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COMBUSTION CHARACTERISTICS OF ESTERIFIED RICE BRAN OIL AS AN ALTERNATIVE FUEL IN A DIESEL ENGINE

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ABSTRACT–The smoke emission of diesel engines is being recognized as one of the major source of the air pollution problems. This study investigates the potential of esterified rice bran oil to reduce smoke emission as an alternative fuel for diesel engines. Because the esterified rice bran oil has approximately a 10.5% oxygen content, the combustion of the diesel engine improved and exhaust smoke decreased. Gas chromatography was used to analyze not only the total amount of hydrocarbon but also the amount of hydrocarbon components from C_1 to C_6 in the exhaust gas to determine an exact source responsible for the remarkable reduction in the smoke emission. The number of individual hydrocarbon (C_1~C_6) as well as the total amount of hydrocarbon of esterified rice bran oil reduced significantly compared to that of hydrocarbon of diesel fuel.

KEY WORDS : Esterified rice bran oil, Diesel engine, Hydrocarbon, Smoke emission, Chromatogram, Alternative fuel

1. INTRODUCTION

Although the demand of diesel engines is increasing, our world is facing a very serious air pollution problem due to the exhaust emissions from diesel engines (Gao and Schreiber, 2001). In particular, the smoke emission from the diesel engine is being recognized as a major factor affecting environmental degredation. Strict regulations for air quality improvement have placed limitations on a design modification for engines. A second problem is that when fossil fuels are burning, they emit CO_2 greenhouse in surroundings (Harold and Irshad, 1999), too. The increase of CO_2 concentration is considered to be a leading cause of global warming.

The trend towards a clean burning is growing in worldwide. Recent studies (Tsurutani *et al.*, 1995; Tanaka *et al.*, 1996; Li *et al.*, 1996) indicate that cetane number, aromatic contents and type, density and sulfur content are important factors for the emission control. In particular, vegetable oils from rice bran, rapeseed, and soybeans are renewable fuels that can reduce the exhaust smoke emission. These sources have different properties compared to conventional fossil fuels and a number of studies have been conducted with vegetable oils in diesel engines (Murayama *et al.*, 1984; Hemmerlein and Korte, 1991; Crookes *et al.*, 1992; Hohl, 1995). Using transesterified fuel from vegetable oil, research has been focused on determining the efficiency and effectiveness of these alternative energy resources. In the future, biodiesel fuels could have wide ranging economic and social effects.

This study analyzed performance of a direct injection diesel engine with a biodiesel fuel. The study also analyzed the performance of esterified rice bran oil as an alternative fuel for diesel engines.

Biodiesel fuel contains 10.5% of oxygen content which significantly reduces the exhaust smoke emission density at high loads and speeds in direct injection diesel engines. In addition to the experiment, this research analyzed the individual unburned hydrocarbon in the exhaust gas. Individual unburned hydrocarbons (C_1~C_6) from commercial diesel fuel, biodiesel fuel and blended fuel (diesel fuel 80 vol-%+biodiesel fuel 20 vol-%) were investigated using gas chromatography. This research also defined a lower boiling point of hydrocarbon (below C_4) and a higher boiling point of hydrocarbon (above C_5) (Oh and Choi, 2000).

2. EXPERIMENTAL APPARATUS AND METHODS

A horizontal, water cooled, single cylinder, naturally aspired, direct injection diesel engine was used, and specifications of the engine are shown in Table 1. Properties of the biodiesel fuel and commercial diesel fuel

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Corresponding author. e-mail: medr@chonbuk.ac.kr used for this experiment are shown in Table 2, and blended fuels-the combination of the commercial diesel fuel and the biodiesel fuels- were used in the test. The fatty acid composition of biodiesel fuel is shown in Table 3. The schematic diagram of the experimental apparatus is shown in Figure 1. Engine speed and load were controlled by the eddy current dynamometer. Exhaust smoke emission was measured with a Bosch smoke meter (Hesbon; HBN-1500) and the NOx concentration was measured with an exhaust gas analyzer (Motor branch; Mod. 588). Exhaust gas was sampled in 50 cc glass syringes to analyze the composition of individual hydrocarbons. After the fuel consumption time was measured with a stop watch, the brake specific energy consumption (BSEC) of each fuel was calculated by a volumetric flow meter. The engine was operated with 80±2°C cooling water under all operating conditions. The engine was operated at speeds of 1000, 1500, 2000 and 2500 rpm, with loads between 0% and 100% with 25% intervals. A specific case of 90% load was also investigated. The biodiesel fuel was blended in conventional diesel fuel between 0 vol-% and 100 vol-% with 20 vol-% intervals. Gas chromatography (Hewlette packard; GC 6890) was also used to measure the total and individual hydrocarbon from C_1 to C_6. This was implemented because hydrocarbons were a type of organic compounds, were flammable, and could be detected through flame ionization detector (FID) in gas chromatography.

