Application to Diesel Engine of Mixed Fuel Comprising DME and A-Heavy Oil (Marine Diesel Oil) (1st Report : Preliminary Setup of Engine System)

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We improved the system of a high-speed single-acting 4-stroke diesel engine to allow it run on a mixed fuel comprised of A-heavy oil (Marine diesel oil) and DME (Di-Methyl Ether), fuel components that discharge no soot, no SOx, and little NOx in combustion. The combustion pressure, rate of heat release, exhaust gas components, and other conditions were measured in experiments using diesel oil, A-heavy oil (Marine diesel oil), and the mixed fuel comprised of DME and A-heavy oil (Marine diesel oil).

As a result, the ignition timing was earliest with gas oil, median with the mixed fuel, and latest with A-heavy oil (Marine diesel oil). Mixed fuel discharged a slightly reduced level of NOx. Overall, results indicated that the engine would require further improvements before long-term operation became possible.

1. Introduction

Various alternative fuels have been investigated in order to overcome the shortage of the fossil resources. In addition, the research of a new alternative fuel that reduces environmental pollution will be a pressing need for the future. In this study, the trial experiment that uses the mixed fuel comprised of dimethyl ether (DME) and A-heavy oil (Marine diesel oil) is conducted using a small high-speed compression ignition (CI) engine.

2. About DME

DME is the simplest ether whose chemical formula is shown with CH_3OCH_3. It is extremely stable inactive compound and low toxicity. Therefore, safe handling is possible in the preservation of a long term. It is originally used as a propellant of spraying systems that is the substitute of chlorofluorocarbon. Its production is about 10,000 ton/year in Japan and is about 150,000 ton/year in the world, respectively [(1)].

Table 1 Properties of Used Fuels

	DME	Marine diesel oil	Gas oil
Chemical formula	$(CH_3)_2O$	---	---
Boiling point (K)	248	623 <	453~643
Oxygen (%)	34.8	---	---
Net calorific value (kJ/kg)	28889	42538	41868
Cetane number	55	40 <	40~55
Viscosity (mm^2/s)	< 1	7	3
Density (g/cm^3)	0.667	0.842	0.831
Ignition point (K)	508	803~884	523
Latent heat (kJ/kg)	467.13	280.00	300.00

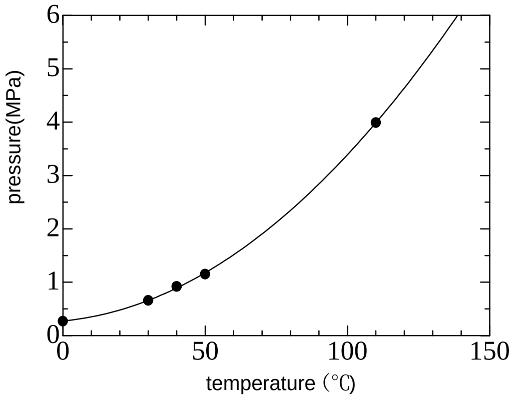


Fig. 1 P-T Diagram of DME

DME is recently paid attention as an alternative fuel of the CI engine because it is easy to transport at a liquid state by pressurizing at several atmospheric pressures. Moreover, its cetane number is higher than the original fuels of the CI engine, such as gas oil and A-heavy oil (Marine diesel oil). It does not generate soot in combustion by the factor of the structure not uniting of the carbons directly. Since it is possible to manufacture DME from the biomass, it has the side as the biomass fuel. On the other hand, the fuel leakage might be caused in the fuel pump system of the CI engine, since the viscosity is very low. And also, there is wearing problem at the nozzle needle and the plunger because lubricity is scarce. Although there is no erosion to the metal, the deterioration of the seal materials such as rubbers has been found [2].
The P-T diagram of DME is shown in Figure 1, and the physical properties value of various fuels is shown in Table 1.

