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Research Article

Optimization of Engine Parameters to Reduce NOx Emission of CIDI Engine Fueled with Fish Oil Biodiesel using Taguchi Method

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Abstract

This research work is aimed to determine the optimum engine parameters that reduce the NOx emissions of the diesel engine when fueled with Fish Oil Methyl Ester (FOME) and its diesel blends. Fuel injection pressure, load on the engine and biodiesel content percentage in the blend were chosen as engine parameters that effects the NOx emission. In this work, Taguchi method was used to investigate the effect of each engine parameter and to identify the right optimum combination of parameters to reduce the NOx emission. Taguchi's L16 orthogonal array was designed using Design of Experiments (DoE) methodology and experimentation was conducted using Fish oil biodiesel and its diesel blends. Taguchi's signal-to-noise (S/N) ratio values shown that NOx emission was principally effected by the engine load followed by percentage of biodiesel content in blend and the influence of fuel injection pressure is modest. The optimized emission was established at 220 bar of injection pressure of diesel engine running at 25% of load condition when fueled with B40 Fish oil biodiesel blend.

Keywords: *Biodiesel, Optimization, Taguchi Method, NOx, Fish Oil Methyl Ester, Design of Experiments.*

1. Introduction

The increased usage of fossil fuel, diminution of fossil fuel reserves and the volatile and always rising crude oil prices and have forced the researchers to search for a alternative renewable fuel to replace the diesel fuel partially or completely to handle the present and future energy crisis. Therefore, the biodiesel has recently garnered interest as one of the most shows potential solution. Biodiesels are oxygenated fuels, and so emits less carbon monoxide, smoke, particulate matter and other chemical compounds, but higher NOx than that of conventional diesel fuel (Lapuerta *et al,* 2008; Feng *et al*, 2012; Gerhard *et al,* 2010). This is because biodiesel contains more than 10% of oxygen by weight and these results in complete burning of fuel, reducing the emissions from the engine. However, biodiesel also has higher density, greater viscosity, and lower volatility that cause changes in the fuel injection system and combustion system behavior (Tat *et al*, 2000a; Tat *et al*, 2000b). The low volatility of biodiesel drops the combustion rate and the higher cetane number makes burning smoother with less vibrations from the engine, but also causes shorter ignition delay time, leading to starting of combustion in advance, which tends to increase the NOx emissions from the engine (Yoshiyuki, 2000; Mustafa *et al,* 2003). These problems can be resolved, by chemically converting the vegetable oils into biodiesel using chemical processes such as Pyrolysis, Micro emulsification, Dilution and Transesterification process (Banapurmath *et al,* 2008; Pramanik, 2003). Transesterification process is one the most widely used process and the past research results revealed that engine problems were significantly decreased with increased performance and decreased exhaust emissions.

Unlike fossil fuels, the biodiesel can be produced at any location where the availability of feedstock is sufficient and unlimited. The production of biodiesel reduces the dependence on the foreign imports of oil and improves rural economy as well. Hence the production of biodiesel from plant based oils has gained momentum. However, the availability of biodiesel feedstock remains the major challenge faced during its production.

The past research studies revealed that edible vegetable oils such as soybean, sunflower, palm, rapeseed, peanut oils etc., can be used as feedstock for biodiesel (Hawkins *et al,* 1983; Recep Alton *et al,* 2001). Conversely, this has raised fear of causing food crisis especially in heavily populated countries. Then the focus was shifted to the use of non-edible vegetable oils such as rubberseed, neem, karanja, cottonseed, castor, jatropha curucas oils, etc. as biodiesel feedstock (Ivana B. Banković-Ilić *et al*, 2012; Murugesan *et al*, 2009). However researchers have noticed that the cost of the biodiesel is more than conventional diesel fuel, because fertilizers, pesticides etc., are required to grow plants.

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It was observed that over a million liters of waste cooking vegetable oil from food industry waste and trillion tons of fish by-products and wastes across the globe have been underutilized or unused. Hence the biodiesel feedstock from industrial wastes such as fish oil from aqua industry byproducts has lucrative as it is profusely available with throw-away price with no other further usage (Canakci *at el,* 2008). Therefore the fish oil from fish wastes was considered for the present study.

The past research studies revealed that even though biodiesel emits less emissions, but releases more NOx than that of diesel engine (Mustafa *et al,* 2003; Yoshiyuki, 2000). The NOx causes global warming, forms the smog and acid rain as well. It has tremendous effect on human health such asthma as short term effect, cancer, heart dieses, chronic bronchitis as long-term effects. The present study aimed to reduce the NOx emission by altering few engine parameters with optimization.

