The Effect of Biodiesel and Ultra Low Sulfur Diesel Fuels on Emissions in 11,000 cc Heavy-Duty Diesel Engine

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It seems very difficult to comply with upcoming stringent emission standards in vehicles. To develop low emission engines, better quality of automotive fuels must be achieved. Since sulfur contents in diesel fuels are transformed to sulfate-laden particulate matters as a catalyst is applied, it is necessary to provide low sulfur fuels before any Pt-based oxidation catalysts are applied. In general, flash point, distillation 90% and cetane index are improved but viscosity can be worse in the process of desulfurization of diesel fuel. Excessive reduction of sulfur may cause to degrade viscosity of fuels and engine performance in fuel injection systems. This research focused on the performance of an 11,000 cc diesel engine and emission characteristics by the introduction of ULSD, bio-diesel and a diesel oxidation catalyst, where the bio-diesel was used to improve viscosity of fuels 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), Cetane value, Distillation 90%, Pour point, Viscosity, B20 (Bio-diesel 20%), PAH (Polycle Aromatic Hydrocarbon)

1. Introduction

Many countries including USA, EU and Japan have made efforts in the simultaneous reduction of PM and NOx in diesel vehicles through various aftertreatment technology. Currently future diesel emission technologies are directed to various aftertreatments technology and fuel types. There are difficulties in developing emission control systems because driving conditions and engine characteristics, performance of aftertreatments, characteristics of catalyst and fuel types must be considered together. A diesel oxidation catalyst has significant effects in reducing emissions of SOF and sulfate, and its durability must be secured through desulfurization prerequisite to any pt-based oxygen catalysts (Oyama, 2003 ; Daniels et al., 1996). Many other researches have been employed in order to improve durability, performance of catalysts and the poisoning effect on DOC (Khair and Mckinnon, 1999 ; Vicent and Richards, 2000). Even in a continuously regenerating trap, the sulfur level has to be maintained below 50 ppm for its successful operation (Allansson et al., 2000 ; Frank et al., 2004 ; Oh et al., 2004).

Biodiesel fuels can be obtained from vegetable oils or animal fats as a substitute for petroleum fuel in diesel engines and has been studied in Europe and USA because it is friendly to environment and a renewable energy source (Schroder et al., 1999 ; Sharp et al., 2000). Biodiesel can give some merits which may be applied to diesel engines without fundamental engine modifications and reduce CO, HC, sulfur and PAH substantially. But biodiesel fuel generally resulted in a loss of engine power, and increase in fuel consumption unregulated emissions somewhat.

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Currently a blend (B20) of diesel (80%) and biodiesel (20%) is used mostly, and also many researchers have investigated on neat biodiesel (100%). In fact, in Germany neat biodiesels have been commercialized at a cheaper price. With its high oxygen content, biodiesel is very effective in reducing solid carbon materials but is not efficient in the reduction of SOF. Therefore, DOC must be applied to any engines in which biodiesels are used in order to reduce SOF.

In this study, four kinds of fuels such as diesel, ULSD, B20 and a blend (ULSD+B20) are applied and investigated the results carefully under two different conditions of with/without DOC. In other words, ULSD must be applied in the presence of DOC because of poisoning effects on the surface of DOC. However, excessively reduced sulfur contents may cause to decrease lubricity of fuel and engine performance of fuel injection systems (Oh et al., 2003). It requires only modest adjusted amounts of sulfur can improve engine performance and DOC, as well as decrease of emissions. To prevent this penalty, biodiesel (B20) is applied to compensate degraded viscosity.

2. Experiment

2.1 Test engine

The specification of an employed test engine and DOC were summarized in Table 1 and 2.

