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COMBINED EFFECTS OF BD20, LOW SULFUR DIESEL FUEL AND DIESEL OXIDATION CATALYST IN A HD DIESEL ENGINE

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ABSTRACT−The enormous increase in the use of fossil energy sources throughout the world has caused severe air pollution and a depletion of energy. Besides, it seems very difficult to comply with the upcoming stringent emission standards in vehicles. In order to develop low emission engines, research on better qualified fuels as alternative fuels to secure high engine performance becomes a more important issue than ever. Since sulfur contained in diesel fuel is transformed in sulfate-laden particulate matters when a catalyst is applied, it is necessary to provide low sulfur fuels before any Pt-based oxidation catalysts are applied. But the excessive reduction of sulfur levels may cause the lubricity of fuel and engine performance to degrade. In this aspect, biodiesel fuel derived from rice bran is applied to compensate viscosity lost in the desulfurization treatment. This research is focused on the performance of an 11,000cc diesel engine and the emission characteristics by the introduction of ULSD (Ultra Low Sulfur Diesel), BD20 (Diesel 80%+Biodiesel 20%) and a diesel oxidation catalyst, where BD20 is used to improve the lubricity of fuel in fuel injection systems as fuel additives or alternative fuels.

KEY WORDS : ULSD (Ultra Low Sulfur Diesel), SOF (Soluble Organic Fraction), Sulfate, PM (Particulate Matter), DOC (Diesel Oxidation Catalyst), BD20 (Diesel 80%+Biodiesel 20%), PAH (Polycle Aromatic Hydrocarbon)

1. INTRODUCTION

There are difficulties in developing emission controlling systems because driving conditions and engine characteristics, performance of aftertreatments and characteristics of a catalyst must all be considered together. Future diesel emission technologies have been directed to various aftertreatments and fuel technology. The aftertreatments have significant effects on reducing emissions (Oyama and Kakegawa, 2003; Lee and Chun, 2006). Even in a continuously regenerating trap, the sulfur level has to be maintained below 50 ppm for successful operation (Allansson *et al.*, 2000; Frank *et al.*, 2004). A DOC may not be effective in the reduction of PM, but it is very effective in reducing SOF contained in PM (Daniels *et al.*, 1996). Many other researchers have studied in order to improve durability and performance of catalysts since the poisoning effect of a DOC can be reduced by ULSD (Khair and Mckinnon, 1999; Vincent and Richards, 2000).

Biodiesel fuels can be obtained from vegetable oils or animal fats as substitutes for petroleum fuel in diesel engines. This has been studied in Europe and USA because it is friendly to the environment and they are renewable energy sources (Olaf *et al.*, 1999; Sharp and Howell, 2000).

Biodiesel fuel has some merits which may be applied to diesel engines without fundamental engine modification and can reduce CO, HC, sulfur, PAH and smoke substantially. However, biodiesel fuel generally resulted in some engine power loss, and an increase in fuel consumption and unregulated emissions such as aldehydes (Masatoshi and Tomoaki, 1997; Nikanjam and Henderson, 1993).

In this study, four fuels: diesel fuel, ULSD, BD20 (diessel 80% + biodiesel 20%) and a blended fuel (ULSD + BD20) were studied carefully under two different conditions; one with and one without DOC. ULSD must be applied in the presence of DOC because of the poisoning effects on the surface of DOC. However, since excessively reduced sulfur contents in diesel fuel might decrease the viscosity in fuel and create a loss of lubricity which produces a negative effect on durability and the system of fuel injection pumps. Only a modest adjustment to the amount of sulfur is required to improve engine performance and DOC, as well as a reduction of emissions (Choi and Oh, 2006; Oh *et al.*, 2003). Biodiesel (BD20) is applied to compensate for the degraded lubricity. However, there is no data available for the combined effects of BD20, ULSD or for catalysts in terms of engine

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performance characteristics, emissions, and catalyst performance tests especially in D-13 or D-3 modes.

2. EXPERIMENT

2.1. Test Engine

An employed test engine and DOC is summarized in Table 1 and Table 2.

