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CHARACTERISTICS OF PERFORMANCE AND EXHAUST EMISSION OF DIESEL ENGINES BY CHANGES IN FUEL PROPERTIES AND APPLICATION OF EGR

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ABSTRACT–In this study, the potential use of oxygenated fuels such as ethylene glycol mono-normal butyl ether (EGBE) was investigated in an attempt to reduce the emission of exhaust smoke from diesel engines. Effects of the combustion method on exhaust emission of DI and IDI diesel engines were also examined. Since EGBE is composed of approximately 27.1% oxygen, this is one of several potential oxygenated fuels that could reduce the smoke content of exhaust gas. EGBE blended fuels have been proven to reduce smoke emission remarkably compared to the conventional commercial fuels. The test was conducted with single and four cylinder, four stroke, DI and IDI diesel engines. The study showed that a simultaneous reduction of smoke and NOx emission could be achieved by the combination of oxygenated blend fuels and the cooled EGR method in both DI and IDI diesel engines. It was also found that a reduction rate of exhaust emission in a DI engine was larger than an IDI diesel engine.

KEY WORDS : EGBE (Ethylene glycol mono-normal butyl ether), Oxygenated fuel, Alternative fuel, Smoke, NOx, EGR (Exhaust gas recirculation)

1. INTRODUCTION

Increasing concerns about the world's supply of energy and environmental pollution has accelerated efforts to develop alternative energy sources that can replace fossil fuels. The automobile industry is not an exception to this requirement (Akasaka and Sakurai, 1994; Liotta and Liotta, 1993; Stoner and Litzinger, 1999). Diesel engines have many advantages over gasoline engines with its affinity for various fuels, high heat efficiency, high compression ratio and running in sparse combustion regions, which has received much attention from an environmental point of view. However, diesel engines have drawbacks in that they gererate large amounts of smoke and NOx which are thought to be the main culprits of photochemical smog, acid rain and ozone layer destruction. The control of permissible emission levels of air polluting substances is cumulative, and, therefore reducing the emission of NOx and smoke from diesel engines stands out as a readily improvable aspect of daily life. Related with this task, there are many current efforts to develop oxygenated fuels (Oh and Choi, 2003; Vertin, 1999; Sirman *et al*., 1998). However, there have been very few studies examining the effect of oxygenated fuels in engine performance and exhaust gas emission with varied methods and configurations of combustion. In this study, attempts were made to achieve a simultaneous reduction of smoke and NOx by using a commercial diesel fuel blended with ethylene glycol mono-normal butyl ether (hereinafter called EGBE) and adopting an exhaust gas recirculation medhod (herein after called EGR) in DI and IDI diesel engines.

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2. EXPERIMENTAL APPARATUS AND METHODS

Two (2) models of diesel engines were used in this study; i.e. one (1) single cylinder, four stroke, water-cooled direct injection (herein after called, DI) engine and one (1) four cylinder, 4 stroke, water-cooled, indirect injection (herein after called IDI) engine. Table 1 shows the specification of these two engines, and Table 2 shows the comparative properties of EGBE and diesel oil respectively. The study is designed to measure engine performance and exhaust gas characteristics when oxygenated fuel containing EGBE 5, 10, 15 and 20% by volume are blended into commercial diesel oil and used.

Figure 1 is the schematic diagram of the experimental apparatus. Experiments were conducted at engine speeds of 1000, 1500, 2000 and 2500 rpm. For measurements, each of the above speeds were kept constant and the injection pump rack was pulled fully to the full load. At this time, torque values were set and classified into regular ratios of 0, 25, 50, 75, 90 and 100%. Engines were run for a sufficient amount of time to allow for stabilization before taking necessary data. Using a smoke measuring device (Hesbon; Korea), specific amounts of smoke was introduced into the device at 300 mm upstream of the tailpipe and the concentration wsa measured based on filter paper absorbance. Concentrations of NOx was measured by a continuous stream of exhaust gas into the exhaust gas analyzer (GreenLine MK2; Italy) with the intake tube connected to the exhaust pipe approximately 400 mm downstream of the exhaust manifold.