Table 1. Specifications of test engine.

Items	Specifications
Engine model	ND130
Cylinder number	1
Bore×Stroke (mm)	95×95
Displacement (cc)	673
Compression ratio	18
Combustion chamber type	Toroidal
Injection timing (CA)	BTDC 23
Coolant temp. (°C)	80±2

Table 2. Properties of test fuels.

Proterties	diesel fuel	biodiesel fuel (BDF)
Flash point (°C)	40	178
Calorific value [MJ/kg]	43.12	39.61
Cetane number	45	57
Kinematic viscosity (50°C, cSt)	3.0	4.2
Sulfur (Wt%)	0.05	0
Carbon (Wt%)	86.76	77.25
Hydrogen (Wt%)	13.05	11.83
Oxygen content (%)	0	10.5

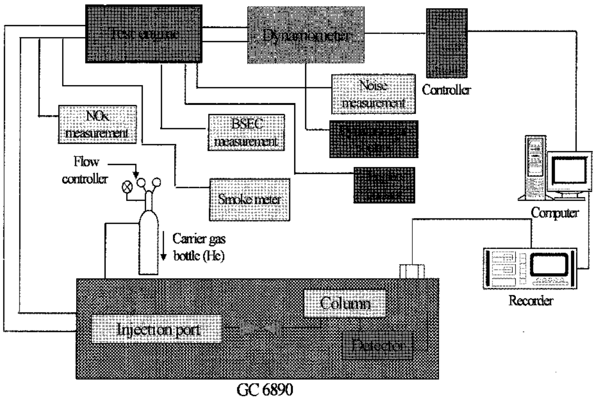


Figure 1. Schematic diagram of experimental apparatus.

Table 3. Fatty acid composition of biodiesel fuel.

Fatty acid	Contents (%)
Palmitic acid	16.0–18.0
Stearic acid	1.5–2.0
Oleic acid	40.0–42.0
Linoleic acid	36.0–38.0
Linolenic acid	1.0–2.0
Etc.	below 1.0

3. RESULTS AND DISCUSSION

3.1. Exhaust Emissions and BSEC Characteristics Based on Biodiesel Fuel Blending Ratio

Figure 2 shows the torque curve of the engine for several blending ratios from 0 vol-% to 100 vol-% at full load. The torque achieved by the engine at full load for all fuels was similar. Although the heating value of the biodiesel

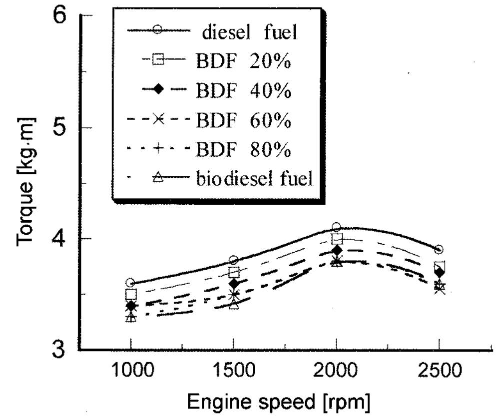


Figure 2. Torque at full load.

