Jurnal Teknologi, 44(A) Jun 2006: 1–12

IMPROVEMENT OF ENGINE PERFORMANCE USING DIETHYLENE GLYCOL DIMETHYL ETHER (DGM) AS ADDITIVE

MD. NURUN NABI[1*] & MD. WAHID CHOWDHURY[2]

Abstract. This research work investigates diesel combustion and exhaust emissions with additives addition to conventional diesel fuel in a four-stroke naturally aspirated direct injection (DI) diesel engine. The additives include DGM, and liquid cerium. The results show that with the addition of DGM to diesel fuel, brake specific energy consumption (BSEC) and all diesel emissions are significantly reduced. The volumetric blending ratios of additives to diesel fuel are 0, 25, 50, 75 and 100%. All emissions including smoke emissions decrease with the increase in oxygen content in the fuel and it is noted that smoke emission completely disappeared at an oxygen content of 36 wt-%. The reason for improvement in BSEC with the addition of additives to base diesel fuel is the improvement of degree of constant volume combustion, and the reduction of the cooling loss. Engine noise and odor concentrations are remarkably reduced with diesel-additive blends. Significant improvement in BSEC and exhaust emissions is not only found at medium load condition but also at high load condition.

Keywords: Diesel engine, DGM, emissions, BSEC, and cooling loss

1.0 INTRODUCTION

As for the fuels in diesel engines, research has been conducted to identify the effects of fuel properties on diesel combustion and exhaust emissions. For example, sulfur content in fuels has been reduced in order to improve the acid rain problem and its reduction to 0.05 wt-% has been set as regulations to reduce particulate levels. Other fuel properties related to the improvement include aromatic content, ignitability, oxygen content, viscosity and distillation temperature [1-11]. As for oxygen content or oxygenates, the addition of lower alcohols such as methanol and ethanol to diesel fuel was effective in reducing particulate emissions without sacrificing other emission components [12, 13]. However, there were problems as the methanol has inherently poor solubility to diesel fuel and poor lubricity, and its lower ignitability made it impossible to use neat alcohols or high blending ratios in conventional diesel fuel without special measures to improve ignition. Non-alcohol organic compounds have also been investigated to improve diesel combustion and emissions [14-16]. Methyl-t-

[1&2] Department of Mechanical Engineering, Rajshahi University of Engineering and Technology, Rajshahi-6204, Bangladesh
* Corresponding author: Tel: 880-721-750742-221/ 880-721-750743-221, Fax: 880-721-750319/880-721-750101, Email: nahin1234@yahoo.com or nahin1234@librabd.net

butyl ether (MTBE) is a promising oxygenated fuel, which has already been used as an octane improver in gasoline. While having extremely poor ignitability like lower alcohols, MTBE may be more easily utilized in diesel engines as it has infinite solubility in diesel fuel. Dimethyl ether (DME) is another recent promising oxygenated fuel easily made from methanol, natural gas or coal [17-19]. The DME has very high ignitability, different from lower alcohols and MTBE, but its utilization in diesel engines is not easy, as DME is gaseous under atmospheric conditions. Miyamoto *et al.* [15] investigated eight kinds of oxygenates blended with conventional diesel fuel up to 10 vol-%. The results indicated that smoke and particulate were effectively reduced without sacrificing thermal efficiency and that the reduction depended almost entirely on the oxygen content of the fuels.

In this work, diesel combustion and exhaust emissions are investigated with the addition of DGM and cerium to diesel fuel. DGM has an oxygen content of 36 wt-%. The addition of DGM to diesel fuel has significantly improved BSEC and exhaust emissions. However, no significant improvement in exhaust emissions is found when cerium is added to diesel fuel.

2.0 EXPERIMENTAL APPARATUS AND PROCEDURE OF EXPERIMENTATION

The experiments were conducted on a single cylinder four-stroke cycle, DI diesel engine (specification is shown in Table 1). The engine operating conditions included an engine speed of 1320 rpm, start of fuel injection at 5° CABTDC (optimum for fuel consumption), and a coolant temperature of 80°C. DGM and conventional diesel fuel (JIS No.2) were used in experiments. The properties of additives and other diesel fuels are shown in Tables 2 and 3 respectively. The NOx concentrations were measured with a Chemiluminescence's analyzer (CLD); the unburned total hydrocarbon was also measured with a heated flame ionization detector (HFID) and the smoke density with a Bosch smoke meter.

