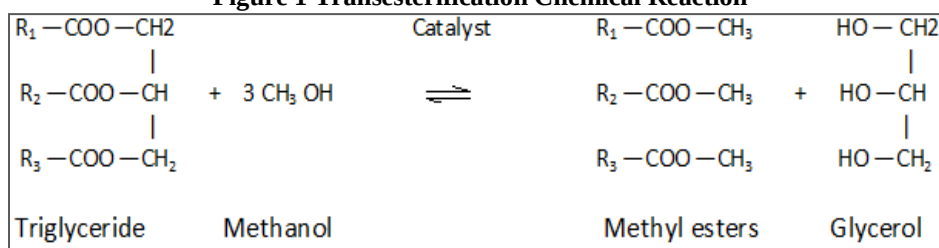
was prepared with pistons containing hemispherical and toroidal re-entrant combustion chamber (TRCC) geometries. The test results revealed that engine has shown increased brake thermal efficiency (BTE), and NO_x for retarded fuel injection timing and the highest performance and lowest emissions at 21° bTDC of fuel injection timing [10]. The purpose of the present research study is to identify the optimum engine parameters to reduce the emissions when DI diesel engine was operated by JCOME biodiesel.

II. Materials and Methods

A. Preparation of Biodiesel

All vegetable oils including Jatropha Curcus oil will have higher viscosity and density which creates problems to the engine. Generally, in order to decrease the viscosity and increase the heating value transesterification process was used. In transesterification process, the carbonyl carbon of the starting ester (RCOOR₁) undergoes nucleophilic attack by the arriving alkoxide (R₂O⁻) to give tetrahedral inter-mediate, which either reverts to the starting material, or proceeds to the transesterified product (RCOOR₂).

Figure 1 Transesterification Chemical Reaction



R₁, R₂ and R₃ are Hydrocarbon chain of 15to21 atoms

The chemical properties of the biodiesel that was prepared from Jatropha curcas oil and diesel fuel was given in table 1.

Table 1 Properties of Biodiesel (JCOME)

Fuel Property	Unit	ASTM Standards	Diesel	JCOME
Kinematic Viscosity @ 40°C	CST	D445	3.52	5.4
Flash Point	°C	D93	49	169
Density @ 15°C	kg/m ³	D1298	830	870
Calorific Value	kJ/kg	D4868	42000	38450
Cetane Number	--	D613	50	53
Ash	% by mass	D1119	0.01	Nil

B. Taguchi's Orthogonal Array

In order to obtain the experimental data, an orthogonal array was designed using design of experiments (DoE) methodology. In this research study, 3 factors and 4 levels were chosen to study the effect of these factors on output parameters. The chosen engine parameters of diesel engine are fuel injection pressure (FIP), percentage of JCOME in blend, and engine load were considered as the factors that influencing the CO, smoke opacity and NO_x emissions which were considered as responsive parameters. The list of parameters and levels are given in table 2. In order to identify the optimized combination of engine parameters with minimum number of experiments, the following orthogonal array was designed. The designed orthogonal array of L16 is presented in table 3.

Table 2 DoE – Control Parameters and Levels

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

Table 3 Taguchi - L16 Orthogonal Array

Experiment Number	Percentage of JCOME in Blend (A)	Engine Load (%) (B)	Fuel 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

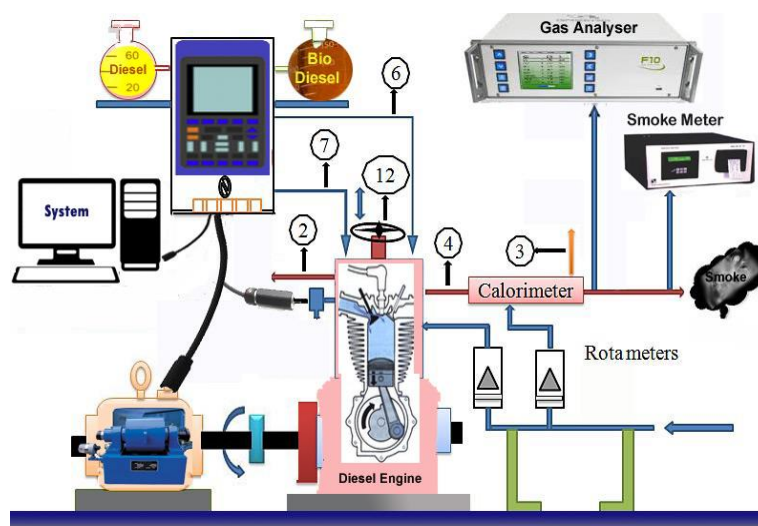
C. Experimental Setup

After designing the L16 orthogonal array, the series of experiments were carried-out using single cylinder, four stroke, water cooled DI diesel engine fuelled with Jatropha curcas oil methyl ester (JCOME). The experiment setup is illustrated as schematic diagram in figure 2. The setup consist of 3.7 KW (5HP) Kirloskar diesel engine, eddy current dynamometer, smoke meter, and exhaust gas analyzer with computer test rig. The specifications of the engine are given in table 4.