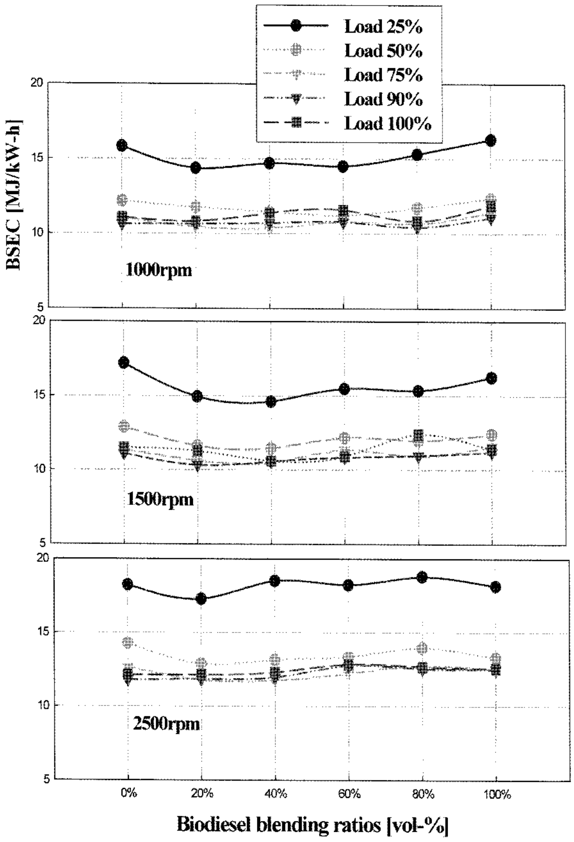


Figure 3. Comparison of BSEC at various engine loads and speeds on biodiesel blending level.

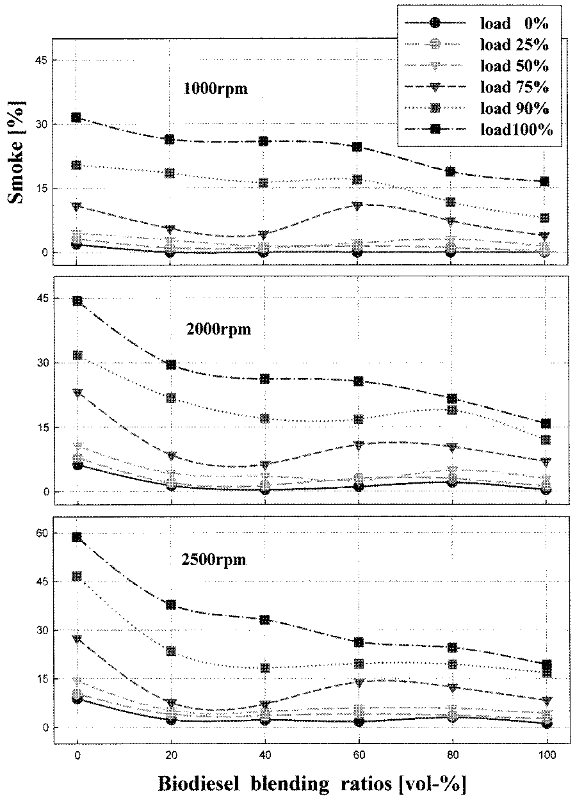


Figure 4. Comparison of smoke density at various engine loads and speeds on biodiesel blending levels.

fuel was lower than that of the commercial diesel fuel by approximately 8%, the engine torque showed no significant differences because the oxygenated component in the biodiesel fuel improved combustion efficiency.

To investigate the effects of the oxygenated component on engine performance, brake specific energy consumption (BSEC) was measured and calculated.

Figure 3 shows BSEC at each blending ratio from 0 to 100 vol-% at various engine speeds and loads. Even though the blending ratio was varied, BSEC did not change significantly. At 2500 rpm, the biodiesel fuel showed better performance than diesel fuel. This result meant that the effects of oxygen components in biodiesel fuel could be used throughout the operating region; that is, the effects of the oxygen component in fuel was very significant in the combustion process at higher loads and speeds.

Figure 4 shows the effect of the biodiesel fuel blending ratio on exhaust smoke emission at various engine speeds and loads. As seen in this figure, there was a remarkable difference in the exhaust smoke emission density among diesel fuel, blended fuel, and neat biodiesel fuel. In particular, the smoke densities were more remarkable at high loads and speeds. The main cause of this difference considered to be due to the variation of oxygen components among the test fuels.

This suggested that the oxygen components in the biodiesel fuel itself increasingly facilitated the oxidization of fuel particles at high loads and speeds during the diffusion combustion period. In general, the oxygen concentration in the diffusion combustion period was leaner than that in the premixed combustion period. The exhaust smoke emission density from the diesel fuel exhibited significant differences in proportion to the load that changed from low to high. However the emissions from the biodiesel fuel did not show significant differences in proportion to the varying load. When biodiesel fuel was used in the diesel engine, the differences between created quantity and oxidized quantity of carbonaceous particulate were reduced, and it was thought to be that the oxygen component in biodiesel fuel increased the oxidization rate of fuel particles.

