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19 The Simultaneous Reduction of Smoke and NOx with Oxygenates Fuel and EGR Method in a Diesel Engine

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Lately, our world has been faced with serious air pollution problems due to diesel engine exhaust emission. In this study, the effects of oxygen component in fuel and exhaust gas recirculation(EGR) method on the exhaust emissions has been investigated for a D.I. diesel engine. It was tested to estimate change of exhaust emission characteristics for the commercial diesel fuel and oxygenate blended fuel which has five kinds of blending ratio. Dimethoxy methane(DMM) contains oxygen component 42.5% in itself, and it is a kind of effective oxygenated fuel for reduction of smoke emission. It was affirmed that smoke emission was decreased with increasing of DMM blending ratio. But, NOx emission was increased compared with commercial diesel fuel. It was needed a NOx reduction counterplan that EGR method was used as a countermeasure for NOx reduction. It was found that simultaneous reduction of smoke and NOx emission was achieved with DMM blended fuel and cooled EGR method(10 ~ 15%).

Keywords : Diesel Engine, EGR(Exhaust Gas Recirculation), Smoke, Nitrogen Oxides, Oxygenates

1. INTRODUCTION

Although the demand for diesel engines, which produce and sustain constant thermal efficiency and the use of various fuels has increased, our world is faced with a very serious problem related to air pollution due to the exhaust emissions from diesel engines.[1] In particular, the smoke emission from the diesel engine is recognized as a major factor contributing to environmental degredation. Strict regulations for air quality improvement have placed limitations on the design modification for the engines themselves. In addition, the use of fossil fuels as an energy source presents its own set of problems, mainly because they are nonrenewable, they do not present a sustainable source or energy. A second problem is that when these fossil fuels are burned they emit CO_2 when they are burned, and thus increases the concentration of greenhouse effects in the surroundings[2], too. The increase of CO_2 concentration is considered to be the leading cause of global warming. Furthermore, the world now depends on foreign sources of fossil petroleum fuels to meet its demand.

The trend towards cleaner burning fuel is growing worldwide. Recent studies indicate that cetane number, aromatic contents and type, density and sulfur content are important factors for emission control[3-4]

The demand for petroleum-derived fuel is increasing. Improvements of fuel properties have become essential for design factors and exhaust gas aftertreatment. Several reports[5] have elucidated the remarkable effects of the addition of oxygenated organic compounds in fuel to obtain cleaner burning. The addition of lower alcohol such as methanol and ethanol to diesel fuel is effective in reducing particulate emissions without sacrificing other emission components[6]. Non-alcohol oxygenated organic compounds have also been investigated for improvements of diesel combustion and emission reduction[7]. Some reports mentioned the effect of adding liquid oxygenated agents in fuel on the diesel combustion and emissions[8-10]. Many of these oxygenates are conventionally used as organic solvents, and their production cost is a key factor in their practical use.

The authors have investigated an oxygenated fuel(dimethoxy methane, below DMM) for direct injection diesel engines, including the conventional diesel fuel blended with ethers up to 2.5～12.5vol-%. The results indicated that smoke and particulate could be reduced without sacrificing thermal efficiency, and that the reduction rate depended almost entirely on the oxygen content of the fuels.

And, exhaust gas recirculation(below EGR) method was applied for reduction of NOx emission. Because DMM is a kind of oxygenated fuel, that is, DMM contains 42.5% oxygen in itself. Because combustion speed and temperature of DMM blended fuel is higher than that of diesel fuel on combustion period. In this study, we applied cooled EGR method to control NOx emission.

2. EXPERIMENTAL METHOD AND APPARATUS

A horizontal, water cooled, single cylinder, naturally aspired, direct injection diesel engine was used, and the principal specifications of the engine are shown in Table 1. Properties of the DMM and commercial diesel fuel for this experiment are shown in Table 2, and the blended fuels of the commercial diesel fuel and DMM were used in the test. The schematic diagram of the experimental apparatus is shown in Fig. 1. Engine speed and load were controlled by the eddy current dynamometer. Exhaust smoke emission density was measured with a smoke meter (Hesbon; HBN-1500) and the NOx concentration was measured with an exhaust gas analyzer(Motor branch; Mod. 588). After the fuel consumption time was measured with a stop watch, the brake specific energy consumption rate(BSEC) of each fuel was calculated by a volumetric flow meter. The engine was operated with 80±2℃ cooling water under all operating conditions. The engine was operated at speeds of 1000, 1500, 2000 and 2500rpm, with loads between 0% and 100% at 25% intervals. And a specific case of 90% load was investigated, too. The DMM was blended in conventional diesel fuel between 0vol-% and 12.5vol-% at 2.5vol-% intervals.