Table 4 Specifications of Test Engine

Type	Kirloskar
Details	Single cylinder, Four stroke, DI, Water cooled
Bore & Stroke	80 × 110 mm
Rated Power	3.7 KW (5 HP)
Speed	1500 rpm
Dynamometer	Eddy Current

Figure 2 Experimental Setup-Schematic Diagram



Nomenclature:

2: Outlet engine Jacket Water Temperature ($^{\circ}\text{C}$); 3: Inlet water temperature ($^{\circ}\text{C}$);
6: EGT before and after Calorimeter ($^{\circ}\text{C}$); 12: Pressure Transducer

A series of tests were conducted on the diesel engine using JCOME as fuel with the selected engine factors at different levels to determine the effect of the engine parameter on the objective. The engine was operated 16 times with the combination of different levels of influencing factors as given in table 5.

III. Results and Analysis

Taguchi technique was applied to identify the optimized engine parameters to decrease the exhaust emissions: CO, smoke opacity and NOx gases. The S/N ratio was calculated for each output parameter using Mini-tab software and presented in Table 6.

A. Optimization of Carbon Monoxide Emission

The Signal-to-Noise (S/N) ratio for the output response parameter: CO was performed using Minitab software (v17.1). In the table, the highest S/N ratio was noticed with B40blend of JCOME at 25% engine load when injection pressure is 220 bar. Figure 3 shows the graphical representation of ratio for three influencing factors in the main effect plot for S/N Ratios.

In optimization, if a line in the *main effects plot for S/N ratios* graph for a particular influencing parameter is almost horizontal, it means the input parameter has less the impact on response parameter. On the other hand, a parameter for which the line has the highest inclination will have the most substantial effect on target parameter. As show in plots (figure 3 and 4), it has been observed that engine load had the most significant effect among the three parameters followed by percentage of JCOME blend. The optimum process parameter combination corresponding to minimum emission was indicated by the max. value for signal-to-noise ratio for each input parameter. The to be BJ40 biodiesel at 25% of engine load with 220 bar injection pressure was found as optimum process parameter combination Taguchi analysis.

The Taguchi's design of experiments (DoE) has generated response table for S/N ratios for response Co-emission variable and is presented in table 6. From the table data, a typical observation was noticed that engine load has the highest influence with highest delta value of 5.62, followed by injection pressure with delta value of 3.89 and the biodiesel percentage in the blend has the least effect with delta value of 3.48 for CO emission.

Table 5 S/N Ratios for Output Parameters

Biodiesel Percentage in Blend (%)	Engine Load (%)	Injection Pressure (bar)	S/N for CO (%)	S/N for Smoke Opacity (%)	S/N for NOx (%)
20	25	210	18.4164	-19.0849	-32.0412
20	50	220	20.9151	-22.3454	-36.6502
20	75	230	18.4164	-25.6207	-41.2892
20	100	240	13.5556	-27.8187	-42.7976
40	25	220	24.4370	-17.2665	-31.3640
40	50	210	20.0000	-22.9226	-37.5012
40	75	240	17.0774	-25.2014	-41.5109
40	100	230	15.9176	-27.1205	-43.4052
60	25	230	23.0980	-17.3846	-32.2557
60	50	240	19.1721	-21.2892	-38.2763
60	75	210	20.0000	-23.6369	-42.1442
60	100	220	20.0000	-25.9333	-43.6369
100	25	240	23.0980	-17.3846	-33.2552
100	50	230	21.9382	-20.3407	-38.3816
100	75	220	23.0980	-22.3454	-42.5421
100	100	210	17.0774	-25.5751	-43.9180

Table 6 Response Table for S/N Ratios of CO

Level	Biodiesel Percentage in Blend	Engine Load	Injection Pressure
1	17.83	22.26	18.87
2	19.36	20.51	22.11
3	20.57	19.65	19.84
4	21.3	16.64	18.23
Delta	3.48	5.62	3.89
Rank	3	1	2

B. Optimization of Smoke Opacity (SOP)

The analysis of Signal-to-Noise Ratio for the output response: Smoke Opacity was done by using Minitab software (v17.1). The effect of each input control parameter on smoke opacity is illustrated in Figure 6. The graph and the S/N ratio values of smoke opacity with highest value of -17.2665 revealed that the engine releases the lowest smoke opacity when B40R biodiesel blend used at 220 bar of injection pressure and running at 25% load condition.