Figure 5 presents effect on NOx emission, which was conducted under the same conditions as those outlined in Figure 4. The NOx concentration increased slightly as the biodiesel fuel ratio increased. The NOx emission was formed as the cylinder temperature increased, possibly due to the oxygen component in the biodiesel fuel.

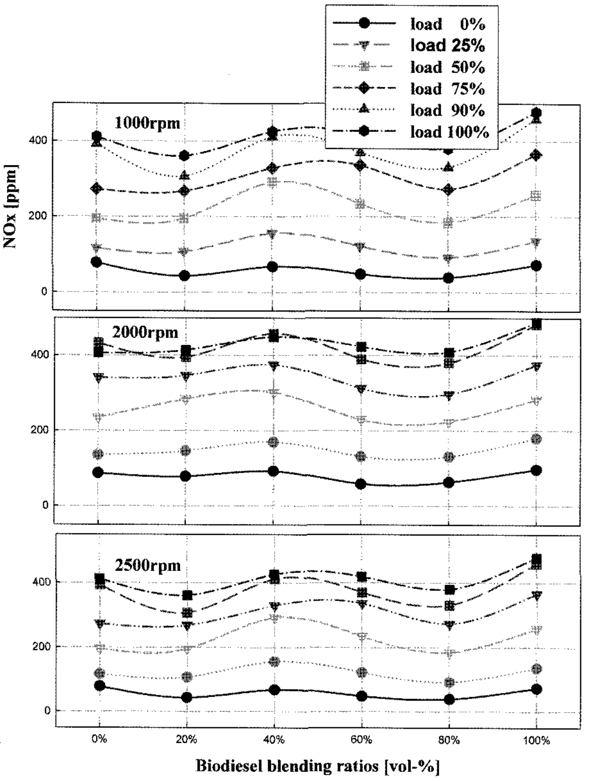


Figure 5. Comparison of NOx concentration at various engine speeds and loads on biodiesel blending levels.

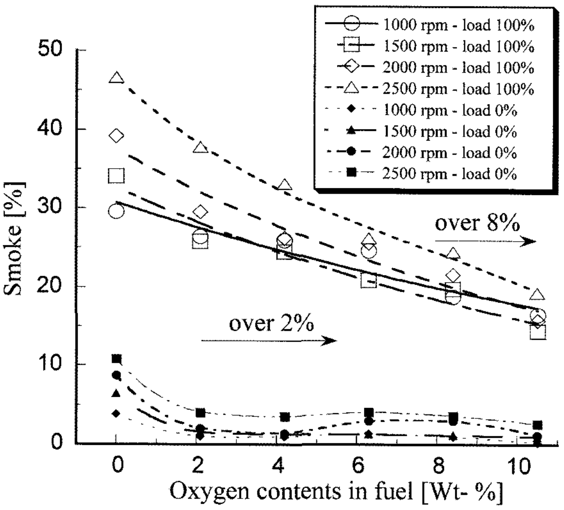


Figure 6. Comparison of smoke density of load 0% vs. full load with various oxygen contents.

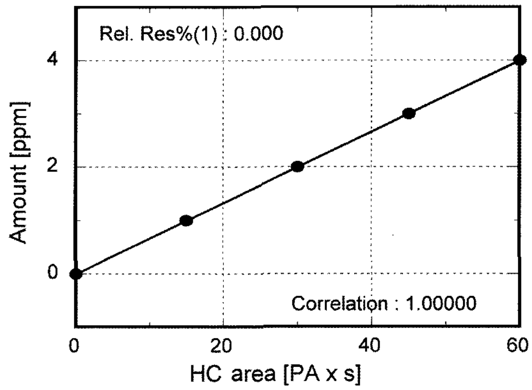


Figure 7. Calibration curve for gas chromatography.

