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17 Improvement of Emission Performance in a Inline-pump Direct Injection Diesel Engine by Using Dimethyl Ether Fuel

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DME(Dimethyl ether) fuel has numerous advantages as an alternative fuel. One is that because it has a high cetane number it can be used in a diesel engine, making it possible to obtain a high level of heat efficiency and reduce CO_2 emissions. Another is that as an oxygenated fuel, it hardly emits smoke. On the other hand, however, it does have its problems such as high compressibility and low lubricity. Also NO_x and CO emission is almost same that of diesel engine. To examine the emission performance improvements as well as problems of using neat DME fuel as an alternative fuel for diesel engines, this study was conducted for a performance test on the 3.3 liter conventional DI diesel engine. In this test, in order to increase the fuel injection rate of DME because of high compressibility and low heating value compared to that of diesel, the nozzle opening pressure of the injectors was lowered and the plunger stroke of the injection pump was extended. Generally EGR system is used to reduce NO_x emission. So this study went on to test the application of EGR as a means to reduce NO_x generation. Also in order to decrease the CO and THC in the exhaust gas the DOC converter was used. The test results show that the EGR and DOC converter are very effective method to reduce the NO_x and CO emissions in case of Dimethyl Ether Fuel in diesel engine.

***Keywords*: Dimethyl ether, DI diesel engine, Oxygenated fuel, Alternative diesel fuel, Exhaust gas recirculation, Diesel oxygen catalyst / DME, EGR, DOC**

1. Introduction

Dimethyl ether (hereinafter DME) is an ether compound composed of 1 oxygen molecule and 2 methane radicals. Due to its high cetane number which enables diesel cycle operation by compressed ignition, high thermal efficiency equivalent to diesel engines with less CO_2 emission can be obtained. Its further merits as an alternative diesel fuel is the fact that, since it contains oxygen, it emits almost no particulate matter (hereinafter PM) which is one of the characteristic problems of diesel engines, therefore, enables the application of exhaust gas recirculation (hereinafter EGR) and reduction of NO_x.

On the other hand, DME has demerits such as lower heating value, higher compressibility which make it difficult to obtain required fuel injection rate when compared with the conventional diesel fuel[1)]. Furthermore, due to the wide difference in the physical properties to those of the conventional diesel, such as lower viscosity liable to leak in the supply system and poor lubricating power causing wear in the friction parts of engine, there are several challenges which require further studies and improvements including the modification of fuel supply system and optimization of engine performance[2, 4)].

The authors have studied on the availability and usability of DME in a air-cooled single cylinder direct injection diesel engine equipped with jerk type fuel supply system, in a prior study[5, 6)]. Through the experiences obtained from the study, DME Fuel Supply System has been developed for a 3.3 liter inline direct injection diesel engine to analyze engine performance and exhaust gas properties using DME fuel[7)]. The effective plunger stroke of the fuel injection pump of the base diesel engine and the opening pressure of the injector nozzle valve were modified to obtain full load output power equivalent to that of the diesel.

By the modification, the DME fuel could provide high output power and heat efficiency equivalent to those of the conventional diesel fuel, however, the NO_x, CO and THC contents in the exhaust gas were also as high. Thus, in order to reduce these contents in using DME, EGR and DOC (hereinafter diesel oxidation catalyst) were applied to improve exhaust gas properties.

2. Experimental Apparatus and Method

2.1 Experimental Apparatus

Fig. 1 and Fig. 2 illustrate the schematic drawing and full view of the experimental apparatus of the DME engine applied with EGR, devised for the performance test. Table 1 lists the specifications of the experimental apparatus, comprised largely of engine power system, peripheral devices, and exhaust gas analyzer. Signals from the sensors are sampled in real time basis and analyzed by a data analysis system.

The fuel injection pump (Inline type) equipped on the existing base diesel engine was modified for DME injection, as shown in Fig.3. Since most of the ether series compounds like DME react with elastomer, the sealant materials in the fuel system need to be replaced. All the sealants in the fuel pump, plunger barrel etc., were replaced with NBR (Nitrile rubber) material. The air vent on the mechanical feed pump at the fuel injection pump was removed to prevent fuel leak.