Figure 2 is a photograph of the experimental apparatus. EGR ratio is a term indicating the ratio of fresh intake air reduced by the regeneration process of EGR and is expressed as the formula (1) below, where, V_0 is intake air volume (m^3/h) when no EGR was EGR performed while

$$\text{Ratio } (\%) = \frac{V_0 - V_a}{V_0} \times 100 \quad (1)$$

V_a is that when EGR was performed. Fluctuating exhaust gas temperature ranging 303~845 K at various engine loads were uniformly maintained at approximately 297 K by passing the gas through a recirculating cooling system. In order to eliminate fine particles from the regenerative exhaust gas, a filter was used.

Table 1. Specifications of test engine.

Items	Specifications	
Engine model	ND130	D4BA
Injection type	DI	IDI
Cylinder number	1	4
Bore×Stroke (mm)	95×95	91.1×95
Displacement (cc)	673	2476
Compression ratio	18	21
Combustion chamber type	Toroidal	Swirl

Table 2. Properties of test fuels.

Proterties	Diesel fuel	EGBE
Molecular formula	$C_{16}H_{34}$	$CH_3(CH_2)_3O(CH_2)_2OH$
Density (kg/m^3)	43.12	39.61
Moleculara weight	45	57
LHV (MJ/kg)	3.0	4.2
Oxygen content (%)	0	10.5

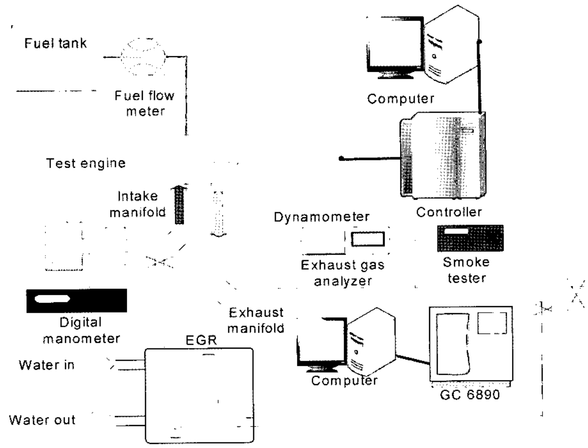

Figure 1. Schematic diagram of experimental apparatus.

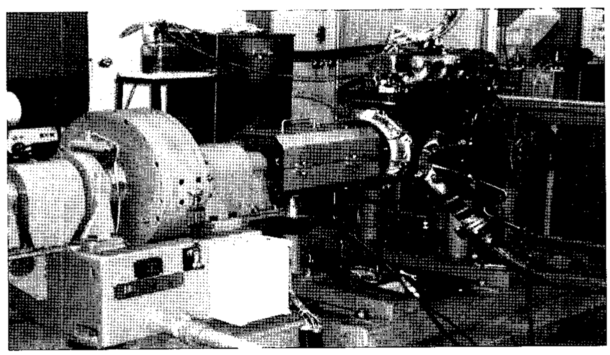

Figure 2. Photograph of experimental apparatus.

3. RESULTS AND DISCUSSION

3.1. Comparison of Engine Performance and Exhaust Gas Emission Characteristics during Use of Oxygenated Fuels

Figure 3 shows changes in energy consumption ratios (BSEC) for varied EGBE mixtures in the respective engines. As shown in Table 2, there was a difference in calorific heat between diesel oil and EGBE mixed fuel. In

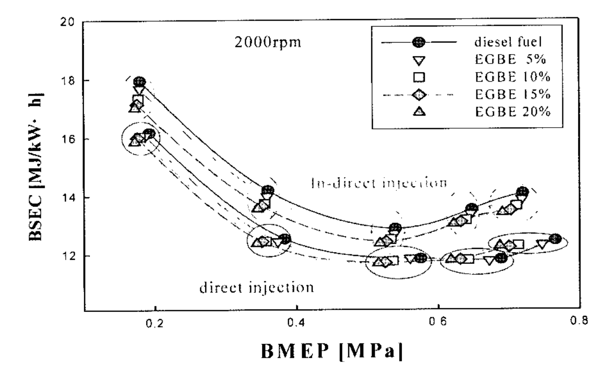

Figure 3. BSEC versus BMEP for different oxygenated fuels at 2000 rpm.