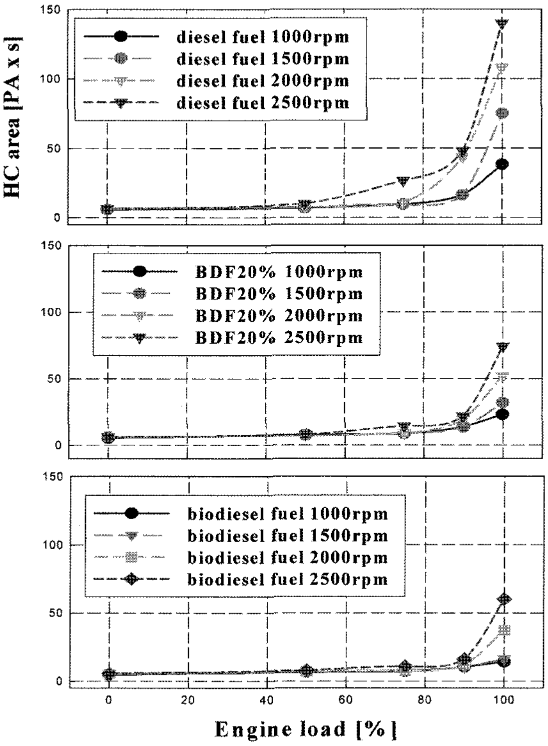


Figure 8. Total area of hydrocarbons of each fuel on chromatogram analysis under various engine speeds and loads.

Figure 6 shows the effect of oxygen content in fuel between non-load and full load at various engine speeds. In the non-load region, the exhaust smoke emission density did not change significantly with increased oxygen content in fuel. Note that smoke emissions barely exhausted at an oxygen content above 2 wt-% at load 0%. At full loads, exhaust smoke emission density was reduced significantly with increased oxygen content in fuel. In particular, when the oxygen content in fuel was above 8%, the exhaust smoke emission density was below 20% at all operating ranges.

3.2. GC Analyses of Individual Hydrocarbons

Figure 7 shows the calibration value, which is the relationship between the hydrocarbon amount and the peak area of chromatogram in GC analyses.

Figure 8 shows each peak area on the chromatogram, when diesel fuel, neat biodiesel fuel and biodiesel blended fuel (80 vol-% diesel fuel + 20 vol-% biodiesel fuel) were used in a diesel engine. To investigate the emitted unburned hydrocarbon characteristics, the diesel engine was operated at 1000, 1500, 2000 and 2500 rpm with the engine load as a parameter. As can be seen from the figure, at the same engine speed and load, unburned hydrocarbon concentration of the diesel fuel increased at a more significant rate than those of the biodiesel blended fuel and only biodiesel fuel. Specially, the unburned hydrocarbon quantity of the neat biodiesel fuel at 2500 rpm and full load was lower than that of diesel fuel at 1500 rpm and full load, about 17%. When the engine was operated below the medium load, because the excess air ratio was sufficient, the oxygen component in the biodiesel fuel did not greatly affect the oxidization of the hydrocarbon component. As the engine was operated in the range of over engine load of 75% and at higher speeds, the difference in the oxygen component between diesel fuel and biodiesel fuel produced differences of unburned hydrocarbon emissions. The oxygen component of the neat biodiesel and blended fuels promoted oxidization of fuel particles that greatly affected the amount of smoke created and significantly reduced the amount unburned hydrocarbon.

Figure 9 shows the characteristics of the unburned hydrocarbons exhausted from the three kinds of fuels at various loads and engine speeds. When the neat biodiesel fuel and the blended fuel were used, the quantity of the exhausted unburned hydrocarbon emissions was much lower than that of the commercial diesel fuel. As presented in Figure 9, in the case of diesel fuel, used at loads exceeding 75%, the unburned hydrocarbon emissions increased rapidly. This rapid increase might be originated from the lack of the oxygen component in comparison with biodiesel fuel. In contrast, neither the