Table 1 Specification of tested engine

Engine name	YANMAR NF 19
Number of cylinder	One
Bore × Stroke	ϕ 110 × 106 mm
Stroke volume	1007 cc
Compression ratio	16.3
Rated power	11.8 kW/2200 rpm
Nozzle hole	ϕ 0.33 mm × 4 –150°
Nozzle opening pressure	19.6 MPa
Injection pump	Zexel XND-PE4A
Plunger diameter	ϕ 9.5 mm

Table 2 Properties of tested additives

Oxygenated fuel	Abbreviation	Molecular formula	Oxygen content (wt-%)	Density (g/cc)	Boiling point (°C)	Lower cal.value (MJ/kg)
Diethylene glycol dimethyl ether	DGM	$C_6H_{14}O_3$	35.8	0.950	163	24.5
Cerium	–	–	–	1.1	–	–

Table 3 Properties of tested base fuels

Fuel	Density (g/cc)	Distillation temperature 90% (°C)	Kinematic viscosity (mm^2/sec)	Lower cal. value (MJ/kg)
Low viscous diesel fuel	0.830	336	2.5	42.74
High viscous diesel fuel	0.850	346	8.5	43.2

3.0 RESULTS AND DISCUSSIONS

3.1 Effect of DGM Addition to Diesel Fuel on Diesel Combustion and Exhaust Emission

Inferior fuels, like high viscous, low cetane number etc. have some problems to ignite in the combustion chamber due to their inherent inferior properties. To use these inferior fuels effectively, an attempt was taken to blend them with a liquid oxygenated fuel, DGM. The volumetric blending ratios are set to 0, 25, 50, 75, and 100%. Among the different fuel properties, one of the major interests in this research is fuel viscosity.

Figure 1 shows the BSEC and exhaust emissions with DGM blended base diesel fuels at medium load condition (brake mean effective pressure, BMEP = 0.69 MPa). It is seen from the figure that with the increase in oxygen content in the fuel, all exhaust emissions and BSEC decrease. Decreasing of BSEC means the improvement of thermal efficiency.

Figure 2 shows smoke and total particulate matter (TPM) emissions for different DGM-diesel fuel blends under the same operating conditions as stated in Figure 1. For high viscous fuels, the smoke emission is apparently higher than that of the low viscous fuel. The smoke emission decreases with the increase in oxygen content for either base fuel. For high viscous fuel, the reduction in smoke emission is remarkable and completely disappeared at an oxygen content of 36 wt-%, regardless of the blends of the base fuels.