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 catalyst

Items	Specifications
Dimension (mm)	229×152
Catalyst	Pt
Pt loading (g/ft3)	40
Washcoat	Ti-Si

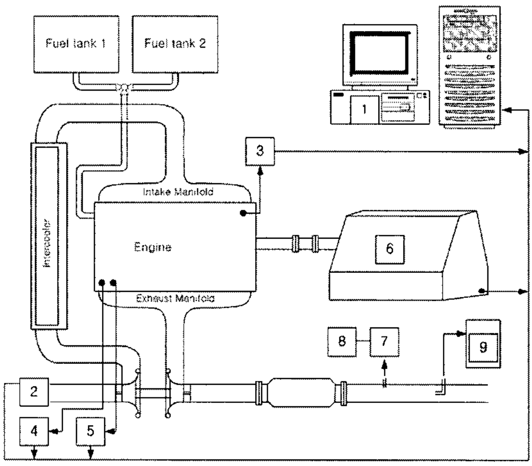
2.2 Experimental apparatus

The type of engine dynamometer is 250kW EC (U.K, Froude consine Co.) and there are 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 HFID (Heated Flame Inoization Detector), CLD (Chemiluminescence Detector) are applied. For measuring PM, MDT (Mini Dilution Tunnel) is used. A schematic diagram of emission test is shown in Fig. 1 and the details of applied fuels are described in Table 3.

2.3 Experimental details

2.3.1 Engine performance

Engine performance test was conducted by increasing engine speeds from 1000 rpm to 2200 rpm at 200 rpm interval and measured fuel consumptions, engine powers and torques. Then took an arithmetical average for 30 seconds after stabilizing intake temperatures, fuel consumptions, engine powers and torques for three minutes under full engine loads.



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

Fig. 1 Schematic diagram of emission measuring apparatus

Table 3 Test fuels

Item of test	Standard	Applied Fuels		
		Base fuel (Diesel) 500 ppm below	ULSD 15 ppm below	Biodiesel (B20)
Flash point (℃)	40 above	59	65	90
Pour point (℃)	0.0 below	−7.5	−25.0	−15
Distillation 90% (℃)	360 below	350	333	360
Carbon residue on 10% residue (%)	0.15 below	0.01	0.01	0.01
Ash (%)	0.02 below	under 0.01	under 0.01	under 0.01
Viscosity (40℃, cSt)	1.9∼5.5	2.9	2.5	3.0
Sulfur content (ppm)	0.05 below	390 ppm	13 ppm	30 ppm
Cetane value	45 above	51	57	46
Low heating Value (MJ/kg)	—	43	45	42

2.3.2 Emission test

Emission test was done with measuring CO, THC, NOx and PM in D-13 mode. The corresponding driving conditions are shown in Table 4.

Table 4 D-13 mode

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

3. Results and Discussion

3.1 Engine power and torque

Figures 2∼5 illustrated engine powers and torques with/without the application of DOC. In the comparison with a standard diesel fuel, the engine power decreased 1.3% to 2% on average by the application of ULSD. In general, the combustion condition can be improved because cetane values in ULSD are higher than diesel fuels but degraded lubricity in ULSD causes injection problems inside cylinders. In bio-diesel fuels, engine power decreased to about 4.5%, which may be due to lower calorific values. However,

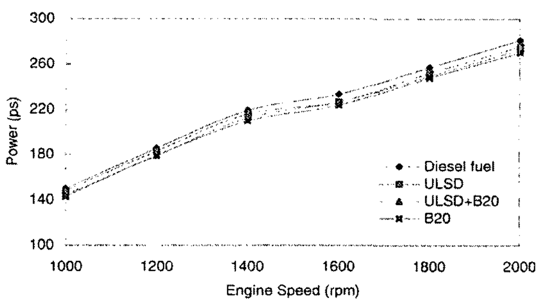


Fig. 2 Engine power test (without DOC)

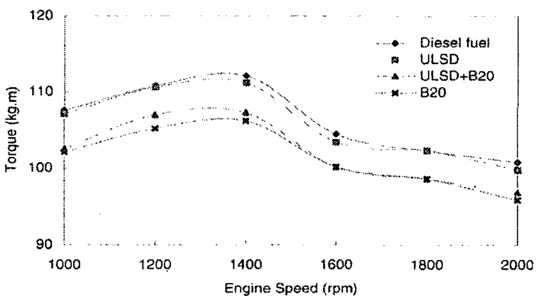


Fig. 3 Engine torque test (without DOC)

