Research paper

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Reduction of Diesel Engine Emissions Using Hybrid Combustion

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Abstract

We propose a new method to apply hybrid fuel combustion to diesel engines in order to reduce NO_X and smoke emissions. In hybrid combustion, subsidiary fuel is fed into intake air, whereas the main fuel of light−oil is directly injected into the combustion chamber as in conventional diesel engines. In this study, we tried to use two different kinds of fuels, di−methyl ether (DME) and gasoline as subsidiary fuels. DME, with a high cetane number and excellence in auto−ignition, is used only to afford preliminary combustion in the early compression period, which promotes and advances the ignition of the sprayed main light−oil and accordingly reduces emissions. Gasoline, by contrast, with no self−ignition characteristic in diesel engines, is used as a part of the main fuel to fill the engine cylinder with a uniform mixture before the injection of diesel fuel, the other main fuel, to ignite both the main fuels smoothly and lower emissions. Experiments with DME demonstrated successful ignition earlier than the conventional method and decrease of NO_X from 160 to 120 ppm without smoke increase at 2 NL/min DME flow. Use of gasoline as the complementary main fuel eliminated smoke emissions and reduced NO_X from 2700 to 1600 ppm.

Keywords : hybrid combustion, diesel engines, subsidiary fuel, di−methyl ether (dme), gasoline, emission reduction

1. Introduction

Diesel engines have advantages of higher reliability, lower fuel consumption, and therefore lower CO_2 emissions than gasoline engines. On the other hand, they emit more smoke and NO_X than gasoline engines. Particularly, because local fuel−air inhomogeneity becomes distinct and the combustion temperature rises with increased fuel consumption at high loads, the emissions worsen ; it is difficult to decrease these emissions at the same time because there is a trade−off relation between smoke and NO_X, and a three−way catalyst cannot be applied to diesel engines unlike in the case of gasoline engines[1)2)]. Thus, there is a need to propose some method to reduce these environmental pollutants together. Based on the idea that homogeneous fuel−air mixing would reduce smoke at middle loads or higher, and that decreasing the amount of initial fuel injection would suppress NO_X emissions, we propose a new method to apply hybrid combustion to diesel engines for the reduction of NO_X and smoke emissions. In hybrid combustion, subsidiary fuel is fed into the intake air whereas the main fuel of light−oil is directly injected to the combustion chamber as in conventional diesel engines. When natural gas is used as the subsidiary fuel it is called a Dual−Fuel system, which has been widely studied and proved to burn cleaner, yet has lowered power and an enlarged fuel system because natural gas fuel is stored in a gaseous state and occupies a larger volume[3)4)]. Hence in this study, we tried two different kinds of fuels not used before, Di−methyl ether (DME) and gasoline, as subsidiary fuels that can be stored in liquid form and are commercially available. DME, with a high cetane number and excellence in auto−ignition, is used only to afford preliminary combustion in the early compression period, which promotes and advances the ignition of the sprayed main light−oil and accordingly reduces emissions[5)6)]. Gasoline, by contrast, having little self−ignition qualities in diesel engines, is used as a part of the main fuel to fill the engine cylinder with a uniform mixture before the injection of diesel fuel, the other main fuel, to ignite both main fuels smoothly and lower the emissions[7)]. In this study we try to reduce pollutants in diesel engines by making use of these two methods of subsidiary fuel.

2. Experiments

Table 1 shows specifications of the test engines used included in Figures 1 and 2.

Figure 1 illustrates a schematic of the experimental apparatus employing the proposed hybrid combustion using DME as subsidiary fuel and light−oil as the main fuel. The amount of DME added to the intake air is adjusted by a mass flow meter and the mixture is supplied into the combustion chamber. The light−oil of the main fuel is supplied to the direct−injection system. The engine load was kept constant by a DC electric dynamometer. Regarding exhaust gases, the contamination level of the smoke emission was measured by the smoke meter, and the amount of NO_X emissions was measured by the NO_X meter, respectively.

Figure 2 illustrates a schematic of the hybrid combustion experiment using gasoline as the complementary fuel or, so to speak, the other main fuel. The carburetor is applied in order to mix gasoline with air. The throttle is set up at WOT (Wide Open Throttle) to lower the pumping loss. The amount of premixed fuel/air is adjusted by the negative pressure apparatus. The revolution speed of the engine was kept constant by an eddy current electrical dynamometer. Measurement of the exhaust gases was conducted as in the case of hybrid combustion with DME.

