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Emission Characteristics of Single Cylinder Diesel Engine Using Blends of Rubber Seed Biodiesel Using Taguchi Method

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Abstract

The aim of the study is to optimize the levels of the parameters such as rubber seed biodiesel blend, injection pressure and applied load of the single cylinder diesel engine with respect to smoke density and exhaust gas temperature through the Taguchi and ANOVA techniques. The optimum levels of the parameters were found using Signal - Noise ratio. Analysis of variance (ANOVA) was used to investigate the contribution of parameters on the response. Multiple linear regression models were generated to predict the responses. It was found that the applied load was the most dominant factor influencing the exhaust gas temperature and smoke density followed by injection pressure and biodiesel blend.

Key words: Biodiesel blend, Injection pressure, applied load, Taguchi, ANOVA.

1. Introduction

In the last two decades, researchers are investigating the possibility of using alternate bio fuels instead of fossil fuels. Due to petroleum based oil crisis, the transport sector is looking for the bio-diesel as an attractive renewable alternative fuel which has environmental and economic advantages. Vegetable oils have several advantages such as renewable, environmental friendly and can be produced easily in rural areas. Therefore in recent years systematic efforts have been made by several researchers [1-5] to use vegetable oils as an alternate fuel in engines. Kapilan and Reddy reported that the blending of vegetable oils with diesel fuel results in low CO, HC and smoke emission and higher thermal efficiency [6]. Bio fuels are oxygenated compounds provide improved combustion, and cleaner emissions. The biodiesel impacts on exhaust emissions varied depending on the type of biodiesel and conventional diesel. Blends of up to 20% biodiesel mixed with petroleum diesel fuels can be used in all the diesel engines [7]. Lin et al. reported that there was remarkable reduction in the smoke emission when engine was tested using eight types of Vegetable oil methyl ester fuels compared to diesel [8]. Özsezen et al. investigated performance characteristics of a diesel engine fuelled with palm oil and canola oil biodiesels. They reported that the biodiesels caused reductions in carbon monoxide, unburned hydrocarbon and smoke opacity, but they caused to increases in nitrogen oxides (NO_x) emissions [9]. Hwang et al. investigated the combustion and emission characteristics of direct injection diesel engine fuelled with waste cooking bio fuel and analysed the effects of different injection pressures and injection timings at two different engine loads. They reported that the biodiesel had benefits in reduction of smoke, carbon monoxide, hydro carbon especially with high fuel injection pressure. The nitrogen oxide (NOx) emissions of the biodiesel were relatively higher than those of the diesel under all testing conditions [10]. Junheng Liu et al investigated the effects of diesel injection pressure on the performance and emissions of a heavy duty common-rail diesel engine fueled with diesel/methanol dual fuel.They reported that with increasing the injection pressure, there is a reduction in CO and HC, and a slight increase in CO_2 emission [11]. Tatur et al reported that NOx which was measured at tail pipe was somewhat lower for soy-based biodiesel (B20) compared to diesel. The higher exhaust temperature of diesel combustion was the main contributor of higher tailpipe-out NOx compared to B20 [12]. Biodiesel contains a higher oxygen content which enhances the complete combustion and reduces the hydrocarbons and carbon monoxide. According to the literature survey, the experimental study of performance and emission characteristics of rubber seed biodiesel on diesel engine is hardly reported. The rubber seed oil, a non-edible type vegetable can be used as a potential alternative for producing bio-diesel. The characteristics of the vegetable oils fall are close to those of the standard diesel oil. Hence it can be used as bio-fuel in compression ignition engines. Demirbas [13] reported that viscosity is a vital property of biodiesel since it will have an effect on the fluidity of biodiesel particularly at low temperature in the operation of fuel injection equipment. Transesterification process was done to reduce the free fatty acid content of rubber seed oil and make it suitable for compression ignition engines. This present work aims to investigate the an experimental study to determine the optimum percentage of rubber seed biodiesel blend, injection pressure and applied load of a single cylinder diesel engine using Taguchi and ANOVA method.

2. Materials and methods

2.1. Apparatus

The study was done on a direct injection single cylinder 4 stroke 18 HP compression ignition engine having Bore: 99mm, Stroke: 98mm, CC: 900cc and compression ratio : 18:1. The rated rpm of the engine is 2000. The diesel engine is coupled to a 3 phase 15 kVa. The experimental set up is shown in Figure 1. The properties of esterified rubber seed oil are dynamic viscosity 6.82cP @ 30^{o}C, Flash point 72^{o}C, Density 0.86 g / cc, Calorific Value 36500kJ/kg, Pour point 12^{o}C and Cetane number 45[14-15].