2.2. Experimental Apparatus

The applied engine dynamometer is a 250 kW EC type (U.K, Froude consine Co.) and the apparatus constitutes a fuel temperature regulator, a cooling water temperature regulator, an intake air flow meter, and a fuel flow meter. Emission measuring apparatus (Horiba Co., MEXA-9100D) is applied. To detect CO, THC and NOx, NDIR (Nondispersive infrared) and a HFID (Heated flame inoization detector) and a CLD (Chemiluminescence detector) are applied.

To measure PM, a MDT (Mini dilution tunnel) is used. A schematic diagram of the emission test is shown in Figure 1. The details of the applied fuels are described in Table 3.

2.3. Experimental Details

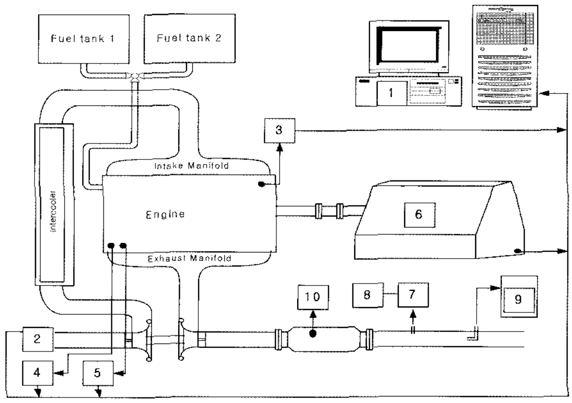
An engine performance test was conducted by increasing the engine speeds from 1000 rpm to a 2000 rpm at 200 rpm interval and fuel consumption, engine powers and torques were measured. Then, an arithmetic average for

Table 1. Test engine.

Items	Specifications
Type	6 Cylinder
Fuel injection type	DI
Displacement (cc)	11,149
Cylinder × Bore (mm)	122 × 156
Max. Power (PS/rpm)	250/2000
Injection timing	12 deg. BTDC

Table 2. Diesel oxidation catalysts.

Items	Specifications
Dimension (mm)	229 × 152
Catalyst	Pt
Pt loading (g/ft^3)	40
Wash coat	Ti-Si



1. Dynamometer control desk 2. Intake air consumption meter
3. Throttle actuator 4. Fuel temperature controller
5. Oil temperature controller 6. Engine dynamometer
7. Exhaust gas analyzer 8. Pen recorder
9. Mini dilution tunnel 10. Diesel oxidation catalyst

Figure 1. Schematic diagram of experimental apparatus.

Table 3. Specification of test fuels.

Item of test	Applied fuels: Commercial diesel fuel (Sulfur 500 ppm below)	ULSD (Sulfur 15 ppm below)	BD20	ULSD +BD20
Flash point (PM, °C)	59	65	90	71
Pour point (°C)	−7.5	−25.0	−15	−21
Distillation 90% (°C)	350	333	360	338
Carbon residue on 10% residue (%)	0.01	0.01	0.01	0.01
Ash (%)	under 0.01	under 0.01	under 0.01	under 0.01
Viscosity (40°C, cst)	2.9	2.5	3.0	2.7
Sulfur content (ppm)	390	13	30	13
Cetane value	51	57	46	53
Low heating value MJ/kg)	43	45	42	44

Table 4. Driving conditions of D-13.

Mode	Engine speed	Load rate (%)	Weight factor
1	Idle	–	0.25/3
2	Intermediate	10	0.08
3	Intermediate	25	0.08
4	Intermediate	50	0.08
5	Intermediate	75	0.08
6	Intermediate	100	0.25
7	Idle	–	0.25/3
8	Rated	100	0.1
9	Rated	75	0.02
10	Rated	50	0.02
11	Rated	25	0.02
12	Rated	10	0.02
13	Idle	–	0.25/3

Table 5. Driving conditions of D-3mode.

Mode	Engine speed	Load rate (%)
1	40% of rated speed	100
2	Intermediate	100
3	Rated	100

30 seconds was taken after stabilizing fuel consumption, engine powers and torques for three minutes under full engine loads.

An emission test was done to measure CO, THC, NOx, PM and the soot in D-13 and D-3 modes. The corresponding driving conditions are shown in Tables 4 and 5.

The performance of a catalyst depends on the amount of platinum catalysts, wash coat, cell density, etc. However, the most important parameters affecting conversion efficiency were exhaust emission temperature and velocity. Purification tests were conducted by increasing the temperatures of exhaust gases and varying engine loads at a fixed engine speed (1200 rpm).