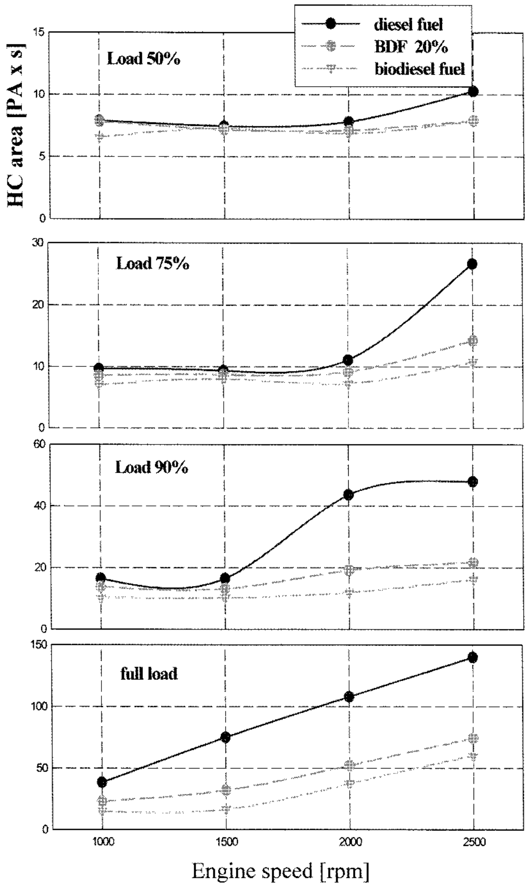


Figure 9. Total area of hydrocarbons on chromatogram analysis under various engine loads.

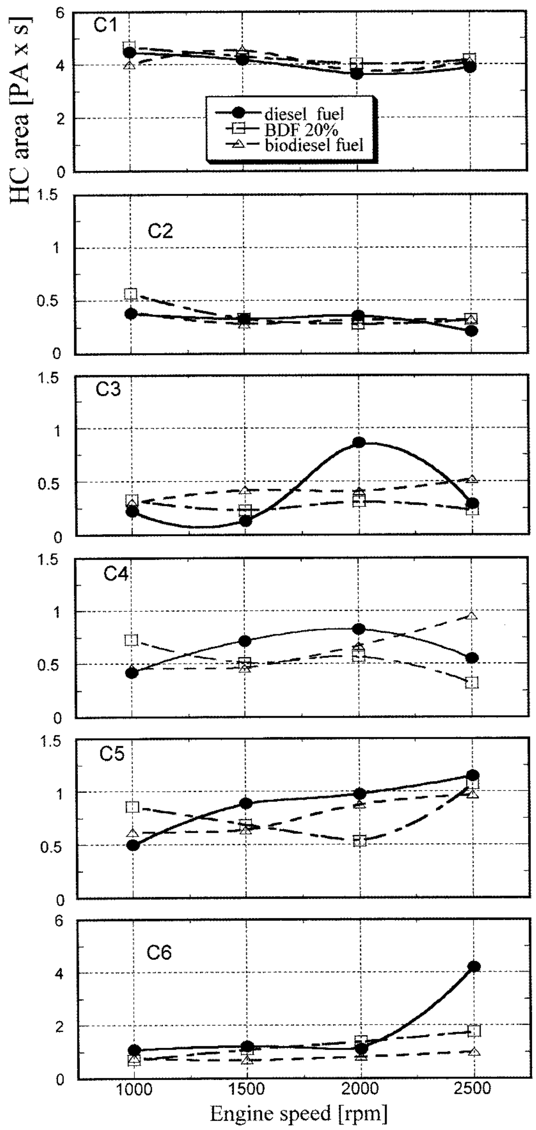


Figure 10. Area of each hydrocarbon in chromatogram analysis for engines at various engine with 50% of load.