Since the DME fuel reacts with rubbers and supplied in pressurized liquid state, the fuel tubing in the existing diesel engine was replaced with stainless tubing and fittings. As for the return tubing of the fuel, in which the pressurized DME flows back to the fuel tank, the returning part of the injector was modified and fittings were replaced.

DME fuel supply system was manufactured for the experiment as shown in Fig. 4. In order to prevent evaporation by temperature increase and to maintain liquid state of DME in the fuel injection pump of the diesel engine, a feed pump was used, supplying DME to the injection pump at pressure higher by 0.5 ~ 1.0 MPa than that of the fuel tank. An accumulator was installed after the fuel injection pump to prevent pulsation. A regulator was installed to control fuel pressure. The return fuel from the injection pump through the regulator and the return fuel from the injector were made to go back to the fuel tank through a check valve.

The DOC was installed in front of the muffler, as shown in the Fig. 5, for the test of reducing the THC and CO from DME fuel. A small quantity of lubricant agent was added to DME fuel to improve the lubricating property of DME of which the viscosity is about 1/20 of diesel. Fuel consumptions of both DME and diesel were measured with precision balance, in combination with the volume measurement by the fuel flow meter (FP-2240, Ono Sokki) modified to be suitable for DME.

In order to measure the properties of the exhaust gas of DME fuel, CO, CO_2 and THC were measured by the Non-dispersive infrared method (MEXA 554JK, Horiba), NO_x by Chemi-luminescent method (10AR, Thermo environ-ment) and the smoke by automatic filtration smoke tester (AFT-2000, World Environment), which are the same methods used for diesel. EGR ratio was calculated with following formula using the measurement of the CO_2. The intake air volume (Laminar flow meter, P7209, Cussions) and the oxygen content in the exhaust gas were measured (MEXA 720, Horiba) for verification.

$$EGR\ Ratio(\%) = \frac{[CO_2]_{EGR} - [CO_2]_{W/O\ EGR}}{[CO_2]_{EGR}} \times 100$$

Where; $[CO_2]_{EGR}$ is the CO_2 concentration of the intake air when the EGR is applied, $[CO_2]_{W/O\ EGR}$ is the intake CO_2 concentration without EGR, $[CO_2]_{EXH}$ is the CO_2 concentration in the exhaust with EGR.

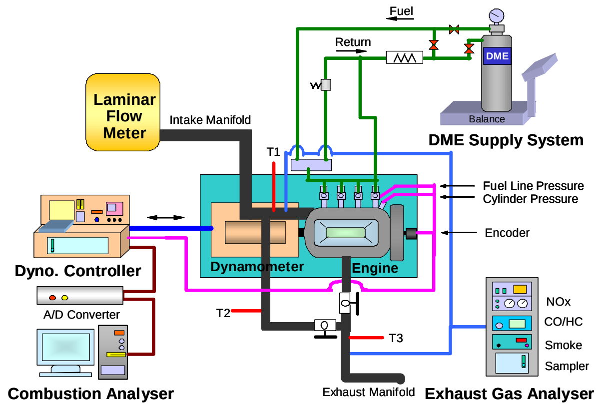

Fig. 1 Schematic diagram of experimental apparatus

Fig. 2 Inline- pump direct injection DME test engine

Table 1 Specification of test engine

Item	D4AE diesel engine
Cylinder number	4
Displacement	3,298 (cc)
Maximum power	120/3,400 (ps/rpm)
Compression ratio	17:1
Injection & nozzle type	Direct Injection & 4 holes
Nozzle opening pressure	22 (MPa)