3. RESULTS AND DISCUSSION

3.1. Engine Performance

DOC may affect the engine performance due to a somewhat increased back pressure. Figures 2 and 3 illustrate engine performance curves with and without DOC. In a comparison with standard diesel fuels, the engine power decreased 1.3% to 2% on average with the application of ULSD. In general, the combustion condition can be improved due to a higher level of cetane. On the other hand, a degraded lubricity in ULSD might affect the control system of fuel injection timing. In biodiesel fuels, the engine power decreased to about 4.5%, which may be due to the lower heating values of biodiesel fuel. However, when the blended fuel of BD20 and ULSD were applied, the engine power improved a little and resulted in a 3% reduction on average. The BSFC in ULSD was reduced and BSFC in BD20 increased about 2–3% but in a blended fuel BSFC increased about 1–2% presumably due to more activated atomization of injected

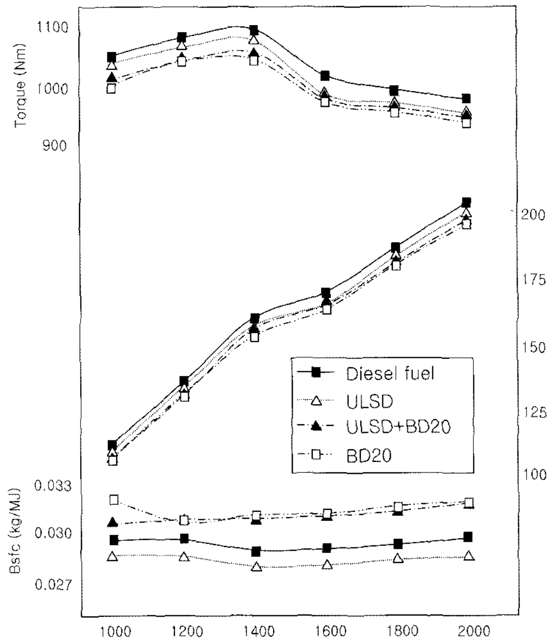


Figure 2. Engine performance test (without DOC).

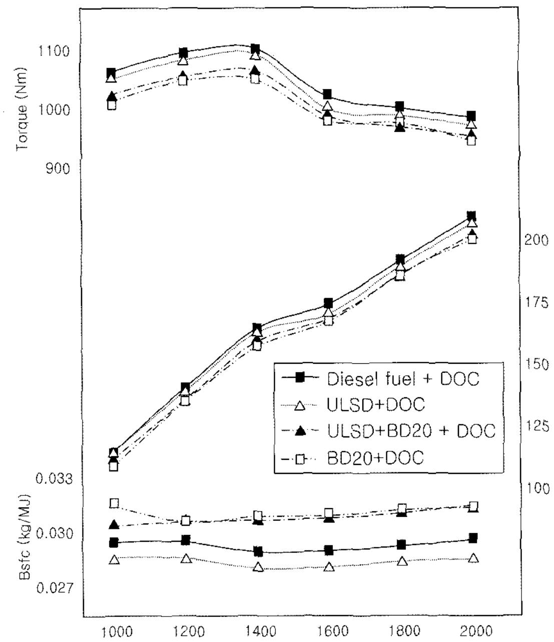


Figure 3. Engine performance test (with DOC).

fuels and oxygen contents in biodiesel fuel.

In the application of DOC, the reduction of power is about 2.5% in ULSD and there is a 4% reduction of power in BD20. In the blended fuel of BD20 and ULSD, the power decreased about 3.5%.

3.2. Emissions

Figure 4 shows a comparison study of CO emissions in the application of four different fuels (diesel fuel, ULSD, BD20, the blended fuel of ULSD and BD20) and also with and without DOC. In both cases of with and without DOC, the CO decreased to about 77.5% in standard diesel, 79% in ULSD, and 82% in BD20 respectively. When the blended fuel of ULSD and BD20 are applied, the CO decreased to about 86.4%. This may be due to higher oxygen contents in BD20 and the cetane values improved by ULSD.

Figure 5 shows the reduction efficiency of THC emissions with the application of DOC. THC is reduced by 76% in diesel fuels and by about 81% in ULSD and by 81.2% in BD20 and by 81.6% in blend fuels (BD20+ ULSD) respectively because of catalysts.