Table 1 Specifications of the test engines.

Subsidiary fuel	DME	Gasoline
Type of engine	Direct injection, single cylinder 4 stroke cycle, 2 valves	
Injection equipment	Direct−injection system	
Compression ratio	18	
Bore×Stroke, [mm]	80×87	82×78
Displacement, [cc]	437	411
Makes	Yanmar Diesel Engine Co., Ltd	Mitsubishi Heavy Industries, Ltd

3. Results and discussion

3.1 Hybrid combustion with DME as subsidiary fuel

3.1.1 Experimental conditions

In this experiment, the engine torque was kept constant by the dynamometer with the engine loading rates at equal to or higher than 95%. The injection timing of light−oil was set at 18 degrees Before Top Dead Center (deg. BTDC afterwards) throughout the experiment. We examined how the emissions were influenced by changing the flow rate of DME from 0 to 3 liters per minutes in the standard state (NL/min afterwards).

3.1.2 Experimental results

Figures 3(a)−(d) show the heat release rate diagram, the cylinder pressure diagram, smoke emissions by

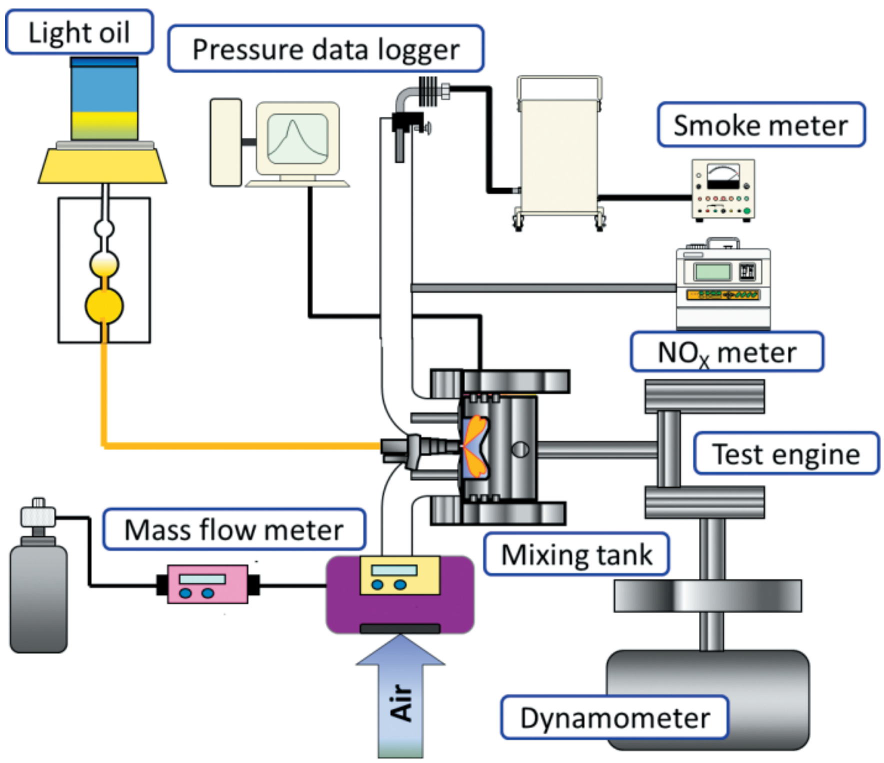


Figure 1 Schematic of hybrid combustion experiment with DME as subsidiary fuel.