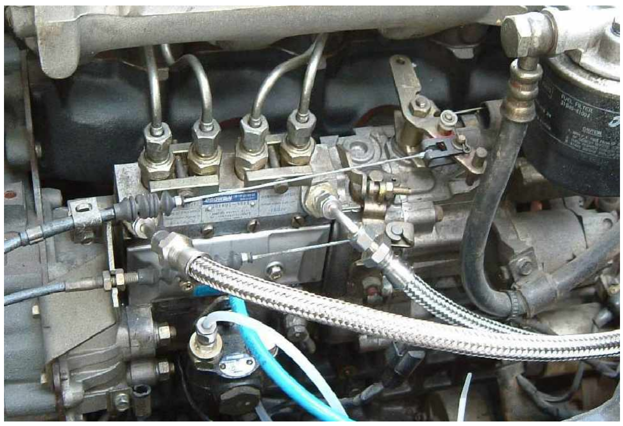

Fig. 3 Modified inline-type injection pump for DME

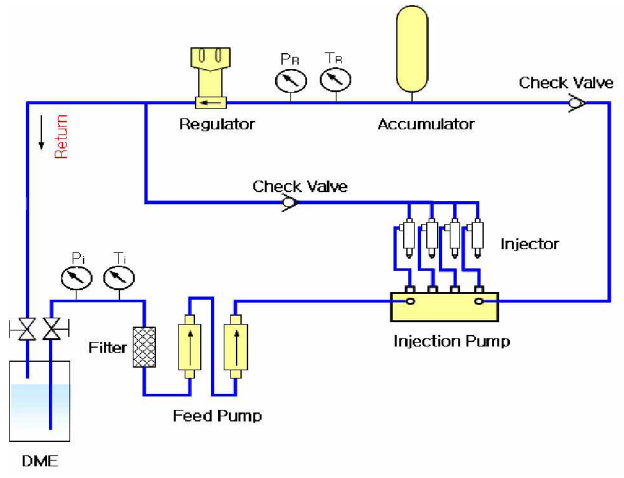

Fig. 4 Schematic diagram of DME fuel supply system

Fig. 5 Diesel oxygen catalyst

2.2 Experiment Method

For both DME and diesel, the engine speed was tested at 1,000 rpm, 1,500 rpm, 2,000 rpm and 2,500 rpm. Engine loads were tested at 20%, 40%, 60%, 80%, and full with respect to the maximum torque of the diesel for each of the said engine speed. EGR ratio was tested within the range of 15% to 35%, at 5% intervals.

In this study, in order to obtain the fuel injection rate which gives the same output power of the full load power of the diesel while using the existing fuel injection pump, the injector nozzle opening pressure was lowered from the conventional pressure 22 MPa to 10 MPa and the effective stroke of the fuel injection pump plunger was increased, for the engine performance test. As the result, using DME in the natural air intake system, the same full load output powers as those of the diesel could be obtained at all the engine speed steps.

For both DME and diesel, the fuel injection time was set at 13° BTDC which is the optimum value for the conventional diesel fuel[2].

The BSEC (brake specific energy consumption) in this study is the brake specific fuel consumption multiplied with the heating value of the fuel, used to compare the performances on the same basis of input heat value of DME and diesel of which heating values differ from the other.

3. Experiment Results and Review

3.1 Characteristics of Engine Performance

Fig. 6 is the BMEP (Brake Mean Effective Pressure) at the engine speeds of 1,500 rpm and 2,500 rpm for the variation of loads of both DME and diesel. In the Figure, the engine load was setup under the same conditions with reference to the maximum torque exerted by diesel.

As shown in the figure, DME fuel can provide the same BMEP with that of the diesel. In the prior experiments, desired injection quantity could not be obtained due to the pressure reduction in the fuel supply line caused by the lower heating value and higher compressibility of DME compared with diesel. In this experiment, the full load output power equivalent to that of the diesel could be obtained by lowering the injector nozzle opening pressure from the conventional value of 22 MPa to 10 MPa and by increasing the effective stroke of the fuel injection pump plunger.

Fig. 7 is the torque in accordance with the variation of engine speed at 60% and 100% of engine load of both DME and diesel.

As shown in the Figure, at 60% and 100% load conditions, the trend of the torque exerted by DME according to the engine speed change is almost the same as that of the diesel. For both DME and diesel, the maximum torque is obtained at the engine speed 2,000 rpm, which corresponds with the specification of diesel engine.

Fig. 8 is the BSFC of DME to the load conditions, at 1,500 rpm and varying EGR ratio, in comparison with the diesel, while Fig. 9 is the BSEC under the same operating conditions.