In this study, the EGR ratio is defined as:

$EGR(\%) = (V_{EGR}/V_a) \times 100$

Where, V_{EGR} is the recirculated exhaust gas mass flow rate, V_a is the intake air mass flow rate for the case of no EGR.

Table 1 Specifications of test engine

Items	Specifications
Engine Model	ND130
Bore × Stroke(㎜)	95 × 95
Displacement(cc)	673
Compression Ratio	18
Combustion Chamber Type	Toroidal
Coolant Temp.(℃)	80 ± 2

Table 2 Properties of test fuels

Properties	diesel fuel	DMM
Molecular formula	$C_{12}H_{26}$	$CH_2(OCH_3)_2$
Molecular weight	226	76.10
Heating value[MJ/kg]	43.12	23.260
Oxygen content (%)	0	42.5

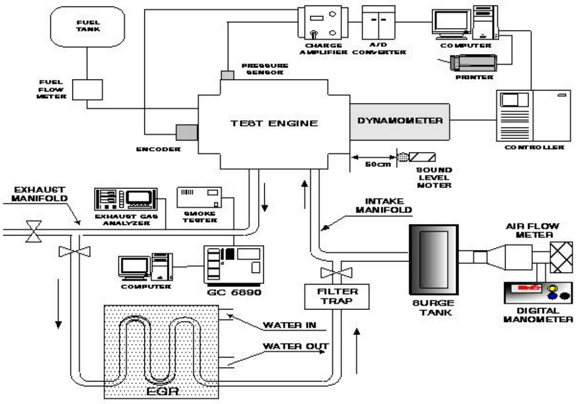

Fig 1. Schematic diagram of experimental apparatus

3. RESULT AND DISCUSSION

3.1 Engine performance and Exhaust Emissions characteristics on DMM blended fuel and diesel fuel

Fig. 2 shows the torque curve of the engine for several blending ratios from 0vol-% to 12.5vol-% at full load. The power and torque achieved by the engine at full load for all fuels was similar. Although the heating value of the DMM blended fuel is lower than that of the commercial diesel fuel by approximately 46%, engine torque and power showed no significant differences because the oxygenated component in the DMM blended fuel improved combustion efficiency.

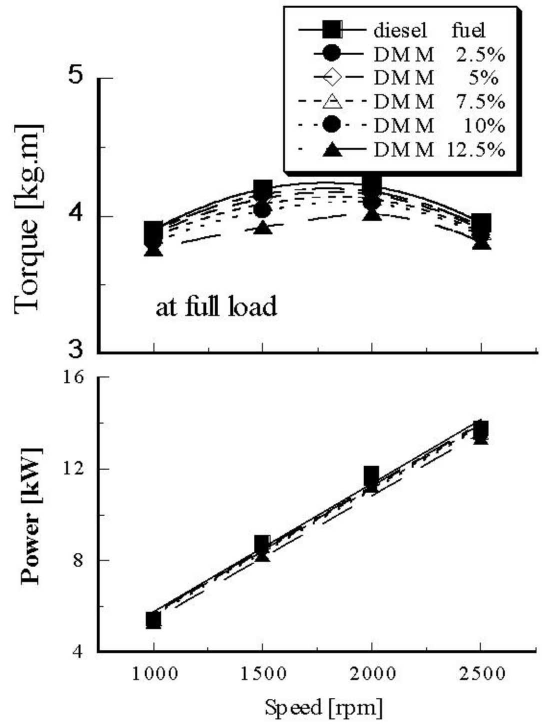

Fig. 2 Comparison of power and torque with diesel fuel versus DMM blended fuel at various engine speeds