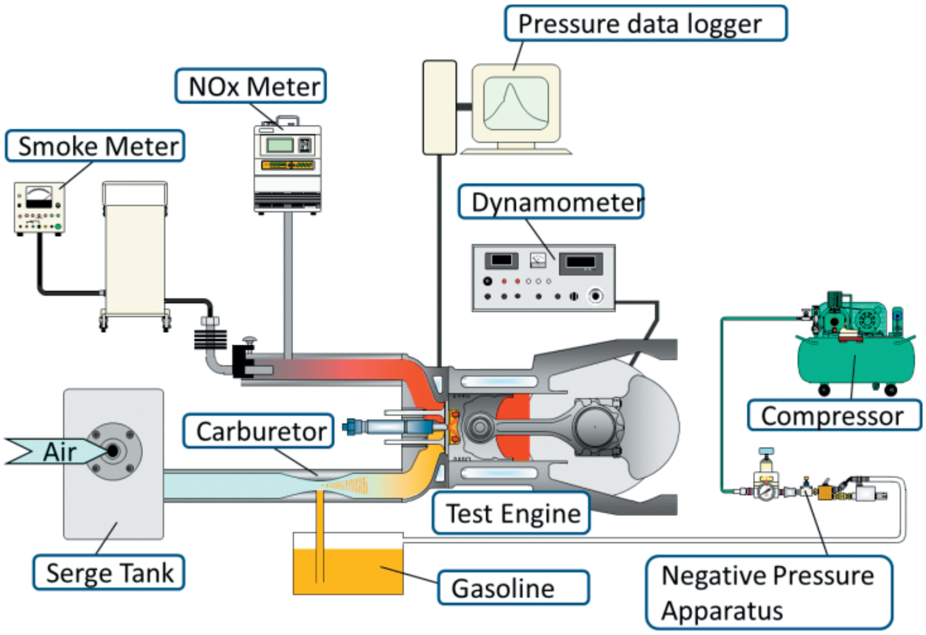
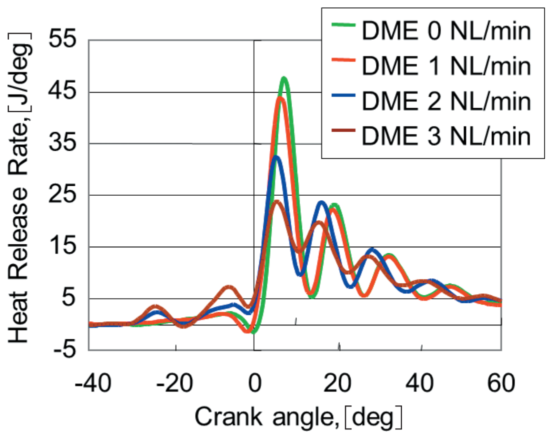
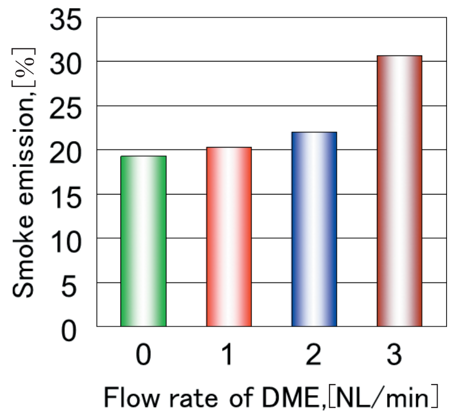


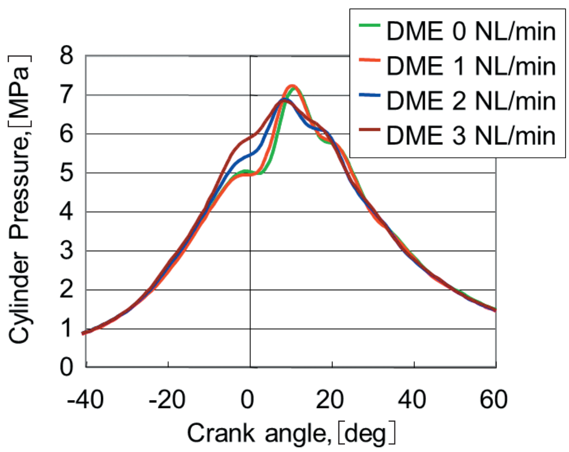
Figure 2 Schematic of hybrid combustion experiment with gasoline as complementary main fuel.