As shown in the Fig. 8, the BSFC of DME is higher than diesel due to its lower heating value, however, as shown in the Fig. 9, the BSEC is almost the same.

Regarding the effect of the EGR, as shown in the Fig. 9, it can be seen that the BSEC do not become worse significantly up to 35% of EGR ratio, at 1,500 rpm. However, due to the insufficient intake air in higher load and higher speed conditions, as shown in the Fig. 10 in full load and engine speed 2,000 rpm or faster conditions, the BSEC and the maximum torque become severely worse in the EGR ratio exceeding 20%.

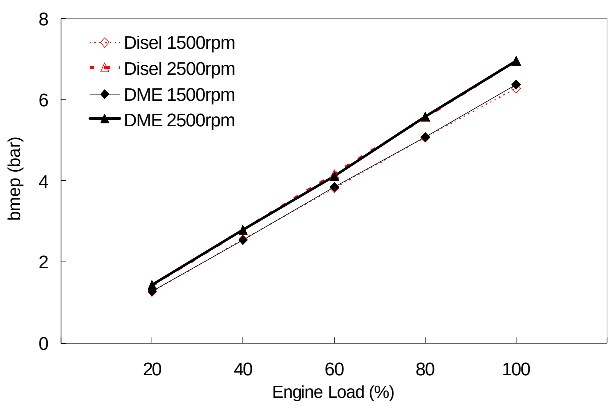

Fig. 6 Comparison of bmep

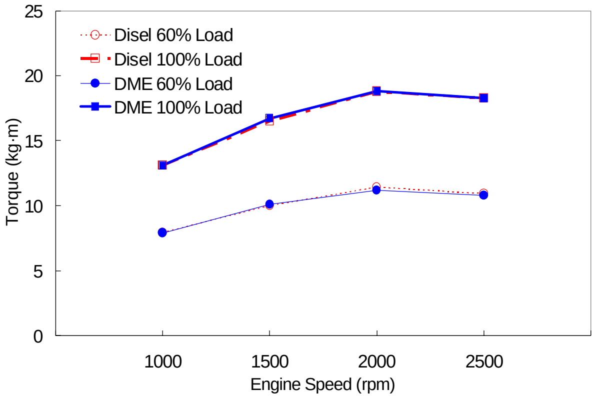

Fig. 7 Comparison of Torque

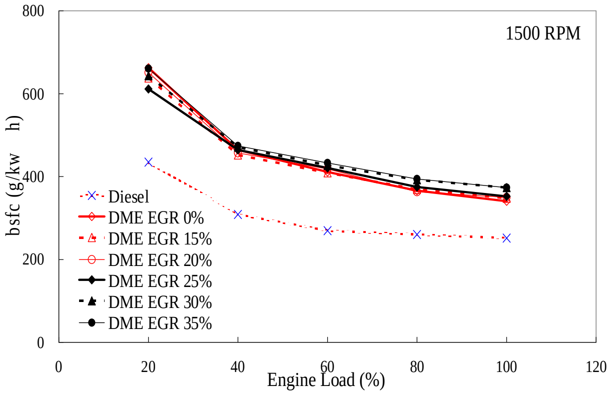

Fig. 8 Comparison of bsfc with load

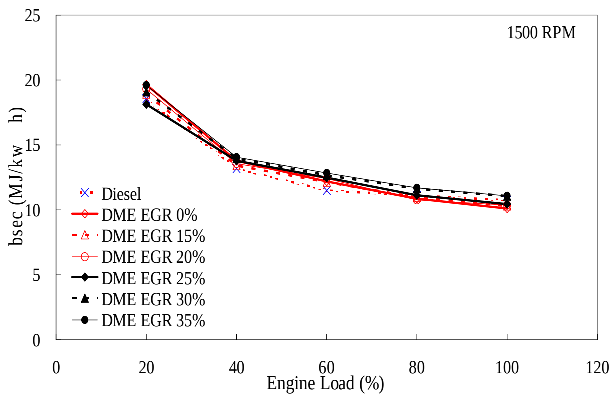

Fig. 9 Comparison of bsec with load

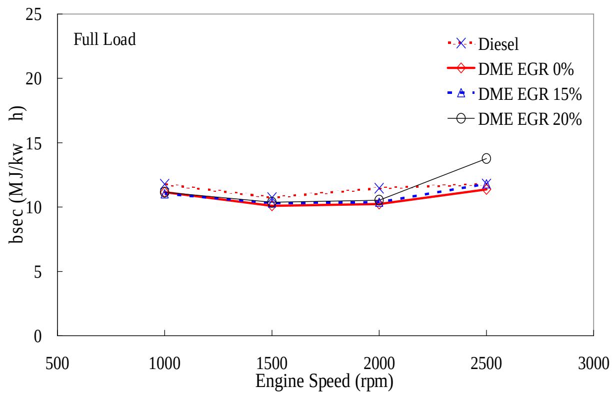

Fig. 10 Comparison of bsec with rpm

3.2 Characteristics of Exhaust Gas

Fig. 11 shows the NO_x concentration in the exhaust gas of DME to various loads and EGR ratio at 1,50 0rpm, in comparison with diesel, while Fig. 12 shows the reduction ratio of NO_x under the same operating condition.

As shown in the Figures, the NO_x concentration decreases in accordance with the increase of the EGR ratio and further to the increase of the load.

Fig. 13 shows the CO concentration in the exhaust gas of DME to the varying EGR ratio and load at 1,500 rpm, in comparison with diesel, while Fig. 14 shows the CO concentration of prior and after the installation of the DOC converter, to the engine speed at 60% and 100% load conditions.

Fig. 13 shows that up to the EGR ratio of 30% except at the full load, the CO concentration in the exhaust gas did not increased, however, it sharply increased in the EGR ratio exceeding 30% in high load conditions. In addition, as shown in Fig. 14, when the DOC converter is applied, almost no CO was emitted in all conditions except full load and engine speed at 2,500 rpm. Therefore, it could be concluded that the DOC converter is a very effective method for reducing the CO emission.

Fig. 15 and Fig. 16 shows the variance of the THC concentration in the exhaust gas under the same operating conditions described hereinabove. As shown in Fig. 15, THC concentration increased slowly in accordance with the EGR ratio up to 30%. Fig. 16 shows that DOC converter did not decreased THC significantly.