Figure 6 shows the NOx emissions of four different fuels. With the application of DOC, NOx decreased to about 0.4% and 1% each in diesel and ULSD. However, in BD20, NOx increased to about 3% and in the blended fuel (ULSD+BD20) NOx increased to about 1%. However, in general catalysts do not affect NOx emissions.

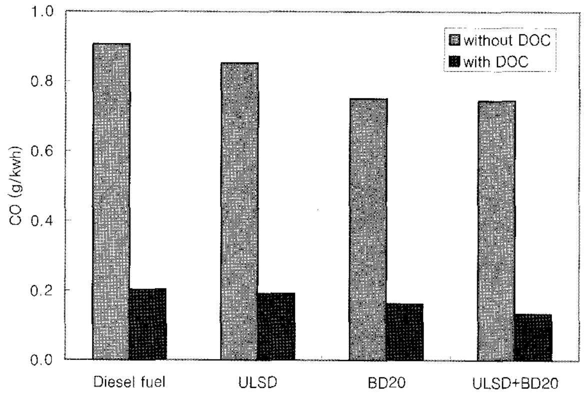


Figure 4. CO emissions.

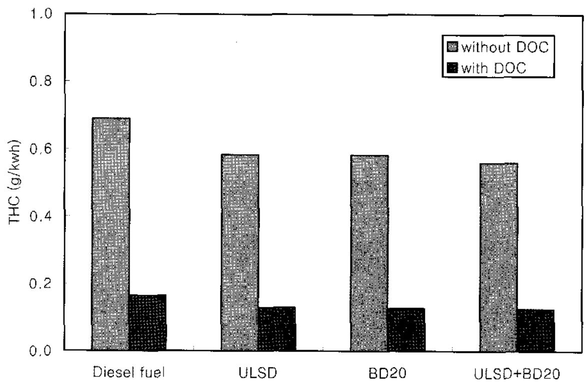


Figure 5. THC emissions.

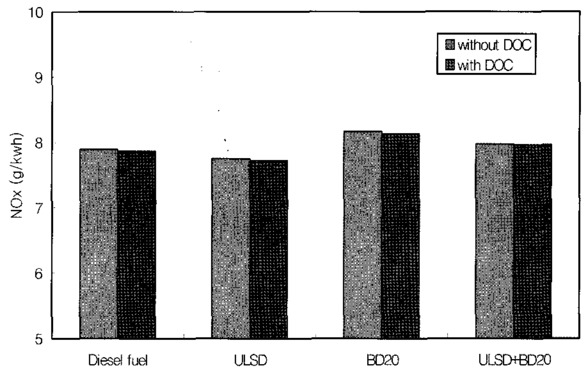


Figure 6. NOx emissions.

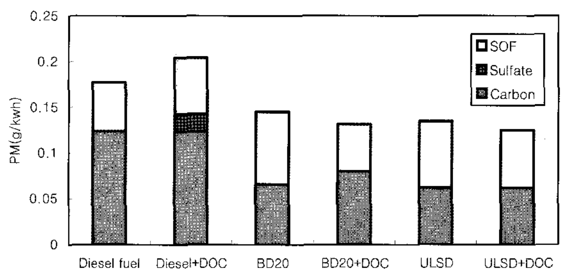


Figure 7. Formation of SOF, sulfate and carbon in PM.

In diesel vehicles, PM emissions constitute carbon soots (50–60%), SOF (20%) and other materials (sulfate, heavy metals, etc: 30–40%). Figure 7 shows the reductions characteristics of SOF and sulfates when different fuels (standard diesel fuels, BD20, ULSD) are applied under the conditions with and without DOC. When DOC is applied to standard diesel fuels, the total PM emissions tend to increase because of the increasing sulfates (0.05 g/kW.h) due to the oxidation of sulfur components. However, when BD20 is applied, SOF increases to 32% but carbons decrease to 57% and it results in a total PM decrease to 15%. As DOC is applied to BD20, the purification of SOF is very effective and shows a 26% reduction. With the application of ULSD, SOF increases to 35% but carbons decrease to 50%. It showed that there is a 15% reduction of total PM without DOC but a 22% total PM with DOC.

Figure 8 shows the effects of the smoke reduction with the application of ULSD or biodiesel. The results of diesel fuels are then compared. When ULSD or biodiesel is applied, the reduction efficiency increased to about 15% and 30% respectively more than standard diesel fuel.