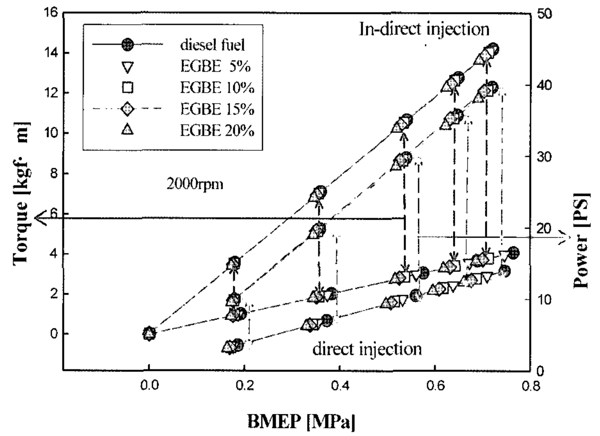

Figure 4. Torque and power versus BMEP for different oxygenated fuels contents at 2000 rpm.

case of BSEC, however, the two fuels were almost identical. In this experiment, even though the difference in calorific heat between diesel oil and 20% EGBE fuel was 6%, the difference in BSEC was less than 1% in the DI diesel engine operating under a full load at 2500 rpm, and less than 4% in the IDI engine. The difference likely can be attributed to enhanced combustion efficiency due to the increased oxygen content in EGBE. Although the (2) models of diesel engines showed similar tendencies, the DI engine appeared to be better in overall BSEC.

Figure 4 shows the engine power and torque output characteristics for varied EGBE mixtures in the respective engines. As shown in the figure, there was a little change in the output characteristics throughout the entire range of engine speeds.

Figure 5 shows smoke emission characteristics by varied BMEP at high and low speeds when EGBE blended fuel was used in the engines. As shown in the figure, it was found that the smoke emission decreased in the IDI diesel engine compared to DI when the EGBE mixture was used, and similarly, it decreased with higher oxygen contents. In the region of low load and low speed where sufficient air is consumable, there was little difference in smoke emission between diesel oil and the EGBE mixture. However, a remarkable difference in the smoke emission could be observed at high loads and high speeds where volumetric efficiency becomes lower and the super concentrated mixture increases. Smoke emission was reduced by 59% in the case of the DI engine while it decreased by 44% in the IDI engine. In the DI engine, even a relatively small oxygen mixture of 5% EGBE resulted in a marked decrease in smoke. On the contrary, in the IDI engine, there was little decrease. It is assumed that in DI engines the mixture of fuel in the combustion chamber is less sufficient as compared to the IDI engine. Thus even small amounts of oxygenated fuel could boost the efficiency of combustion.

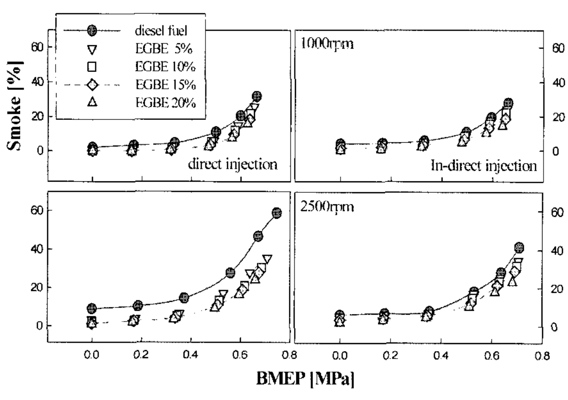

Figure 5. Comparison of smoke emission for different of oxygenated fuels under varying BMEP and engine speeds in DI and IDI diesel engines.