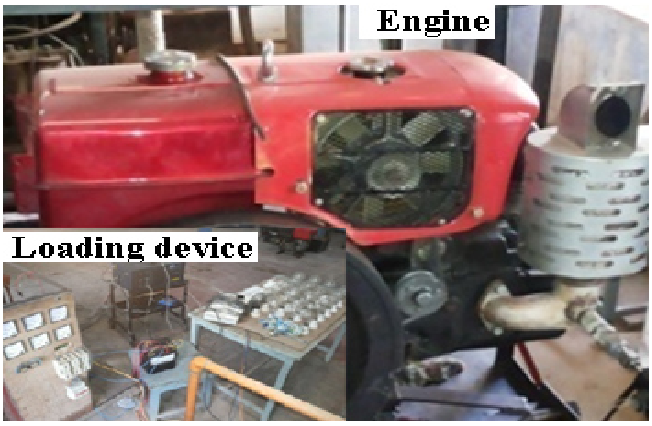

Figure 1: Experimental set up

3. Results and Discussion

3.1. Taguchi analysis

Taguchi's technique provides an efficient method to find the optimum levels of the parameters which have an effect on the process and performance. In this study, "smaller is better" S/N ratio was used to predict the optimum values of parameters because lower exhaust gas temperature and lower smoke density were considered for this study. Accordingly, 9 tests were carried out and each test was performed twice in order to minimize the errors. The selected factors and the corresponding levels are presented in Table 1.Also the test results were analyzed using analysis of variance (ANOVA) to study the influence of the factors on the outcome. The measured values and the corresponding S/N ratios are provided in the Table.2. Response diagram of S/N ratio for smoke density and exhaust gas temperature are given in the Figure 2 and 3 respectively. It was found that the optimum parameters for minimum smoke density and exhaust gas temperature of the engine were applied load (60%), injection pressure (200bar) and fuel (B20% blend).

Table 1: Factors and levels

Level	Fuel (A)	Injection Pressure (Bar) (B)	Load (%) (C)
I	Diesel (1)	180	20
II	B20 (2)	200	60
III	B50 (3)	220	100

3.2. Results of ANOVA

ANOVA determines the optimum combination of process parameters more accurately by investigating the relative importance among the parameters. ANOVA was performed with the help of the software package MINITAB16 for a level of significance of 5%. In the ANOVA Table 3, there is a P-value for each independent parameter in the model. When the P-value is less than 0.05, then the parameter can be considered as statistically highly significant. It can be observed from the Table 3 that the percentage contribution (Pc %) of each variable in the total variation indicating their degree of influence on the smoke density and exhaust gas temperature of the engine. Load (91.57%) was the major contributing factor followed by fuel blend (4.07%) and finally injection pressure (3.3 %) influencing the smoke density of the engine. Load (93.71%) was the major contributing factor followed by injection pressure (3.99 %) and finally fuel blend (2.21%) influencing the exhaust gas temperature of the engine.

Table 2: Measured values and S/N ratios

Exp .No	Fuel (A)	Injection Pressure (Bar) (B)	Load (%) (C)	Measured Values		S/N ratios	
				Smoke density	Ex. Gas Temp (˚C)	Smoke density	Ex. Gas Temp
1	Diesel (1)	180	20	7.6	175	-17.6163	-44.8608
2	Diesel (1)	200	60	15	220	-23.5218	-46.8485
3	Diesel (1)	220	100	35	325	-30.8814	-50.2377
4	B20 (2)	180	60	13.5	226	-22.6067	-47.0822
5	B20 (2)	200	100	24.1	285	-27.6403	-49.0969
6	B20 (2)	220	20	2.5	135	-7.9588	-42.6067
7	B50 (3)	180	100	36.1	340	-31.1501	-50.6296
8	B50 (3)	200	20	2.2	131	-6.84845	-42.3454
9	B50 (3)	220	60	13.1	234	-22.3454	-47.3843

Table 3: ANOVA analysis

Factors	DoF	Smoke Density			Exhaust Gas Temperature (˚C)		
		F	P value	Pc%	F	P value	Pc%
Fuel(A)	2	3.91	0.203	4.07	29.24	0.033	2.21
Injection	2	3.17	0.240	3.30	52.86	0.019	3.99
Load (%) (C)	2	87.88	0.011	91.57	1239.18	0.001	93.71
Error	2	-	-	1.04	-	-	0.07
Total	8			100			100