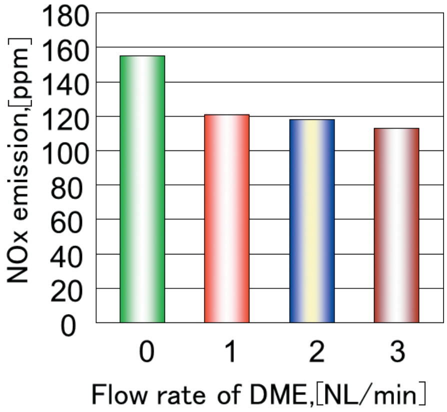
(a) Heat release rate diagram



(c) Smoke emission



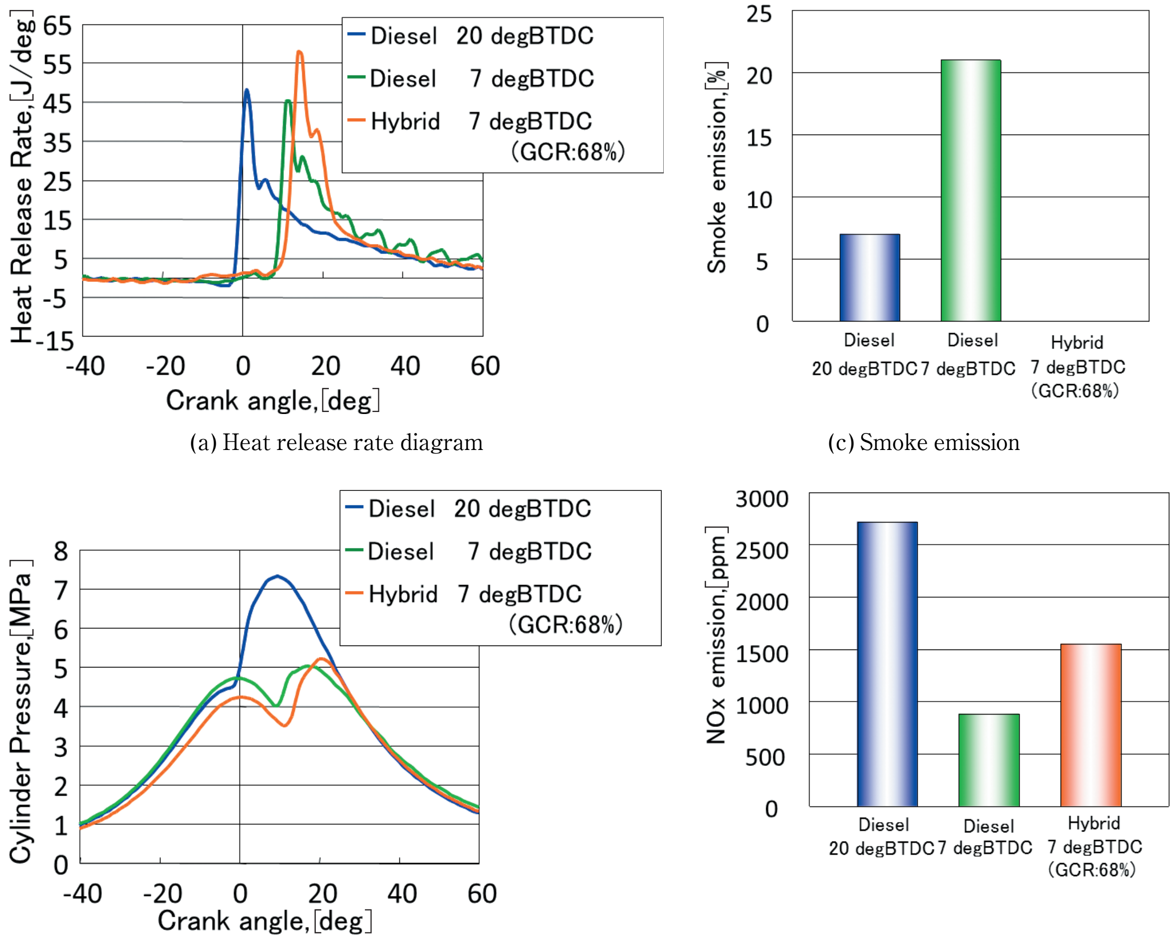
(b) Cylinder pressure diagram



(d) NO_x emission

Figure 3 Experimental results with DME as subsidiary fuel.

contamination degree and the amount of NO_x emissions, respectively. Figures 3(c) and 3(d) together show the tendency where the NO_x emissions decrease as the flow rate of DME increases and the smoke emission increases at over 3 NL/min. This is thought to be due to the decrease of the combustion temperature, which is probably caused by shortening the ignition delay period of direct-injection light-oil with the effect of easily ignitable DME. The NO_x emissions are decreased without raising smoke emissions when the DME flow is equal to or lower than 2 NL/min, which means that the flow rate of DME around 2 NL/min is enough and appropriate.



(a) Heat release rate diagram

(c) Smoke emission

(b) Cylinder pressure diagram

(d) NO_X emission

Figure 4 Experimental results with gasoline as complementary main fuel.