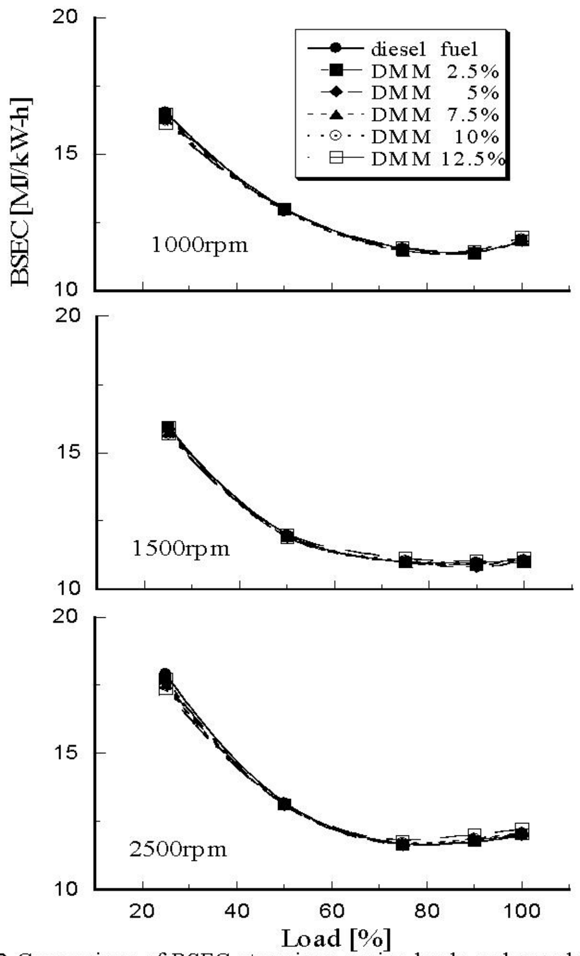

Fig. 3 Comparison of BSEC at various engine loads and speeds on DMM blending ratios

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

Fig. 3 shows BSEC at each blending ratio from 0 to 100vol-% at varying engine speeds and loads. Even though the blending ratio was varied, BSEC did not change significantly. At higher engine loads, which was maximum load in our experiment, the cases in which the engine used DMM blended fuel showed better performance than the cases in which the engine used diesel fuel. This result means that the effects of oxygen components in DMM blended fuel can be used throughout the operating region; that is, the effects of the oxygen component in fuel were much more significant in the combustion chamber at higher loads and speeds than at lower loads and speeds. Additionally, combustion efficiency was improved due to the oxygenated component into DMM blended fuel at high loads and speeds.

Fig. 4 shows the effect of the DMM blending ratio on exhaust smoke emission density 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 12.5vol-% DMM blended fuel. In particular, the densities were more remarkable at high loads and speeds. The main cause for this difference may be due to the presence or absence of oxygen components between diesel fuel and DMM blended fuels. This suggests that the oxygen components in the DMM blended 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 DMM blended fuel did not show significant differences in proportion to the varying load. When DMM blended fuel was used in the diesel engine, the differences between created quantity and oxidized quantity of carbonaceous particulate matter were reduced, and it was thought that the oxygen component in DMM blended fuel increased the oxidization rate of fuel particles.