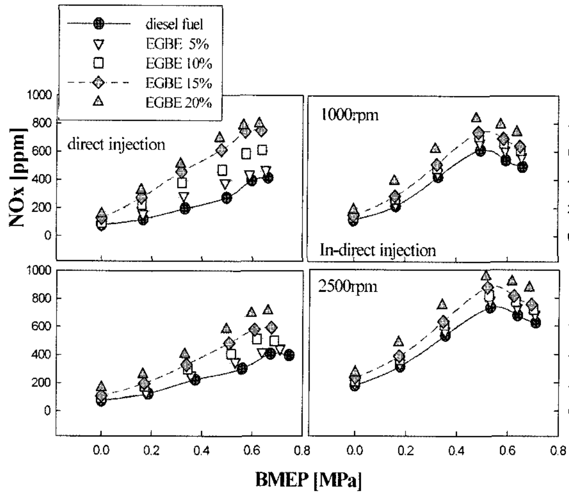

Figure 6. Comparison of NOx emission for different oxygenated fuels under varying BMEP and engine speeds in DI and IDI diesel engines.

Figure 6 shows the NOx emission characteristics under the same conditions as in Figure 5. In general, NOx emission is higher for the EGBE mixture than for diesel oil, and it increases with higher EGBE content. This observation likely reflects the increase in flame temperature induced by oxygenated fuels during the after burning period when the combustion is most active, eventually increasing NOx (Choi and Oh, 2005). In the case of the DI engine, NOx increased by a maximum of 50%, and IDI showed a maximum increase of 33%.

In order to show a clearer picture of emission characteristics described in Figure 5 and 6, Figure 7 describes changes in smoke and NOx emissions for varied EGBE contents at engine operating conditions of half and full loads in both DI and IDI diesel engines. As can be seen in

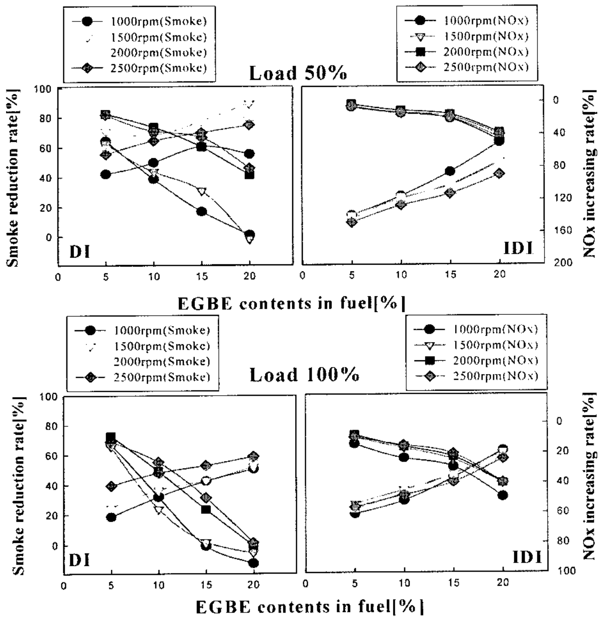

Figure 7. Comparison of Smoke reduction and NOx increase rates at various oxygen contents at 50%, 100% load in DI and IDI diesel engines.

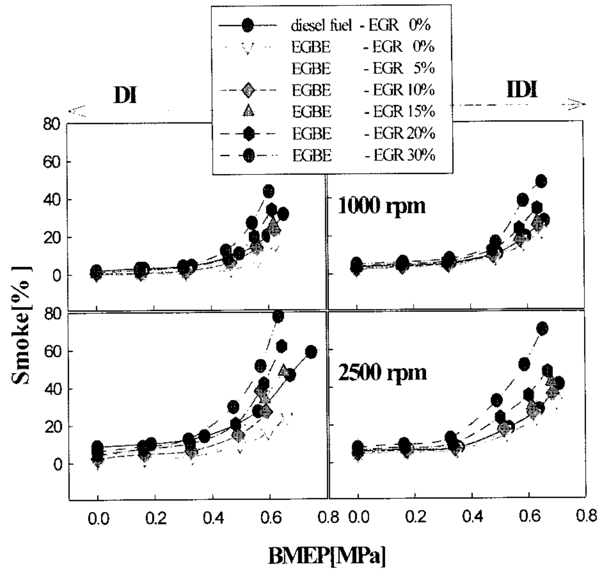

Figure 8. Comparison of smoke versus BMEP at various engine speeds under varying EGR rates in DI (EGBE 20%) and IDI (EGBE 10%) diesel engines.