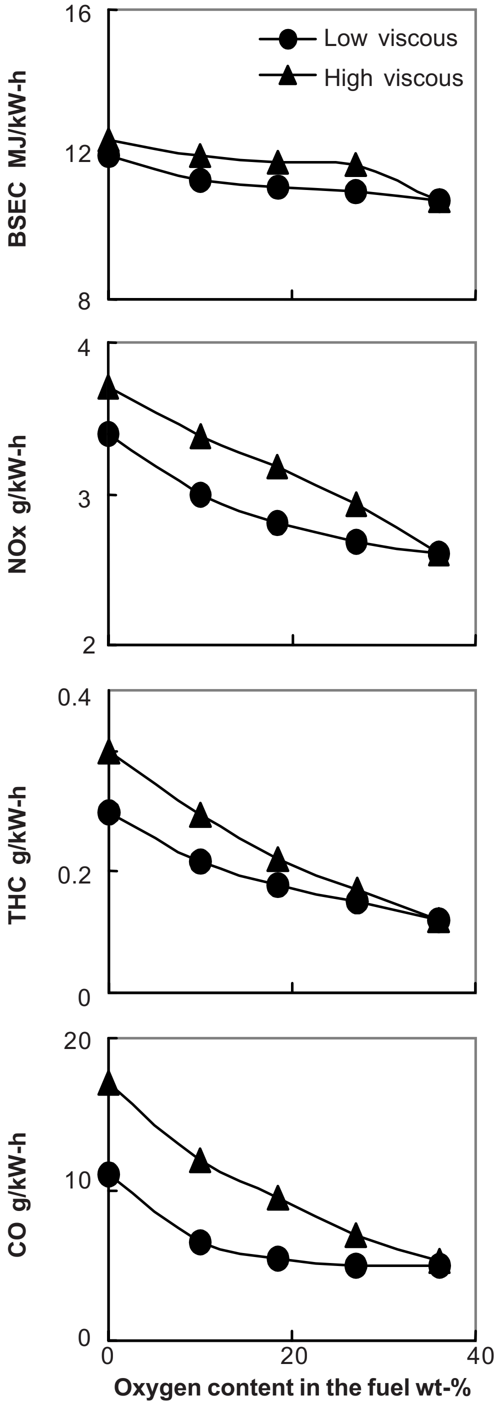

Figure 1 Effect of diethylene glycol dimethyl ether (DGM) addition to diesel fuels on BSEC and exhaust emissions (BMEP = 0.69 MPa)

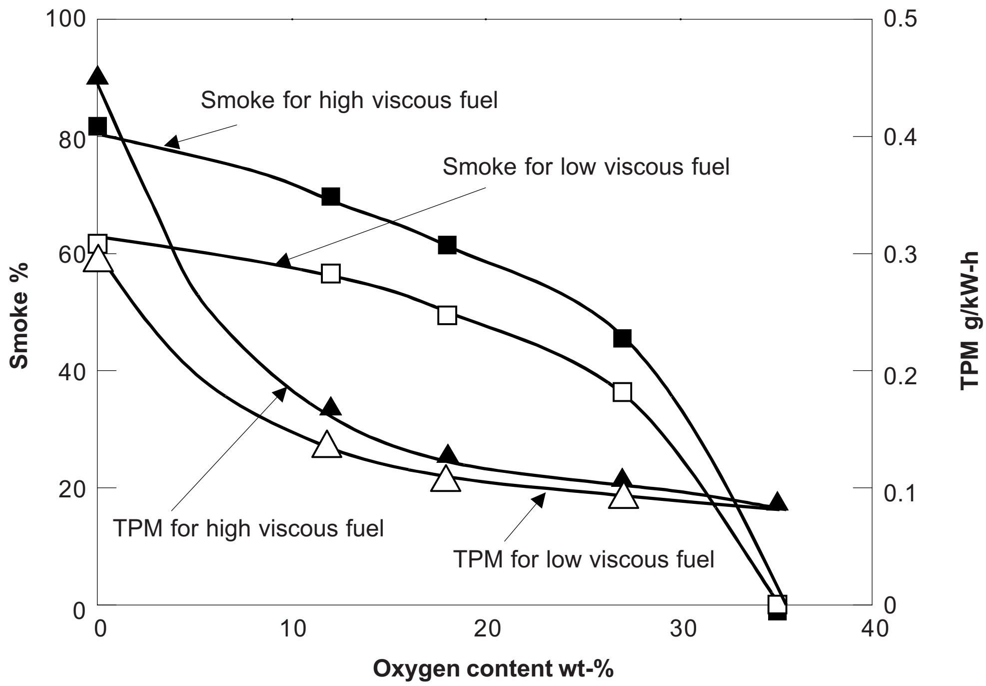

Figure 2 Effect of diethylene glycol dimethyl ether (DGM) addition to diesel fuels on smoke and TPM emissions (BMEP = 0.69 MPa)