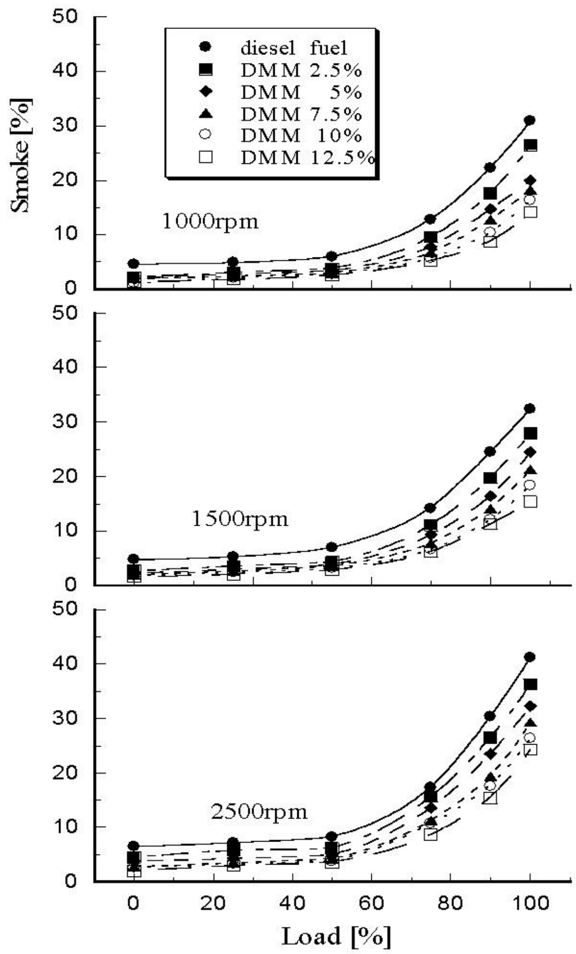

Fig. 4 Comparison of smoke at various engine loads and speeds on DMM blending ratios

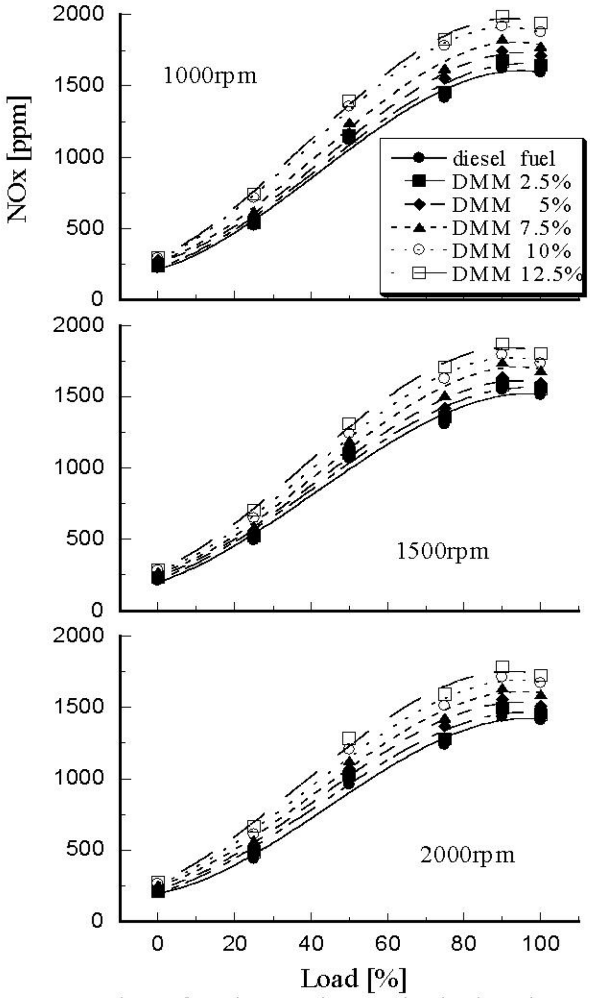

Fig. 5 Comparison of smoke at various engine loads and speeds on DMM blending ratios

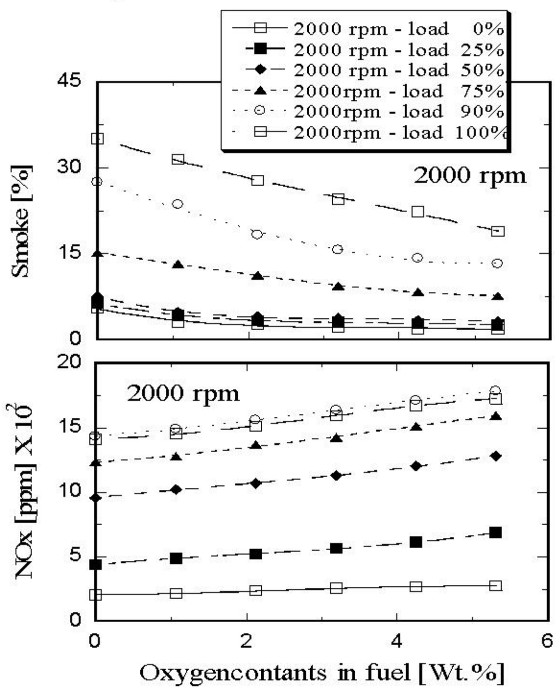

Fig. 6 Comparison of smoke and NOx mission with various oxygen contents

Fig. 5 presents the results of the investigation of effect on NOx emission, which was conducted under the same conditions as those outlines in Fig. 4. The NOx concentration increased as the DMM blended fuel ratio increased. The NOx emission was formed as the cylinder temperature increased, possibly due to the oxygen component in the DMM blended fuel.