the figure, a typical trade-off relationship between smoke and NOx exists regardless of engine speed. Along with an increase in EGBE contents, i.e., increase of oxygen contents, rates of smoke emission increased in contrast to a decrease NOx emission. Increased smoke levels and decreased NOx levels following an increase in engine speed was found to be greater in the DI engine. This effect could be explained by the fact that oxygen content in the fuel likely improved combustion and raised combustion temperature to act as a priming factor. Futthermore, changes in exhaust gas emissions were greater in the DI engine than in the IDI engine.

As a result of the engine experiment in general, it was found that smoke was reduced remarkably by using 20% EGBE content fuel in the DI engine and for 10~15% EGBE in the IDI engine respectively. A lesser increase of NOx emission was observed by using 15~20% EGBE in the DI engine and for 10~15% EGBE in the IDI engine respectively. The most optimum mixture of EGBE, therefore, was set to 20% in the DI engine and 10% in the IDI engine respectively for further experiments.

3.2. Comparison of Engine Performance and Exhaust Gas Emission Characteristics for DI and IDI engines during Application of EGR and Optimal EGBE Mixtures

As shown thus far in this study, smoke was reduced remarkably by using an oxygenated fuel, blended with commercial diesel oil, and very little difference was found in energy consumption between the two types of fuels. However, the emission concentration of NOx consistently increased with increased EGBE content, and NOx is currently a major item for emission control. Therefore, in an effort to reduce NOx emissions from diesel engines, the EGR method, which is a known NOx reduction methods, was adopted in this experiment. In particular, a cooled EGR method (Ham and Chun, 2002) was applied in this experiment for increasing volumetric efficiency.

Figure 8 is a graph comparing smoke emissions by varied EGR ratios and BMEP changes in the low and high speed regions using optimal mixture of EGBE. In both model engines, larger amounts of smoke emission was found when applying a EGR ratio fo 20% in the high speed region than when conventional diesel oil was used. This was more prominent in the DI engine which showed larger amounts of smoke emission with increasing EGR ratios in the high speed region compared to the IDI engine.

Similar to Figure 8, Figure 9 show a comparison of NOx emission by varied EGR ratios and changes in BMEP using optimal mixtures of EGBE for the model engines. A tendency of lesser emission of NOx was observed when applying an EGR ratio of 15% in the DI engine and more than 10% in the IDI engine. Larger changes in NOx emission by EGR were found in the DI diesel engine than in the IDI engine.

Figure 10 shows changes in NOx emission by varied engine speeds under 90% high load in both model engines when using an oxygenated fuel and applying EGR as in Figure 9. As shown in Figure 9, NOx emission decreases rapidly with an increase in the EGR ratio, a phenomenon that is more prominent in the DI engine than in the IDI

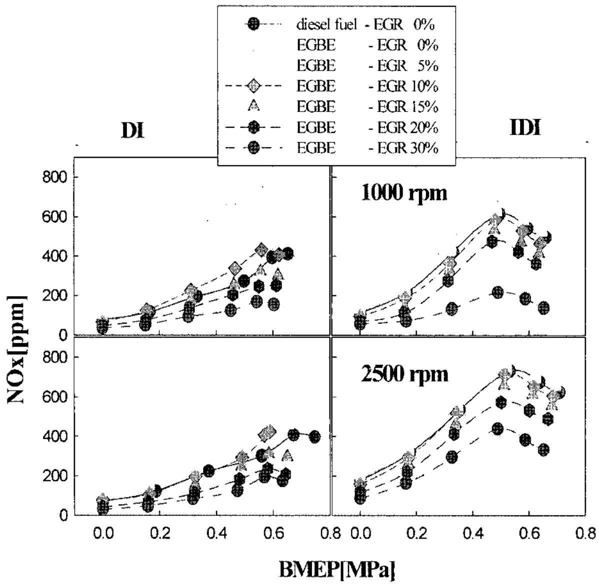

Figure 9. Comparison of NOx versus BMEP at various engine speeds under varying EGR rates in DI (EGBE 20%) and IDI (EGBE 10%) diesel engines.