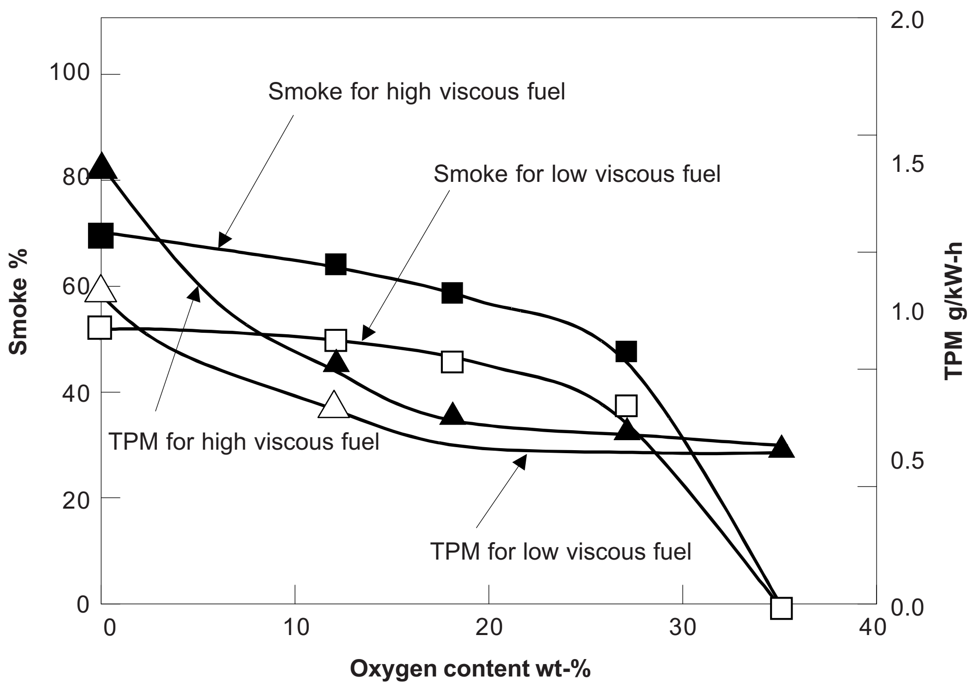

Figure 3 Effect of diethylene glycol dimethyl ether (DGM) addition to diesel fuels on smoke and TPM emissions (BMEP = 0.83 MPa)

Figure 3 shows smoke and total particulate matter (TPM) emissions for different blends of DGM-diesel fuel at high load condition (BMEP = 0.83 MPa). Same trends of results are experienced, as found in Figure 2.

3.2 Reason for BSEC Improvement

To clarify the mechanism for improvement of BSEC with DGM, the combustion efficiency η_c, the degree of constant volume combustion $\eta_{glh,}$ and the heat loss to the coolant η_{cool} are shown in Figure 4. With the increase in DGM content, which implies the increase in oxygen content in the fuel, the degree of constant volume combustion improves slightly, while the combustion efficiency improves significantly, but the cooling loss is unchanged. The increases in constant volume combustion and combustion efficiency are the two reasons for BSEC improvement with DGM addition.

An additional factor, which affects the improvement in BSEC may include the increase in the number of molecules by fuel injection and combustion, which is considerably larger with the DGM than with diesel fuel, as shown in Figure 5. The ordinate shows the number of molecules calculated from the fuel injection and combustion processes. This larger number of molecules after burning is an indication of BSEC as well as thermal efficiency improvement.

3.3 Improvement of Engine Noise with DGM Addition to Diesel Fuel

Figure 6 shows the ignition lag and engine noise with different blending ratios of DGM to diesel fuels. The figure shows that engine noise decreases dramatically by about 3 dB(A) for DGM. Ignition lag, which has a relationship with engine noise decreases with the increase in DGM content (oxygen content) in the fuel. The cetane number of DGM is three times higher than that of conventional diesel fuel. Higher cetane number means higher ignitability. Higher ignitability fuel causes lower combustion peak, which results in lower engine noise. The remarkable reduction in engine noise and ignition lag cause higher ignitability of DGM than that of diesel fuel.

3.4 Improvement of THC and Diesel Odor with the Addition of DGM to Diesel Fuel

Figure 7 shows the changes in unburnt THC emissions and odor concentration under starting condition with neat DGM and diesel fuel. The abscissa shows the elapsed number of cycles for the first fuel injection cycle. The odor concentration, which is obtained by sensory inspection, shows a dilution ratio of air and exhaust gas, where human senses no smell [20]. With DGM, the unburnt THC and odor concentration