2. Experimental Section

2.1 Biodiesel Preparation

The crude fish oil which was prepared from the fish waster such as fish heads, skin, fins, liver and viscera was collected from the local vendor to prepare the biodiesel.

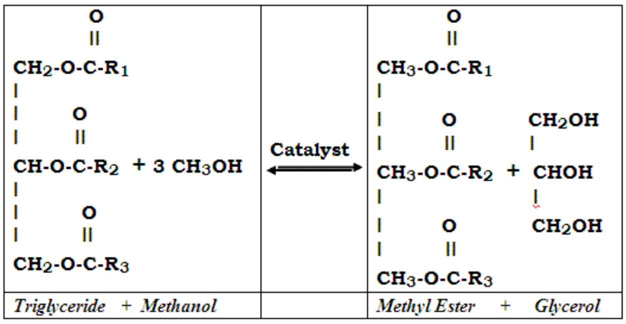

Fig.1 Transesterification Reaction

Table 1 Properties of Diesel and Biodiesel

Fuel Property	Units	ASTM Standards	Diesel	FOME
Kinematic Viscosity @ 40^{0}C	CST	D445	3.52	5.89
Flash Point	^{0}C	D93	49	165
Density @ 15^{0}C	kg/m^3	D1298	837	876
Calorific Value	kJ/kg	D4868	42850	3800
Cetane Number	--	D613	50	52
Carbon Residue	% by mass	D4530	0.1	0.47
Total Sulphur	% by mass	D5453	0.01	0.05
Ash Content	% by mass	D1119	0.01	0.03

The biodiesel was prepared from fish oil using transesterification process. As shown in Figure 1, in this transesterification process, triglycerides were converted into methyl esters of fish oil (FOME) through a chemical reaction in the presence of catalyst such as sodium hydroxide or potassium hydroxide (Diwani *et al*, 2009). The biodiesel was then blended with diesel at ratios of 20:40, 40:60, 60:40 and 100:0 and used to prepare B20F, B40F, B60F and B100F biodiesels respectively which were further used as test fuels of the study.

2.2 Application of Taguchi Method

Taguchi method is a robust optimization technique that is used to determine the effect and identify the optimum combined effect of engine parameters on the characteristics of diesel engine.

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

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

The selection of controllable engine parameters is a most important factor in Taguchi optimization process in order to obtain the best results. In this work, fuel injection pressure, engine load and percentage of biodiesel content in the blend was selected as most influencing factors on the engine's emission characteristics. The three control parameters that are selected for the investigation with four levels are presented in Table 2. Using the design of experiments (DoE) of Taguchi, 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.

2.3 Experimental Setup

As shown in Figure 2, a 3.7 kW, 4-stroke, single cylinder, water cooled compression ignition direct injection (CIDI) engine was used for experimental investigation. The engine was connected to an eddy current dynamometer for applying load. The smoke meter and multi-gas analyzer was used for emission measurement.

Fig.2 Photographic View of Experimental Setup

The test engine specifications are presented in Table 4.

Table 4 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
Rated Speed:	1500 rpm
Injection Pressure:	200 bar
Compression Ratio:	16.5:1
Dynamometer:	Eddy Current

3. Results and Analysis

Taguchi methodology determines the effect of engine parameters on each response variable using uses the signal-to-noise (S/N) ratio. The S/N ratios and Mean values for NOx emission due to control parameters were computed using Minitab software (v17.1) and are presented in Table 5.

Nitrogen oxides (NOx) damages the ozone layer and causes acid rains that leads to adverse effects on human health and should be regulated stringently (Ueki, 1999). Hence the S/N ratio of *Smaller-is-Better* option was chosen for the optimization of response parameter of NOx emission. 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. The pattern exhibited in Figure 3 shows that residuals are dependent on engine parameters. The main effects plot for S/N Ratio and Mean plots are shown in Figure 4 and 5. The graphs and the delta values of Table 6 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.