Table 7 Response Table for S/N Ratios of SOP-JCOME

Level	Biodiesel Percentage in Blend	Engine Load	Injection Pressure
1	-23.72	-17.78	-22.8
2	-23.13	-21.72	-21.97
3	-22.06	-24.2	-22.62
4	-21.41	-26.61	-22.92
Delta	2.31	8.83	0.95
Rank	2	1	3

Figure 3 Main Effects Plot for S/N Ratios of CO Emission

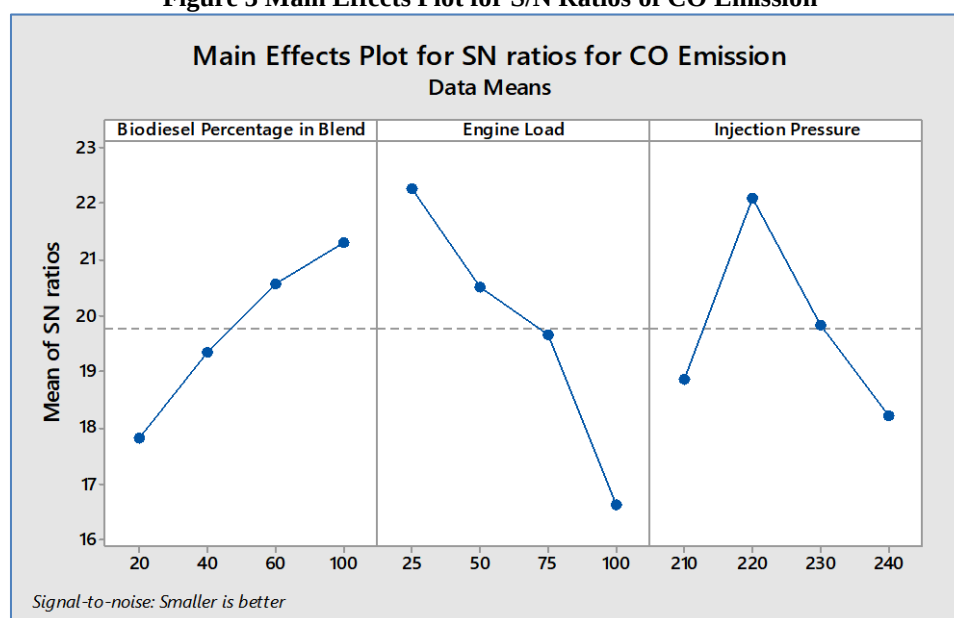
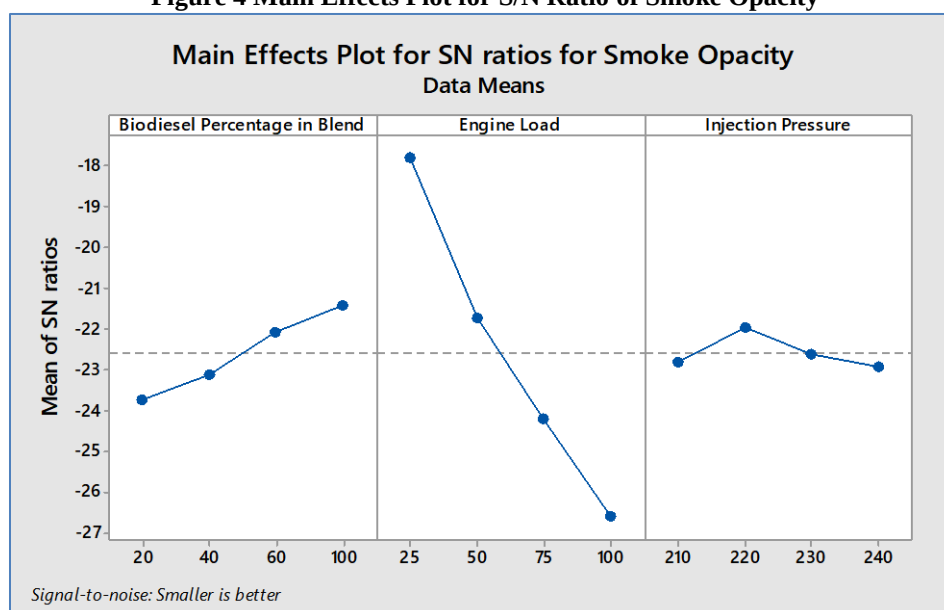