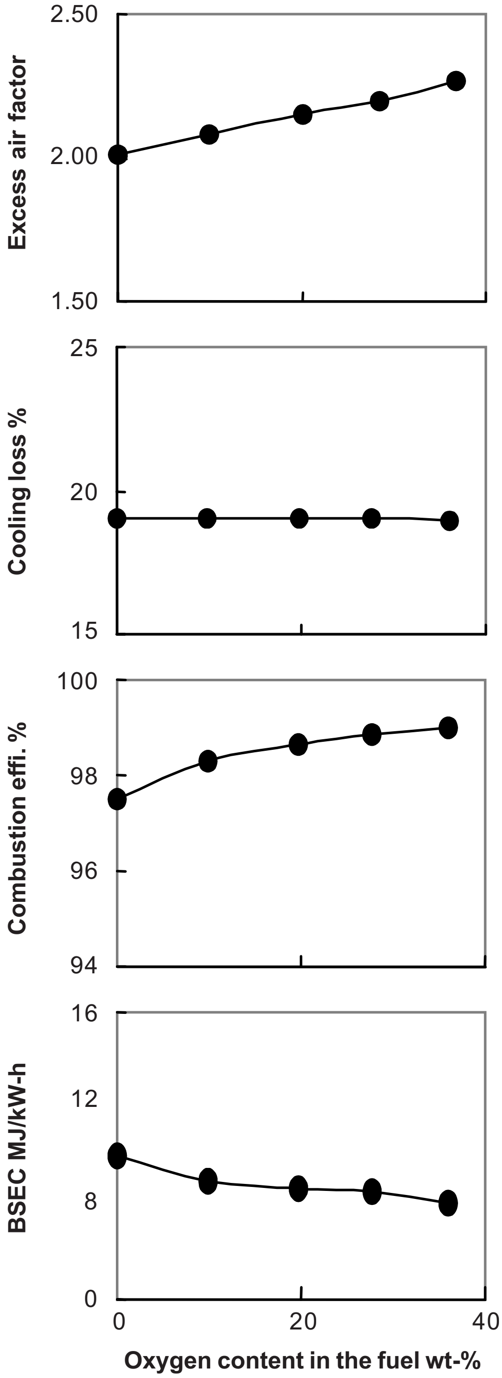

Figure 4 Factors related to BSEC improvement (BMEP = 0.83 MPa)

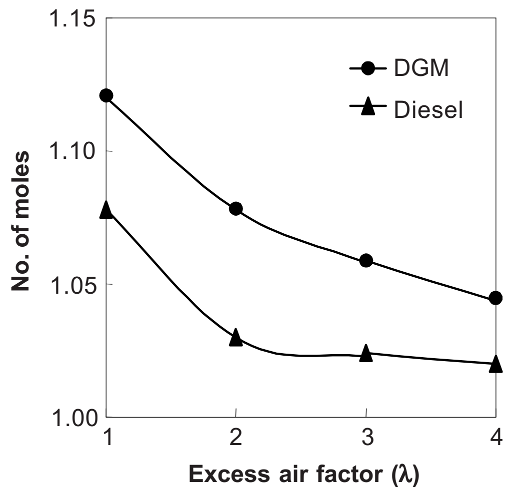

Figure 5 Number of molecules after burning with respect to the excess air factor

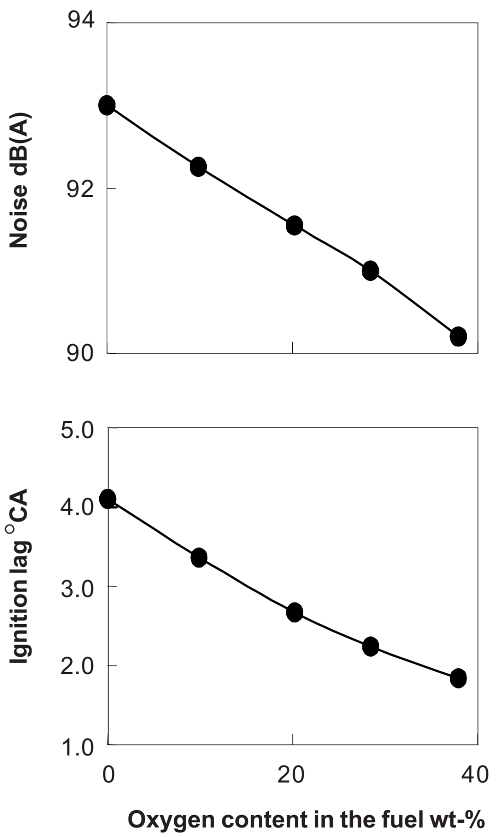

Figure 6 Relationship between ignition lag and engine noise with diethylene glycol dimethyl ether (DGM) -diesel fuel blends (BMEP=0.69 MPa)