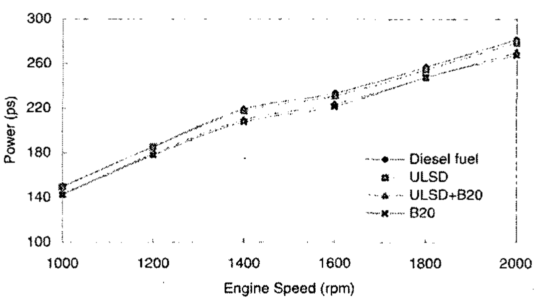


Fig. 4 Engine power test (with DOC)

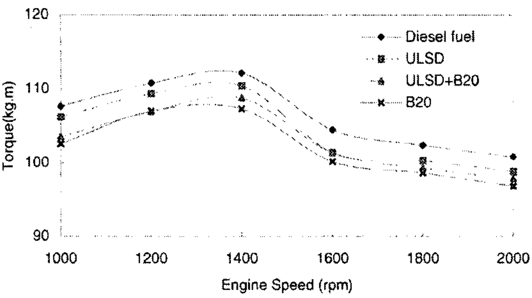


Fig. 5 Engine torque test (with DOC)

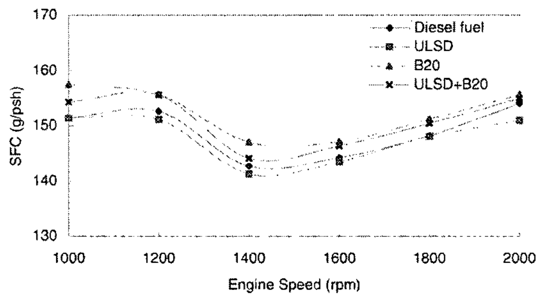


Fig. 6 BSFC test (without DOC)

when a blend of B20 and ULSD was applied, the engine power improved a little and it results to 3% reduction on average. In the application of DOC, the deduction of power is about 2.5% in ULSD and 4% deduction of power in B20. In the case of a blend of B20 and ULSD, the power decreased to about 3.5%. This is caused by somewhat improved viscosity of B20. (See Figs. 4 and 5)

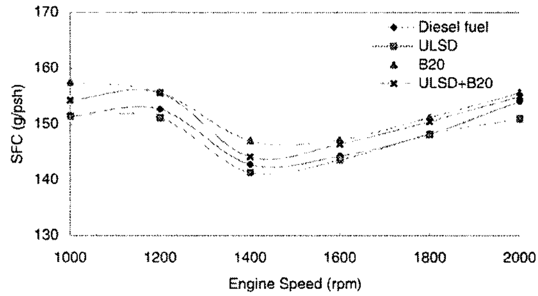


Fig. 7 BSFC test (with DOC)

3.2 Specific Fuel Consumption

Figures 6 and 7 show some change of fuel consumption with/without DOC and the rates can be negligible. Without DOC the fuel consumption in ULSD decreased about 1%, and fuel consumption in B20 increased to about 2~3% with respect to diesel fuels. This may be due to the improved atomization of injected fuels.

In the application of a blend of ULSD and B20, the fuel consumption increased to about 1~2%. Therefore, the effects on specific fuel consumption can be negligible in both cases of with/without DOC.

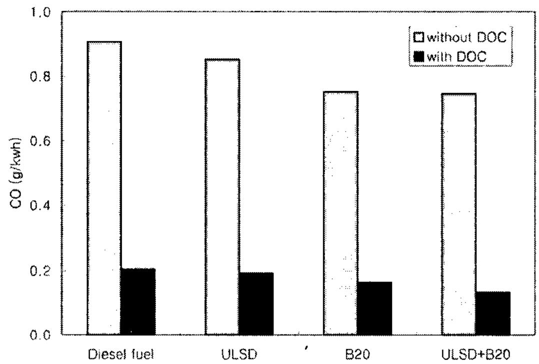


Fig. 8 CO in D-13 mode

3.3 Exhaust emissions

CO

Figure 8 shows the comparison study of CO emission in the application of diesel fuel, ULSD, B20 and a blend of ULSD and B20 and also in the presence of DOC or not. In both cases of with/without DOC, CO decreased to about 77.5%, 79% and 82% respectively in standard diesel fuels and ULSD and B20. When a blend of ULSD and B20 is applied, CO decreased to about 86.4%. This may be due to oxygen contents in B20 and cetane values improved by ULSD.