Table 5 S/N Ratio and Mean for NOx Emission

Trial	Biodiesel Percentage in Blend	Engine Load (%)	Injection Pressure (bar)	S/N Ratio	Mean
1	20	25	210	-30.8814	32.625
2	20	50	220	-36.2583	65.375
3	20	75	230	-40.9065	111.375
4	20	100	240	-42.7976	139.625
5	40	25	220	-30.6296	36.125
6	40	50	210	-37.5012	74.875
7	40	75	240	-41.6557	119.125
8	40	100	230	-43.2274	144.875
9	60	25	230	-32.2557	40.625
10	60	50	240	-37.8419	77.625
11	60	75	210	-41.8684	126.375
12	60	100	220	-43.6369	150.375
13	100	25	240	-33.0643	45.625
14	100	50	230	-38.0618	80.125
15	100	75	220	-42.1442	127.125
16	100	100	210	-43.918	157.125

It was noticed from the graphs of Signal-to-Noise ratio and the Mean that the NOx emission can be reduced to its lowest level when the test engine runs at quarter load condition with 220 bar of injection pressure, when fueled with B40J jatropha biodiesel.

Table 6 Response Table for S/N Ratios – NOx

Level	Biodiesel Percentage in Blend	Engine Load	Injection Pressure
1	87.25	38.75	97.75
2	93.75	74.50	94.75
3	98.75	121.00	94.25
4	102.50	148.00	95.50
Delta	15.25	109.25	3.50
Rank	2	1	3

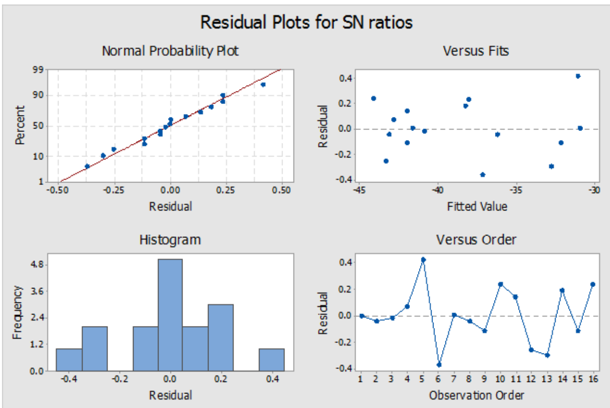

Fig.3 Residual Plots for S/N Ratios

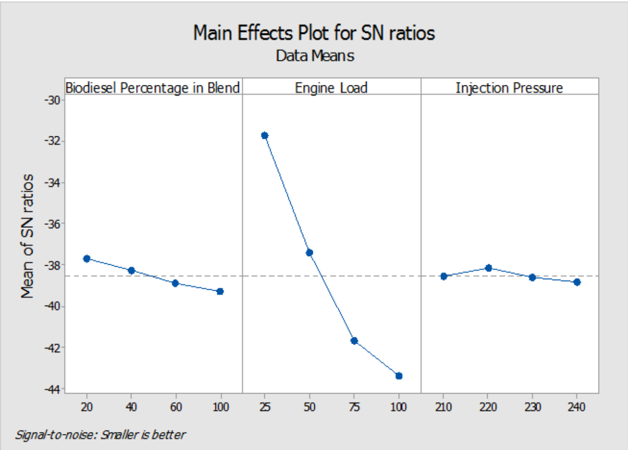

Fig.4 Main Effects Plot for S/N Ratio

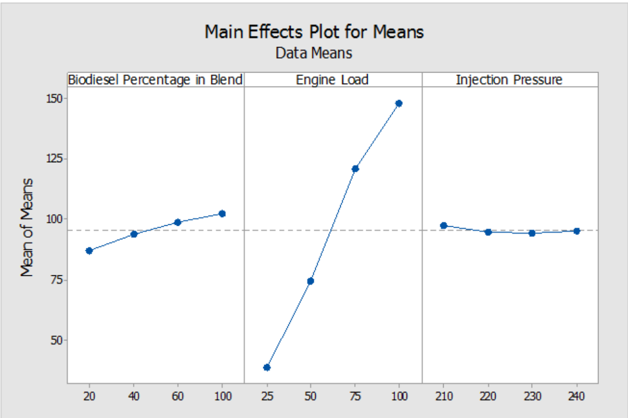

Fig.5 Main Effects Plot for Means

Conclusions

The optimization process was carried-out based on the experimental results that was acquired through series of trials using single cylinder CIDI engine as outlined in L16 orthogonal array. In this research study, load on engine, biodiesel percentage in the blend and injection pressure were considered as input control engine parameters of the model to reduce the NOx emission of the engine when fueled with Fish oil 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 condition that reduces the NOx emission. The analysis identified that the selected response parameters were mainly influenced by the engine load, followed by the biodiesel content percentage in blend and is least influenced by injection pressure. It can be concluded that better optimization of engine parameters is essential to reduce the NOx emission of the engine. 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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