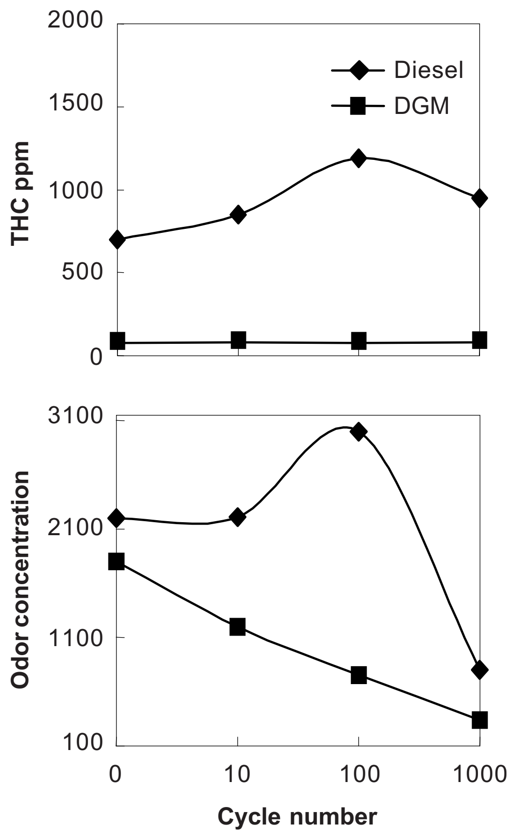

Figure 7 THC and odor concentration under starting condition with diethylene glycol dimethyl ether (DGM) and diesel fuel

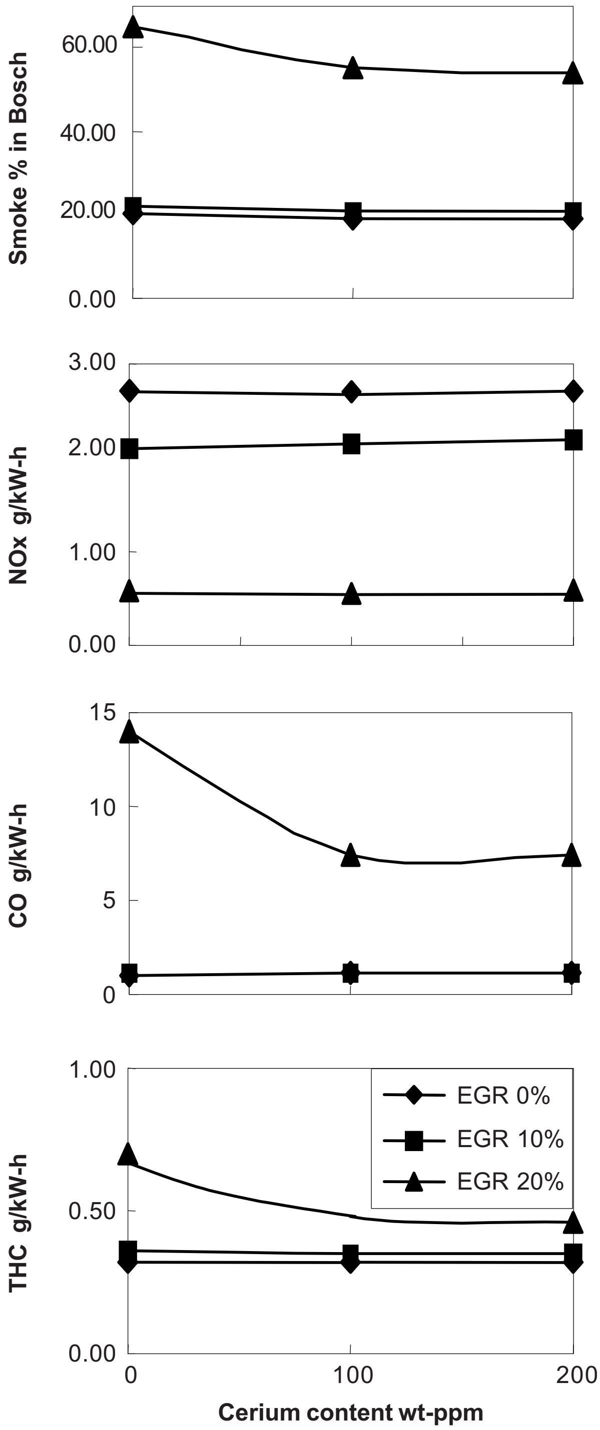

Figure 8 Effect of cerium addition to diesel fuel on exhaust emissions (Engine speed = 1300 rpm, BMEP = 0.69 MPa)