Figure 4 Main Effects Plot for S/N Ratio of Smoke Opacity



C. Optimization of NO_x Emission

The analysis of Signal-to-Noise Ratio for the output response was done by using Minitab software (v17.1). The calculated S/N ratios are presented in Table 8 and the effect of each input control parameter is depicted in figure 5. From the graphs, the control factor of biodiesel percentage (A) at level 2 (40% blend), the engine load factor (B) at level 1 (25% load) and the injection pressure control factor (C) at level 2 exhibits the best results. So, the optimized combination of parameters and levels for all from the analysis which provides the low NO_x emission was found to be A2-B1-C2. The S/N ratios of the same combination of control factors with the values of -31.3640 confirms that the engine releases less NO_x emission when B40R Jatrophacurcas biodiesel blend at 25% of engine load condition with 220 bar of injection pressure. As shown in Table 8, the delta values indicates that engine load has most effect with delta value of 11.21, followed by biodiesel content percentage with delta value of 1.33 and least influenced by injection pressure with the delta value of 0.41.

Figure 5 Main Effects Plot for S/N Ratios of NO_x Emission

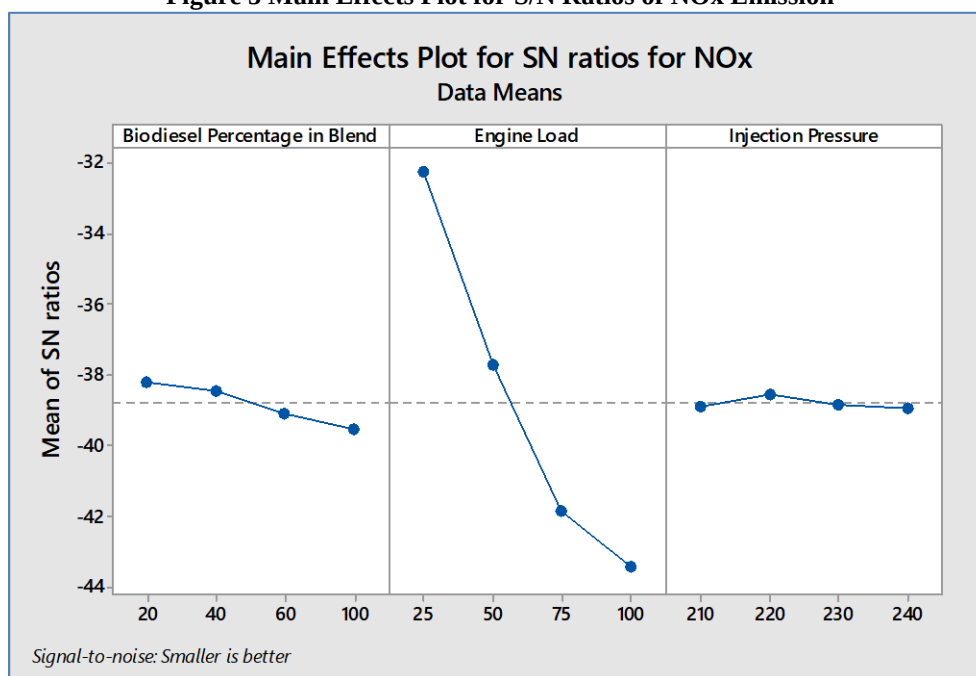


Table 8 Response Table for S/N Ratios of NO_x

Level	Biodiesel Percentage in Blend	Engine Load	Injection Pressure
1	-38.19	-32.23	-38.9
2	-38.45	-37.7	-38.55
3	-39.08	-41.87	-38.83
4	-39.52	-43.44	-38.96
Delta	1.33	11.21	0.41
Rank	2	1	3

IV. Conclusions

This research work intended investigate and determine the optimum level and effect of the experimental parameters such as load, blend percentage and injection pressure of diesel engine on emission of biodiesel using Taguchi optimization technique. The experiments were conducted to assess the emission characteristics of single cylinder, 4-stroke compression ignition direct injection engine fuelled with different blends (BJ20, BJ40, BJ60 and BJ100) of Jatropa curcas oil methyl ester (JCOME) as biodiesel. Orthogonal arrays, signal-to-noise (S/N) ratios of Taguchi were employed to identify the optimal levels and to analyze the effect of the operational conditions on emission values of JCOME. The results of Taguchi experiment identifies that that fuel injection pressure 220 bar, blend BJ40 at 25% of engine load are optimum parameter setting for lowest CO, smoke opacity and NO_x emissions. Engine emission characteristics are mostly influenced by engine load, followed by biodiesel percentage in blend and is least influenced by fuel injection pressure.

V. References

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