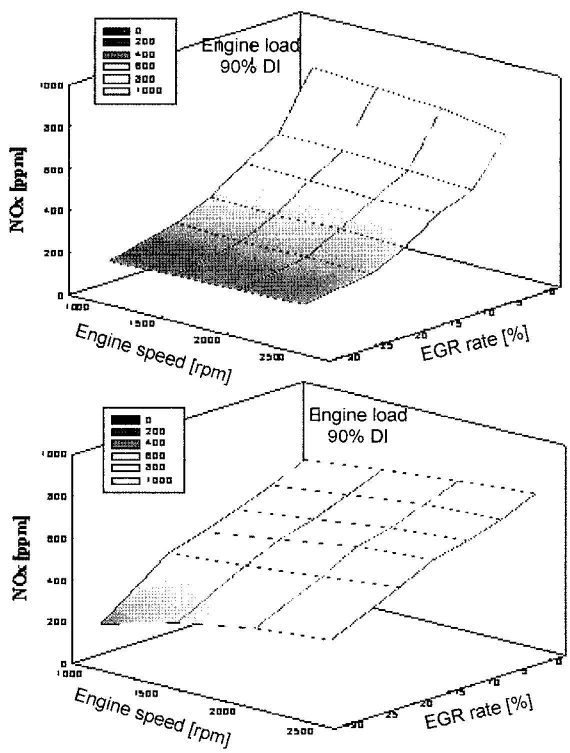

Figure 10. Comparison of NOx reduction rate of EGBE contents under varying engine speed at load 90% in DI and IDI diesel engines.

engine. It could be seen that changes in smoke and NOx emissions increases with higher loads when using an oxygenated fuel and applying EGR. Greater changes in smoke emissions are observed in the lower region of the medium load, while NOx emissions becomes larger at higher loads. With an increased EGR ratio, smoke emission increases rapidly in the high load region, which is thought to be caysed by imperfect combustion due to a steep reduction in the oxygen supply in the intake air at a high EGR ratio. Comparing conventional diesel oil and the most optimal EGBE mixture, a variation in the combustion chamber configuration yielded the following observations: In the case of the DI engine, a simultaneous reduction in the level of smoke and NOx could be achieved by a 10~15% EGR ratio under a low load, by a 10% EGR ratio under a medium load and by a 10% EGR ratio under a high load. On the other hand, a simultaneous reduction of smoke and NOx could be achieved by a 10~30% EGR ratio under a low load, by a 10~20% EGR ratio under a medium load and by a 10~15% EGR ratio under a high load in the IDI engine.

4. CONCLUSIONS

EGBE, an oxygenated fuel containing a large oxygen content, was blended into commercial diesel oil in various volume percentages, and used in single cylinder DI diesel engine, as well as a four cylinder IDI diesel engine. Engine performance and exhaust gas emission characteristics from the engines were investigated for varied EGBE mixtures. By applying a cooled EGR method for reducing NOx emission, the most optimum mixture of oxygenated fuel was obtained. After conducting experiments to deduce the effect of oxygen in the oxygenated fuel on combustion chamber configuration and EGR ratio, the following conclusions could be drawn.

(1) With an increased mixture ratio of EGBE in varied combustion configurations, smoke was reduced remarkably almost in a linear fashion.
(2) By using an EGBE mixture in the high speed and high load region, a marked reduction of smoke emission could be found; maximum 59% in the DI engine and 44% in the IDI engine respectively.
(3) In the view point of smoke reduction and NOx increase, the most optimum mixture of EGBE was 20 wt-% in the DI engine and 10 wt-% in the IDI engine respectively.
(4) When using the most optimum mixture of EGBE, the EGR ratio for simultaneous reduction of smoke and NOx were slightly different by engine loads; 15% in the DI engine and 10~15% in the IDI engine under medium load respectively.

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