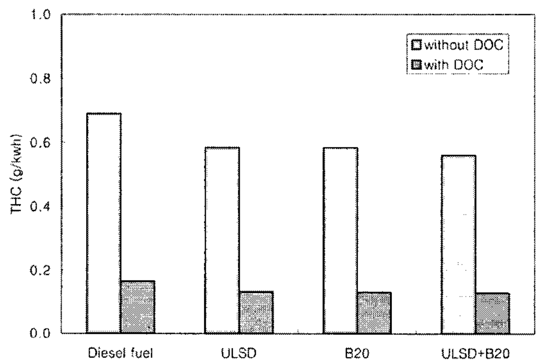


Fig. 9 THC in D-13 mode

NOx

Figure 10 shows NOx emissions in four different fuels. By the application of DOC, NOx decreased to about 0.4% and 1% each in diesel and ULSD. However, in the case of B20, NOx increased to about 3% and in a blend (ULSD+B20) NOx increased to about 1%. In general, NOx emissions are not affected by the application of DOC.

Particulate Materials

PM emissions are shown in Fig. 11. With the application of DOC, PM emissions increased to about 15% in diesel fuel, but PM decreased to 37% in ULSD and 26% in B20. When blend a blend of B20 and ULSD was applied, PM decreased to about 43%. In general, ULSD fuel is very effective in the reduction of PM since reductions of HC and SO_2 keep sulfates from generating.

SOF, Sulfate, Carbon Soot

In diesel vehicles, PM emissions constitute carbons soot (50~60%), SOF (20%) and others (sulfate, heavy metals, etc: 30~40%) generally. Fig. 12 shows the reductions characteristics of SOF and sulfates when different fuels (standard diesel fuels, B20, ULSD) were applied under the condition of with/without DOC. When a DOC was applied to standard diesel fuels, total PM tend to increase due to sulfates (0.05 g/kWh) formed by higher exhaust emission temperatures. However, when B20 was applied, SOF increased to 32% but carbons decreased to 57% and it results total PM decreased to 15%. As a DOC was applied to B20, the purification of SOF is very effective and it shows 26% reduction. In a case of the application of ULSD, SOF increased to 35% but carbons decreased to 50%. It turns out there were reductions of 15% total PM without DOC but 22% total PM with DOC.

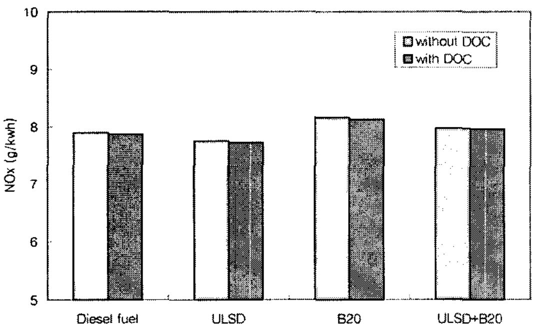


Fig. 10 NOx in D-13 mode

3.4 DOC performance

Performance of DOC depends on the amount of platinum catalyst, washcoat, cell density, and etc. But the most important parameters affecting on conversion efficiency were exhaust emission temperature and velocity. Catalyst performance test for different fuels was conducted by increasing temperatures of exhaust emissions and varying engine loads with a fixed engine speed (1200 rpm).