Fig. 6 shows the effect of oxygen content in fuel between smoke and NOx emission at various engine speeds. The exhausted smoke emission density change significantly with increased oxygen content in fuel. Note that smoke emissions barely exhausted at an oxygen content above 7wt-% below load 25%. 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 5%, the exhaust smoke emission density was below 23% at all operating ranges.

3.2 The Effects of EGR on DMM blended fuel

EGR is currently considered an effective technique for reducing NOx emissions in diesel engine, but it can result in a substantial increase in smoke emission. from the point of view of smoke emission, the application of EGR represents a source of contamination with a large amount of smoke. As it stated above, smoke emission was reduced remarkably with DMM blended fuel, NOx emission was increased slightly with DMM blended fuel.

Fig. 7 shows the effect of EGR with DMM blended fuel on the BSEC for the lower and higher engine speeds. At EGR 20%, the BSEC increase to about 6%. The BSEC increase is due to the lower combustion efficiency with the application of EGR. But, BSEC do not show the large difference all operating range.

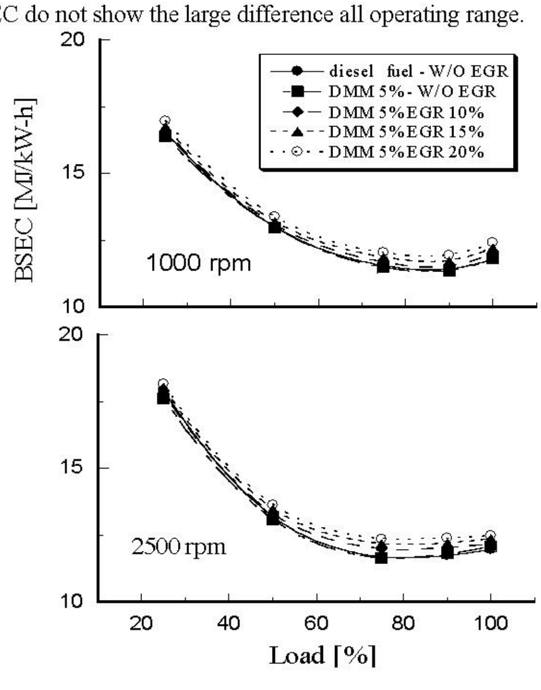

Fig. 7 The effect of EGR with DMM blended fuel on BSEC

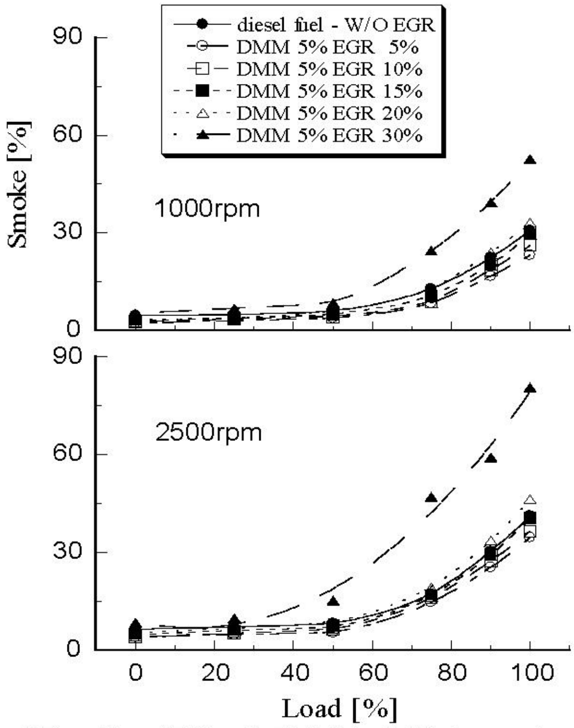

Fig. 8 The effect of EGR with DMM blended fuel on smoke

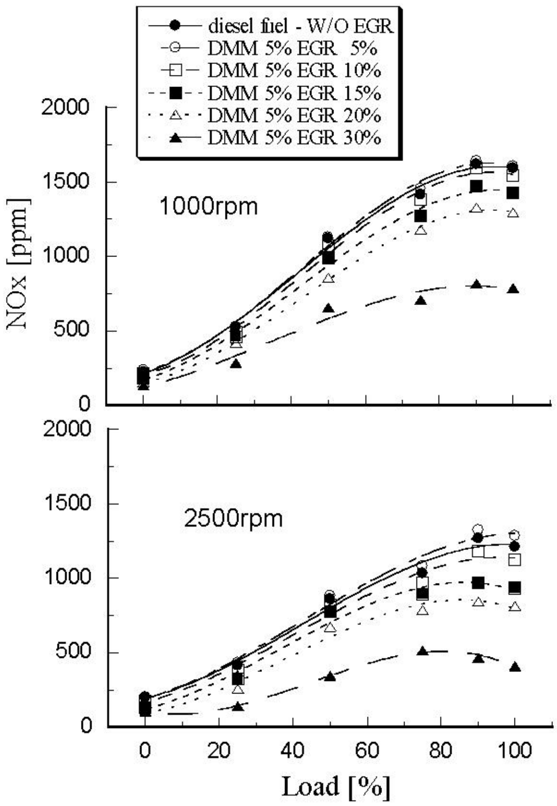

Fig. 9 The effect of EGR with DMM blended fuel on NOx

Fig. 8 shows the effects of EGR with DMM blended fuel on smoke for the various engine speeds and loads. This figure showed that the increasing of EGR rates caused increasing of smoke emission.