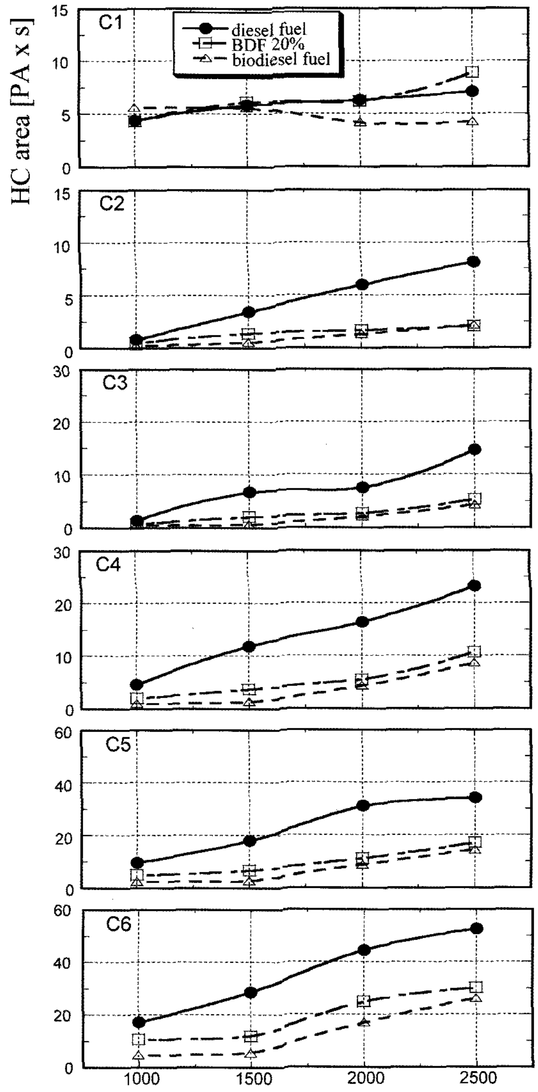


Figure 11. Area of each hydrocarbon on chromatogram analysis under various engine speeds at full load.

neat biodiesel, nor the blended fuels exhibited a rapid rise unburned hydrocarbon at a high load above 75% in the chromatogram.

Because the charging efficiency of the diesel engine decreased at a higher speed range, the air for complete combustion was not supplied sufficiently into the cylinder.

If biodiesel fuel was used as a base fuel in a diesel engine, its oxygen component could be in charge of the part which was lacking in the oxygen component at high speeds and loads. Also, a sufficient oxygen quantity could increase the oxidization rate of a fuel particle, and the exhaust smoke emission density could be reduced significantly, as well.

Figure 10 and Figure 11 show the exhaust individual unburned hydrocarbons from C_1 to C_6 with a load of 50% and 100%, respectively. The exhaust amount of lower and higher boiling points of hydrocarbons presented no significant difference among various operating conditions.

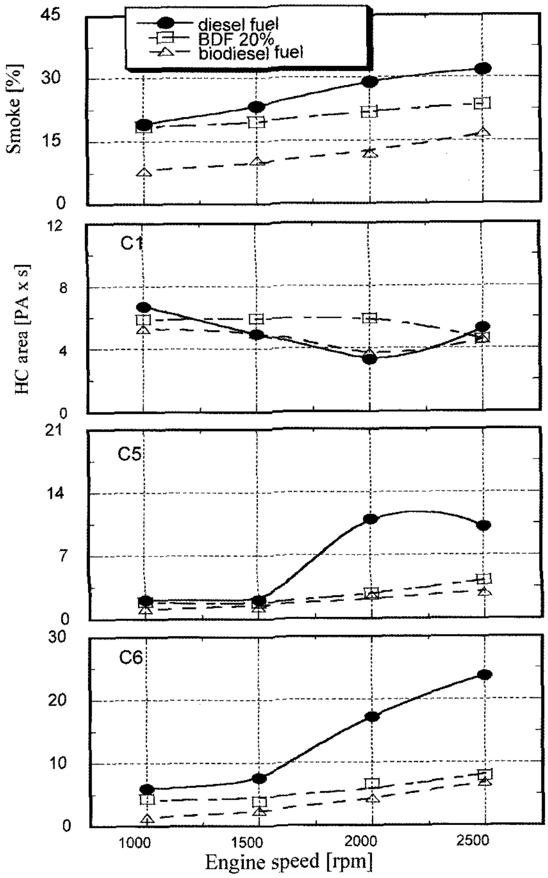
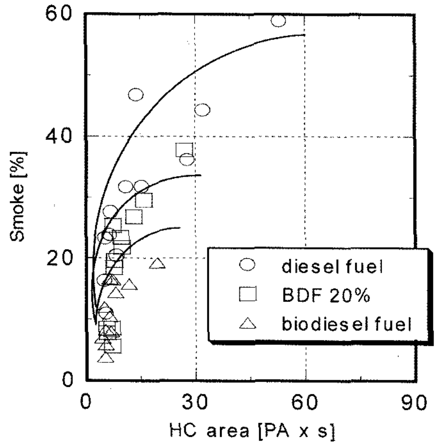