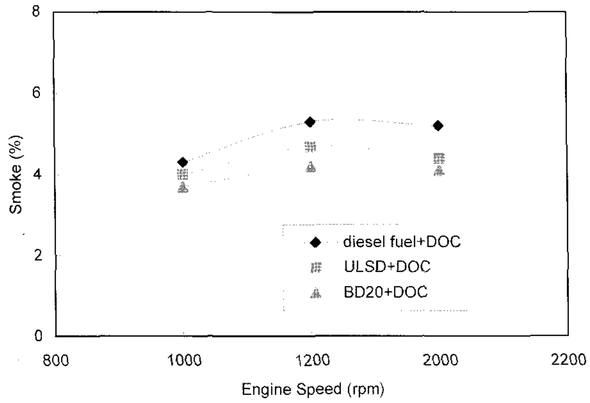


Figure 8. Smoke in D-13 mode.

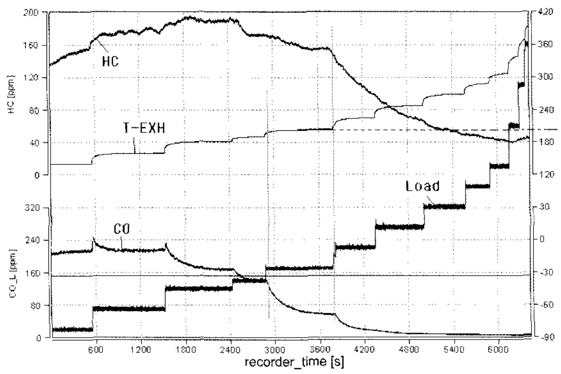


Figure 9. DOC performance test in diesel fuel.

3.3. Purification Test

Figure 9 shows the light-off temperatures for CO and HC emissions when standard diesel fuels were applied. CO decreased until a recording time of 3000 sec around an exhaust gas temperature of 200 and then the purification was completed at 350. However, HC emissions decreased suddenly at 3800 sec and the corresponding exhaust temperature was 220.

Figure 10 shows the light-off temperatures for CO and HC emissions when ULSD fuels were applied. Due to desulfuration, CO decreased drastically at the recording time of 1580 sec and the exhaust temperature was at 180. In Figures 9 and 10, light-off occurred earlier in ULSD than in standard diesel fuel due to poisoning effects (or sulfate generation).

4. CONCLUSIONS

(1) With the application of DOC, there is a slight decrease in engine power and a slight increase in fuel consumption of the four different fuels.

(2) With the application of DOC, there was a 5% reduction of PM in standard diesel fuel and 18.3% in BD20. CO and HC decreased to 6%–17% in BD20.

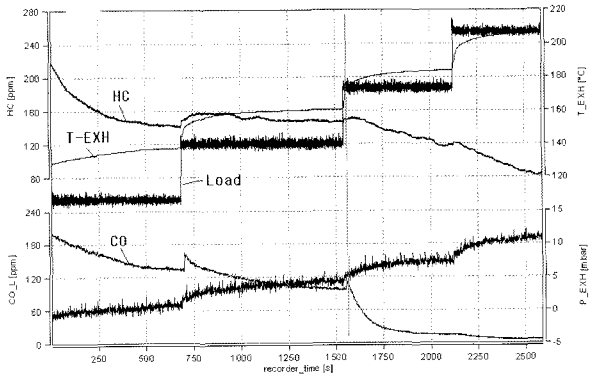


Figure 10. DOC performance test for ULSD.

When the blended fuel of ULSD and BD20 were applied, the effect of the reduction was quite sensitive, and PM, CO, and HC decreased to about 20% respectively.

(3) With the application of DOC, PM decreased 26% and 37% in BD20 and ULSD respectively, and CO and HC decreased to 80%. When blend fuel of ULSD and BD20 was applied simultaneously, PM emissions decreased to 43%, and CO and HC were reduced to about 80–85%.

(4) BD20 fuel is very effective for the reduction of smoke because the higher oxygen contents in BD20 fuel accelerated the combustion process faster.

(5) In ULSD fuels, the light-off temperatures were lower than in standard diesel fuels due to sulfur levels contained in diesel fuels.

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