Figure 13 shows light-off temperatures for CO and HC emissions when standard diesel fuels were applied. CO decreased until recording time 3000 sec around an exhaust emission temperature 200℃ and then the process was finished at 350℃. But, HC decreased suddenly at 3800 sec and the corresponding exhaust emission temperature was

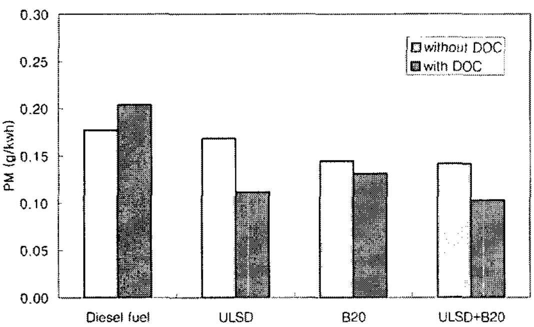


Fig. 11 PM in D-13 mode

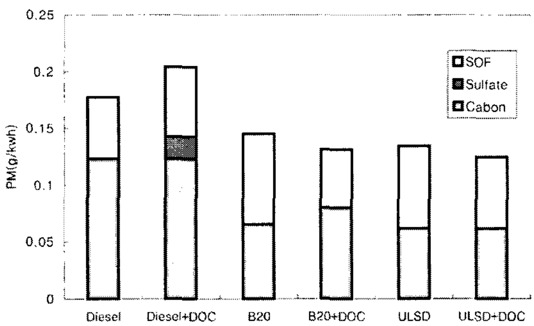


Fig. 12 SOF, Sulfate, Carbon in D-13 mode

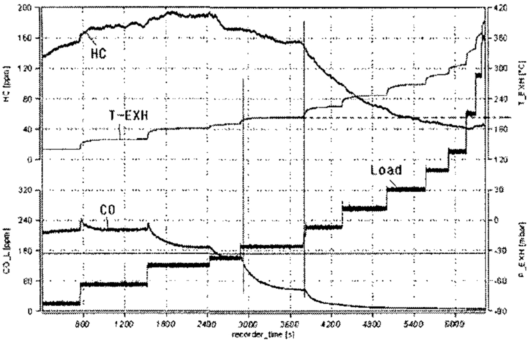


Fig. 13 The result of DOC test (diesel fuel)

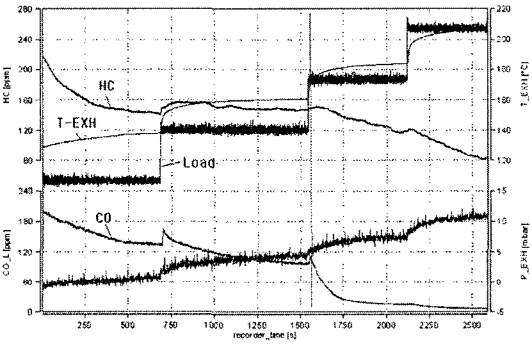


Fig. 14 The result of DOC test (ULSD)

220℃.

Figure 14 shows light-off temperatures for CO and HC emissions when ULSD fuels were applied. CO decreased suddenly around recording time 1580 sec and exhaust emission temperature 180℃. In Figures 13 and 14, light-off temperatures occurred earlier in ULSD than in standard diesels due to less poisoning effects (or sulfate generation).

4. Conclusions

(1) With/without DOC, there is a little decrease in engine power and a little increase in fuel consumptions in four different fuels. It results that DOC and four different fuels did not affect on engine performance tests critically.

(2) Without DOC, PM reduced to 5% in standard diesel fuel and 18.3% in B20. CO and HC decreased to 6%~17% in bio-diesel fuel. When a blend of ULSD and B20 was applied, the effect of reduction is sensitive, and PM, CO, and HC decreased to about 20% respectively.

(3) With the application of DOC, PM decreased to 26% and 37% in B20 and ULSD. In general, CO and HC decreased to 80%. When ULSD and B20 were applied, PM emissions decreased to 43%. The reduction rates of CO and HC were about 80~85%.

(4) The emission reduction is very effective on DOC without giving any penalty in engine performance when a blend of ULSD and B20 is applied simultaneously.

(5) Both in B20 and ULSD fuels, the light-off temperatures are lower relatively than in standard diesel fuels due to reduced sulfur levels.

Acknowledgments

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