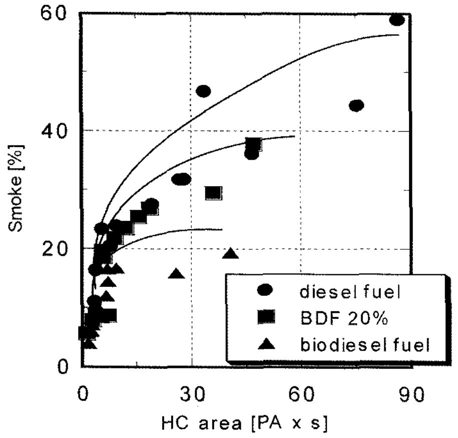
Figure 12. Relationship between smoke and hydrocarbons of low and high boiling points at various engine speeds at a load of 90%.

Figure 11 demonstrates that individual hydrocarbons of diesel fuel increased significantly except C_1 (methane) at 100% load. With respect to NMHC (non-methane hydrocarbon), the comparison data on diesel fuel and blended biodiesel fuel 20 vol-% showed that C_2 reduced by 74%, C_3 by 64%, C_4 by 54%, C_5 by 50% and C_6 by 44%. Additionally, in the case where the engine used only neat biodiesel fuel as its primary fuel, it exhibited a more significant reduction. These two results were similar to the results in Figure 4 with respect to exhaust emission.

Figure 12 shows the relationship between smoke and hydrocarbons of lower and higher boiling points at various engine speeds with 90% of load. As can be seen from the figure, the exhaust smoke emission density increases linearly with engine speed, and the rising curve of the diesel fuel is sharper than that of any other case.



(a) Lower boiling point hydrocarbons



(b) Higher boiling point hydrocarbons

Figure 13. Comparison of smoke density vs. lower and higher boiling point hydrocarbons.

The amount of exhaust smoke for lower boiling point hydrocarbon C_1 was similar to in all three kinds of fuels, while those of the higher boiling point hydrocarbons C_5 and C_6 varied greatly among the three kinds of fuel. As the engine speed increased, the higher boiling points hydrocarbons of diesel fuel increased significantly. As the engine speed increased, the oxidized quantity of the hydrocarbon component influencing the creation of smoke emission reduced because smoke emission was oxidized due to sufficient oxygen quantity at lower loads.

In general, smoke emission was mainly created in the later stage of combustion, and the amount of oxygen supplied to the combustion chamber was not sufficient at higher loads and speeds. If blended biodiesel fuel (above 20 vol-%) was supplied to diesel engines, the oxygen component in blended biodiesel fuel would be an oxidized hydrocarbon component, and was capable of reducing smoke emission density during the combustion period.

Figure 13 presents the relationship between the exhaust smoke emission density and hydrocarbons of lower and higher boiling points at all operating conditions. As expressed in the figure, the exhaust smoke emission density was directly related to the emitted higher boiling point hydrocarbon quantity. Exhaust smoke emission density increased in proportion to the increment of higher boiling point hydrocarbons, but that of the lower boiling point hydrocarbons did not increase sharply in proportion to the increment of the exhaust smoke emission density.

4. CONCLUSIONS

A four stroke, single cylinder, water cooled, direct injection diesel engine operating with blended biodiesel fuel at various engine speeds and loads was experimentally investigated. The ratio of the blended biodiesel fuel was set as a parameter in the experiment to clarify the effect of the oxygen component on smoke emission and unburned hydrocarbons, and to determine the relationship between exhausted smoke emission density and unburned hydrocarbons.

The conclusions extracted from this investigation are summarized as follows:

(1) When neat biodiesel fuel or blended biodiesel fuel (20–80 vol-%) was used in place of a commercial diesel fuel, there was no significant difference in engine torque and brake specific energy consumption.

(2) As oxygen content in the fuel increased, the exhausted smoke emission density reduced significantly. In particular, when the oxygen content in the fuel was above 8 wt-% at a higher load, the smoke reduction rate was significant at all engine speeds.

(3) A quantitative analysis method for C_1 to C_6 was established by using a gas chromatography, and the relationship between exhausted smoke emission density and the higher boiling points hydrocarbons was presented.

(4) The combustion improvements and the reduction of exhausted smoke emission density could be originated from the oxygen component in fuel. Finally, the remarkable reduction of exhausted smoke emission density was related to reduced higher boiling point of hydrocarbons.

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