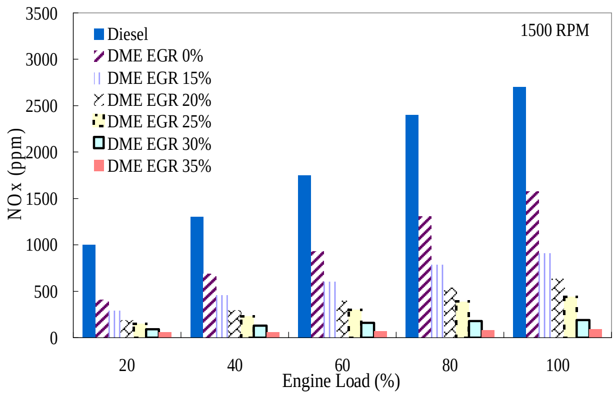

Fig. 11 Comparison of NO_x

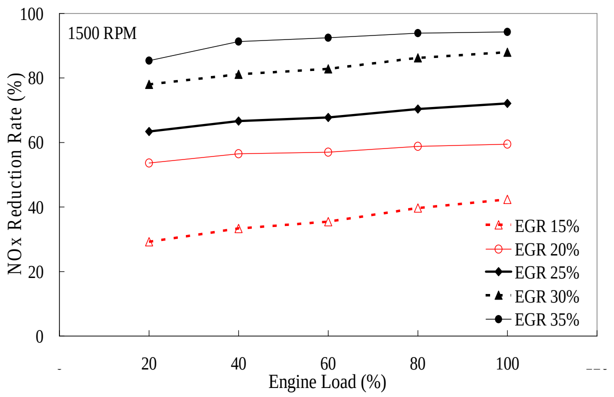

Fig. 12 Comparison of NO_x reduction rate

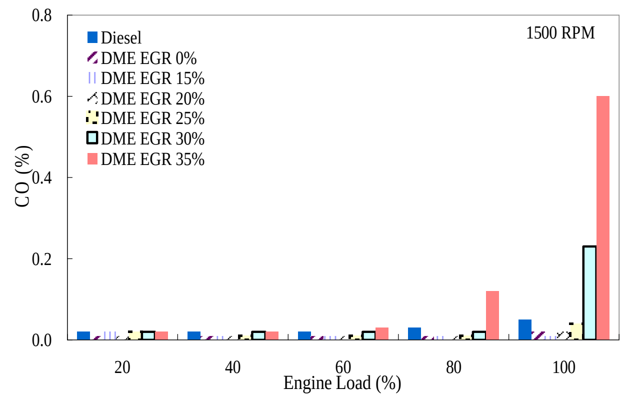

Fig. 13 Comparison of CO (With EGR)

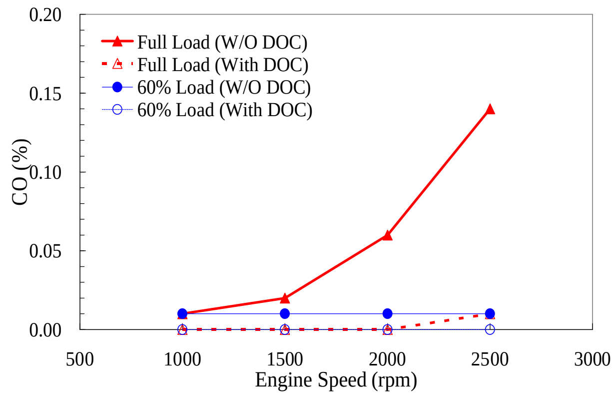

Fig. 14 Comparison of CO (With DOC)

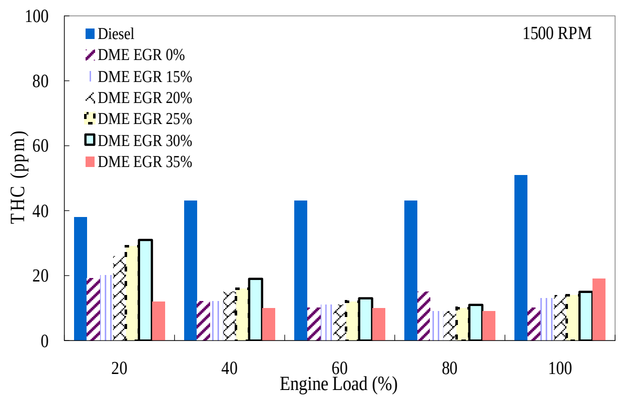

Fig. 15 Comparison of THC (With EGR)

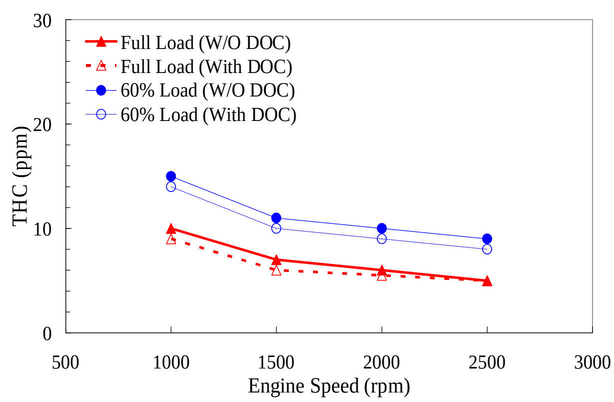

Fig. 16 Comparison of THC (With DOC)

4. Conclusion

1) When utilizing DME as a diesel engine fuel, full load output power same as that of the diesel could be obtained by reducing the injector nozzle opening pressure from conventional pressure of 22MPa to 10 MPa and increasing the effective stroke of the fuel injection pump plunger.

2) Due to the lower heating value of DME, the BSFC was higher than that of the diesel, however, BSEC was almost the same.

3) When using DME, NO_x concentration in the exhaust gas could be greatly decreased without significant increase of CO and THC by applying the EGR System. CO concentration could be greatly reduced with DOC converter.

Postscript

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