3.2 Hybrid combustion with gasoline and light–oil

3.2.1 Experimental conditions

In this experiment, the revolution speed of the engine was kept at around 1500 rpm with the engine loading rates equal to or higher than 95%. We define the Gasoline Charge Ratio (GCR) as an experimental parameter to express the percentage of the equivalence ratio of gasoline ϕ_{gasoline} to the total ϕ_{Total} equivalence ratio ;

$$GCR\% = \frac{\phi_{\text{gasoline}}}{\phi_{\text{total}}\left(=\phi_{\text{gasoline}}+\phi_{\text{lightoil}}\right)}\times 100 \qquad (1)$$

3.2.2 Experimental results

We conducted ordinary diesel engine combustion tests with two different injection timings, 20 deg.BTDC and 7 deg.BTDC, and hybrid combustion using gasoline mixed with intake air and light–oil by injection direct into the cylinder at 7 deg. BTDC. The emissions were measured with different GCR. The best GCR was 68%, over which knocking occurred and under which smoke started to be emitted.

Figure 4 show the same kinds of diagrams as in Figure 3. Figures 4(c) and 4(d) show that smoke emissions increase whereas NO_X emissions decrease when delaying the injection timing with ordinary diesel combustion. This is due to the temperature drop caused by delaying the direct–injection timing of light–oil, therefore indicating an insufficient mixing of fuel and air. Compared with the diesel combustion with a typical injection timing of light–oil at 20 deg.BTDC, hybrid combustion using gasoline and light–oil can reduce smoke and NO_X. This is probably because it promotes the premixing of fuel/air, which causes a shorter high temperature duration, by a shorter combustion period. For these reasons, employing hybrid combustion using gasoline and light–oil is useful for the reducing the pollutants at the same time for high loads.

4. Summary

Whereas existing researches to use gasoline or DME for diesel combustion are on gasoline/light oil blend fuels, such as by Rolf Reitz at the University of Wisconsin, or use as an alternative for diesel light oil[8], in this paper we aimed to reduce NO_X emissions at high loads by employing hybrid combustion using DME as a subsidiary fuel and light–oil as the main fuel by inducing the earlier ignition of injected fuel than conventional diesel combustion. The results show that :

- The concentration of NO_X in the exhausts decreases, and the smoke emissions increase when the flow rate of DME increases.
- The concentration of NO_X emissions is decreased without raising smoke emissions when the flow rate of DME is as small as or lower than 2 NL/min.

Next, we attempted to reduce smoke emissions by employing hybrid combustion using gasoline as a complementary main fuel fed with the intake air and light−oil as the main fuel by increasing the premixing rate in the combustion chamber. The results show that :

- This hybrid combustion is effective for the reduction of smoke and NO_X emissions together at high loads.

5. References

1) B. Milton, "Thermodynamics, Combustion and Engines", pp.227 & 328, Chapman & Hall (1995).
2) S. McAllister, "Fundamentals of Combustion Processes", pp.220−237, Springer (2011)
3) Y. Daisho, et al., "Controlling Combustion and Exhaust Emissions in a Direct−Injection Diesel Engine Dual−Fueled with Natural Gas", SAE Paper, No. 952436, (1995).
4) R. Papagiannakis, et al., "Combustion and Performance Characteristics of a DI Diesel Engine Operating from Low to High Natural Gas Supplement Ratios at Various Operating Conditions", SAE Paper, No. 2008−01−1392, (2008)
5) Japan DME Forum, "DME handbook", pp.30−57, Ohmsha (2006).
6) W. Bartok and A. Salofim, "Fossil Fuel Combustion", pp.39−40, John Wiley & Sons (1991).
7) C. Taylor, "The Internal Combustion Engine in Theory and Practice Vol.2", pp.165−166, MIT Press (1985).
8) R. Reitz, "A study of dimethyl ether (DME) as an alternative fuel for diesel engine applications", Transport Canada Report TP 13788E (2008)

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ハイブリッド燃焼によるディーゼル排気ガスの浄化

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副燃料を用いるハイブリッド燃焼に新手法を考案・適用し，ディーゼルエンジンからの有害排気物質の低減を図る。従来通りのシリンダ内へ直噴する軽油主燃料の他に，副燃料を吸気空気に予混合して用いるが，狙う浄化機構の違いにより２つの性質の異なる副燃料を試みる。一つは自着火性の高いディメチルエーテル（DME）で，少量を予混合して圧縮行程早期にシリンダ内で燃焼させ，後に噴射される主燃料軽油の燃焼をスムーズにし，排ガス浄化を図る方法。もう一つは自着火しにくいガソリンで吸気を予混合化させ，主燃料噴射軽油量をその発熱相当分を減じ，噴霧軽油の気化均一に要する時間を短縮して浄化を図る方法。先のDMEによる方法ではNOXが，後のガソリンによる方法では，スモークの低減にも効果が見られた。

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