under starting condition, which may have some relation to each other, are seen to be much lower than with the diesel fuel.

3.5 Diesel Emissions with the Addition of Cerium to Diesel Fuel

Figure 8 shows the effect of cerium addition to diesel fuel on diesel emissions using exhaust gas recirculation (EGR). The engine speed is set at 1320 rpm and the BMEP is 0.69 MPa. It is seen from the figure that with the increase in cerium content in the diesel fuel, the exhaust emissions including NOx has no changes for every EGR conditions, while smoke, THC and CO emissions reduced with the addition of cerium to the diesel fuel when 20% EGR is applied.

Figure 9 shows the TPM with and without cerium addition to diesel fuel. The engine speed is set at 1320 rpm, BMEP is 0.69 MPa, cerium content to diesel fuel is 200 wt-ppm and EGR rate is 20%. It is obviously seen from the figure that with cerium addition to diesel fuel, TPM is lower than that of conventional diesel fuel. Thus it can be concluded that diesel exhaust emissions can be reduced or unchanged with the addition of cerium to diesel fuel when EGR is applied.

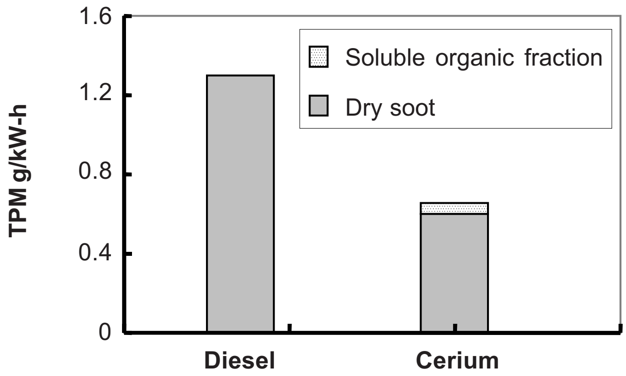

Figure 9 Effect of cerium addition to diesel fuel on TPM (Engine speed = 1300 rpm, BMEP = 0.69 MPa, cerium content to diesel fuel = 200 wt-ppm, EGR = 20%)

4.0 CONCLUSIONS

This work investigates diesel combustion and exhaust emissions with the addition of additives to diesel fuels. The results of this research may be summarized as follows:

(i) Significant improvements in BSEC, THC, NOx, CO, engine noise and ignition lag are obtained with the addition of DGM.

(ii) With DGM-diesel blends, remarkable reductions in smoke and TPM emissions are experienced not only for medium load condition but also for high load condition.

(iii) Improvements of BSEC and exhaust emissions depend on the oxygen content in the fuels regardless of the DGM-diesel blending ratios.

(iv) The BSEC improvement with DGM is caused by the desirable increases in the degree of constant volume combustion and the higher combustion efficiency.

(v) The unburnt THC emission and odor intensity under starting condition are much lower with neat DGM than with diesel fuel.

(vi) With EGR, addition of cerium to diesel fuel, exhaust emissions almost unchanged for 0 and 10% EGR rate but CO, THC and smoke emissions reduced slightly for EGR rate of 20%. TPM is also reduced with cerium addition to diesel fuel.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Mr. M. Minami, and Mr. Obata, graduate students of Hokkaido University, Japan for their cooperation in this investigation.

REFERENCES

[1] Likos, B., T. J. Kalahan, and C. A. Moses. 1982. Performance and Emissions of Ethanol and Ethanol-Diesel Blends in Direct Injected and Pre-Chamber Diesel Engines. *SAE Paper No. 821039*.