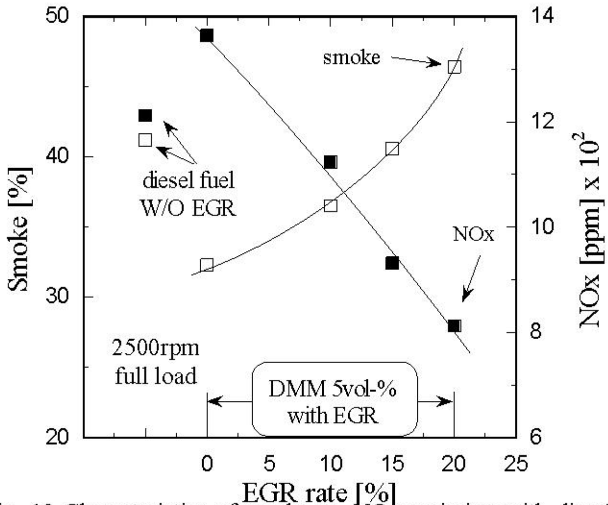

Fig. 10 Characteristics of smoke vs. NOx emission with diesel fuel and DMM blended fuel on various EGR rates at 2500rpm, full load

In particular, exhausted smoke emission of DMM blended fuel was more increased than that of diesel fuel above 20% EGR rate. As seen in this figure, EGR rate of 20% or more did not match DMM blended fuel in a diesel engine.

Fig. 9shows the effects of EGR with DMM blended fuel on NOx emission for the various engine speeds and loads. This figure showed that the increasing of EGR rates caused decreasing of NOx emission. From Fig. 98, it is evident that EGR was very effective in reducing NOx emission at all operating conditions.

Fig. 9 shows the effect of EGR with DMM blended fuel on smoke and NOx emission. Typical results of EGR where NOx reduction is attained but with a corresponding increase in smoke can be clearly recognized.

4. Conclusions

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

The conclusions extracted from this investigation are summarized as follows:

(1) When DMM blended fuel was used in place of a commercial diesel fuel, there was no significant difference in engine torque, power and brake specific energy consumption.

(2) As oxygen content in the fuel increased, the exhausted smoke emission density was reduced significantly. In particular, when the oxygen content in the fuel was above 5wt-% at a higher load, the smoke reduction rate was significant at all engine speeds.

(3) The combination of DMM blended fule and EGR mathod(10-15%) achieved the simultaneous reduction of smoke and NOx

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