DoF- Degrees of Freedom; Pc %-Percentage of contribution

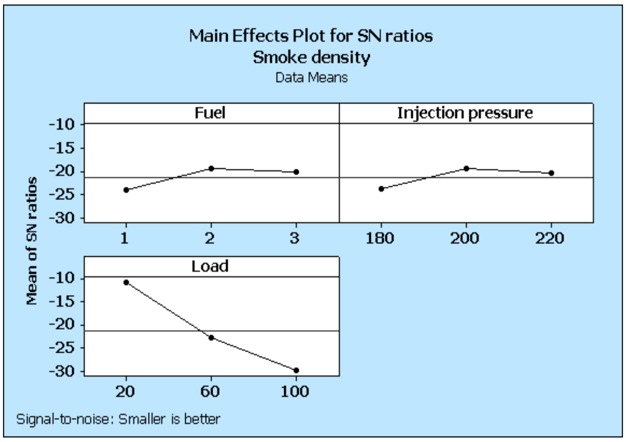

Figure 2: Response diagram of S/N ratio for smoke density

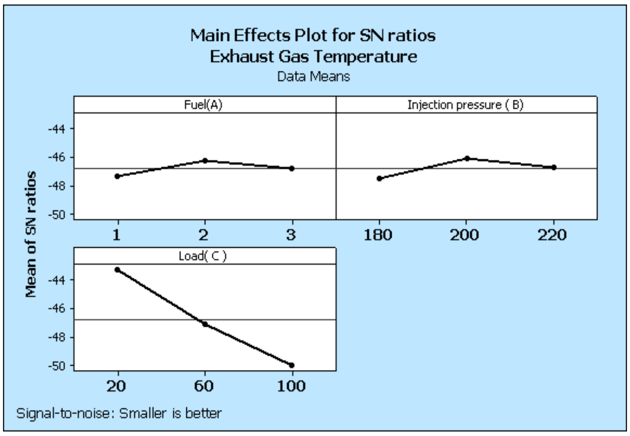

Figure 3: Response diagram of S/N ratio for exhaust gas temperature

3.3. Multiple Linear Regression Model

A multiple linear regression equation was developed to establish the correlation among the significant factors on the response. The value of regression coefficient, R^2 (0.9896) is in good agreement with the adjusted R^2 (0.9583) for smoke density. The value of regression coefficient, R^2 (0.9992) is in good agreement with the adjusted R^2 (0.9970) for exhaust gas temperature. Since both the values are reasonably close to unity, models provide reasonably good explanation of the relationship between the independent factors and the response.

The regression equation developed for smoke density of the engine is:

$= 8.9 - 1.03 (A) - 0.055 (B) + 0.345 (C)$ Eq. 1

The regression equation developed for exhaust gas temperature of the engine is

= 186 - 2.50(A) - 0.392(B) + 2.12(C) Eq. 2

From the Eqn. (1) & (2), it is observed that the load (C) plays a major role on smoke density and exhaust gas temperature of the engine.

From the Taguchi results, the lower smoke density and exhaust gas temperature were observed at a load of 60%. B20 provides the lower smoke density and exhaust gas temperature compared to B50 and standard diesel at 60 % load. Lower smoke density infers that lesser amount of unburnt hydrocarbons present in the engine exhaust gas. The hydrocarbon emissions of the biodiesel blend B20 is lower than the standard diesel due to complete combustion process. Because the biodiesel blends have more oxygen content than that of diesel and it ensures the complete combustion process. On the other hand, smoke density increases when engine fuelled with B50 or standard diesel. Since the bio diesel has a higher cetane number than diesel, combustion would happen before the proper mixing of air and fuel. It leads incomplete combustion of fuel resulting in higher smoke density.

The exhaust gas temperature was found to be low when the engine fuelled with B20 blend than that of diesel fuel due to the lower heating value of the bio fuel. Moreover exhaust gas temperature increased with increasing the quantity of biodiesel in the diesel. As the engine load increases, average exhaust gas temperature increased due to the large quantity of fuel injected in the combustion chamber. Higher combustion temperature is responsible for raising the level of NOx in the exhaust gases. When the load on the engine increases beyond 60%, smoke density and exhaust gas temperature tends to increase. It was observed from the results that the injector pressure of 200 bar was found to be the optimum pressure. Lower injection pressure (180 bar) causes the incomplete and improper atomization of the fuel which increases the smoke density. On the other hand very high injection pressure makes very fine fuel spray which has less penetration ability, resulting in higher smoke density.

Conclusion

Based on this study, the following conclusions have been summarized.

1. It was found that the optimum parameters for minimum smoke density and exhaust gas temperature of the engine were applied load (60%), injection pressure (200bar) and fuel (B20% blend).
2. It was observed that the load (91.57%) was the major contributing factor followed by fuel (4.07%) and finally injection pressure (3.3%) in influencing the smoke density of the engine.
3. Load (93.71%) was the major contributing factor followed by injection pressure (3.99%) and finally fuel (2.21%) in lowering the exhaust gas temperature of the engine.
4. From the above conclusions, the appropriate percentage (20%) of rubber seed oil can be blended with diesel without any engine modifications.

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