[2] Sienicki, E. J., R. E. Jass, C. I. McCathy, W. J. Slodwske, and A. L. Krodel. 1990. Diesel Fuel Aromatic and Cetane Number Effects on Combustion and Emissions from a Prototype 1991 Diesel Engine. *SAE Paper No. 902172*.

[3] Bennethum, J. E., and R. E. Winsor. 1991. Toward Improved Diesel Fuel. *SAE Paper No. 912325*.

[4] Fukuda, M., D. R. Tree, D. E. Foster, and B. R. Suhre. 1992. The Effect of Fuel Aromatic Structure and Content on Direct Injection Diesel Engine Particulates. *SAE Paper No. 920110*.

[5] Miyamoto, N. 1997. Emission Reduction and Fuels in High-Speed Diesel Engine. Proceedings of International Conference on IC Engine in China.

[6] Baranescue, R. A. 1988. Influence of Fuel Sulfur on Diesel Particulate Emissions. *SAE Paper No. 881174*.

[7] Kobayashi, S., T. Nakajima, and M. Hori. 1991. Effect of Fuel Sulfur and Aromatics on Diesel Exhaust Emission. *SAE Paper No. 912221*.

[8] Ulman, T. L., R. L. Mason, and D. A. Montalvo. 1990. Effects of Fuel Aromatics, Cetane Number, and Cetane Improver on Emissions from a 1991 Prototype Heavy-Duty Diesel Engine. *SAE Paper No. 902171*.

[9] Murayama, T., N. Miyamoto, T. Yamada, J. Kawashima, and K. Itoh. 1982. A Method to Improve the Solubility and Combustion Characteristic of Alcohol-Diesel Fuel Blends. *SAE Paper No. 821113*.

[10] Lange, W. W. 1991. The Effect of Fuel Aromatic Structure and Content on Particulate Emissions in Heavy Duty Truck Engines under Transient Operating Conditions. *SAE Paper No. 912425*.

[11] Montage, X., and B. Martin. 1991. Relation between Chemical Composition and Pollutant Emissions from Diesel Engines. 13th World Petroleum Congress. Buenosaires, Argentina.

[12] Konno, M., S. Kajitani, M. Oguma, T. Iwase, and K. Shima. 1999. NO Emission Characteristics in CI Engine Fueled with Neat Dimethyl Ether. *SAE Paper No. 1999-01-1116*.

[13] Akasaka, Y., P. D. Curran, T. Sasaki, S. Kato, and S. Onishi. 1990. Evaluation of Oxygenated Fuel by Direct Injection and Direct Fuel Injection Impingement Diffusion Combustion Diesel Engines. *SAE Paper No. 901566*.

[14] Tsurutani, K., Y. Takei, Y. Fujimoto, J. Matsudaira, and M. Kumamoto. 1995. The Effect of Fuel Properties and Oxygenates on Diesel Exhaust Emissions. *SAE Paper No. 951113*.

[15] Miyamoto, N., H. Ogawa, T. Arima, and K. Miyakawa. 1996. Improvement of Diesel Combustion and Emissions with Various Oxygenated Fuel Additives. *SAE Paper No. 962115*.

[16] Akasaka, Y., and Y. Sakurai. 1994. Effect of Oxygenated Fuel and Cetane Improver on Exhaust Emissions from Heavy Duty DI Diesel Engine. *SAE Paper No. 942023*.

[17] Sorenson, S. C., and S. Mikkelson. 1995. Performance and Emissions of a 0.273L DI Diesel Engine Fueled with Neat Dimethyl Ether. *SAE Paper No. 950064*.

[18] Kajitani, S., C. L. Chen, M. Konno, and K. T. Rhee. 1997. Engine Performance and Exhaust Characteristics of a Direct Injection Diesel Engine Operated with DME. *SAE Paper No. 972973*.

[19] Kajitani, S., C. L. Chen, M. Oguma, M. Alam, and K. T. Rhee. 1998. Engine Performance and Exhaust Characteristics of a Direct Injection Diesel Engine Operated with Propane and DME-Blended Fuel. *SAE Paper No. 982536*.

[20] Minobe, R. 1997. Method of Measuring Odor at the Discharge Port on the Ground Surface at the Site Boundary Line. Notification No. 238 of Tokyo Metropolis. 1, 1997.