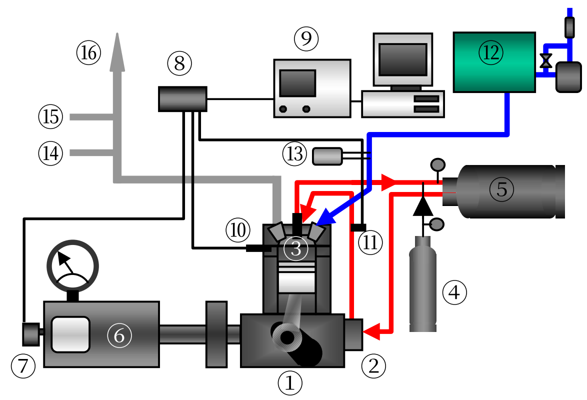
3. Experimental Apparatus and Method

3.1 Experimental Apparatus

A horizontal water-cooled single cylinder 4-stroke diesel engine was used for the experiment. Table 2 shows the specification of the test engine. Since DME evaporates in the atmospheric temperature and pressure, it is put into the fuel tank with applying high pressure. Returned fuel from the injection nozzle is led to the fuel tank and the fuel lines were reinforced to endure the high pressure [1] [2]. The Teflon tube was used for the fuel system in this experiment. Figure 2 shows the experimental apparatus and setup of the measurements.

Table 2 Specification of Test Engine

Engine type	Horizontal, Water cooled 4 cycle, Diesel engine
Bore×Stroke	92×96 mm
Stroke volume	0.638 *liter* (Single cylinder)
Combustion type	Direct injection
Compression ratio	17.7
Rated output	11.0 PS (8.1kW) @2400rpm
Maximum output	12.5 PS (9.2kW) @2400rpm
Injection pump	Jerk type
Injection nozzle	4 holes, Hole type nozzle
Opening pressure	200 kg/cm^2 (19.6MPa)



①Test engine
②Injection pump
③Injection nozzle
④Nitrogen cylinder
⑤Fuel tank
⑥Dynamometer
⑦Rotary encoder
⑧Amplifier
⑨Combustion analyzer
⑩Pressure transducer
⑪Injection pressure sensor
⑫Air tank
⑬Flow meter
⑭Smoke meter
⑮Exhaust gas analyzer
⑯Exhaust

Fig.2 Experimental Setup

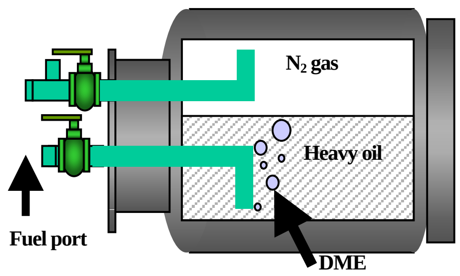


Fig.3 Fuel Tank for Mixing DME

3.2 Test Fuel

The mixture ratio of DME and A-heavy oil (Marine diesel oil) was 1:1 by weight ratio. A-heavy oil (Marine diesel oil) was filled to the fuel tank first, and then DME was filled with bubbling while measuring the weight. Figure 3 shows the fuel tank for mixing fuels. The separation was not seen when it was preserved in the airtight transparent container. The neat fuels of A-heavy oil (Marine diesel oil) and gas oil were also used for the reference.

3.3 Experimental Method

In the experiments, the engine speed was kept constant at 2000rpm. The intake air pressure was pressurized at 130mmHg(17kPa) by the gauge pressure. The engine load was controlled by the fuel injection amount. The DME and A-heavy oil (Marine diesel oil) mixed fuel was pressurized to 1.1MPa with the nitrogen gas. The history of pressure in the combustion chamber, the rate of heat release, and the exhaust emission gases (O_2, CO, CO_2, NOx) in each fuel were measured. Pressure in the combustion chamber is measured as a mean value of 50 cycles with the Piezo type pressure sensor, and it is calculated the rate of heat release based on the mean value of the pressure history. As for CO and CO_2, the non-dispersion type infrared rays analysis meters were used, and the chemical luminescence method analysis meter for NOx, the magnetic pressure type oxygen analysis meter for O_2, respectively. The fuel consumption rate is not measured for the malfunction in the measurement equipment.

4. Results and Discussion

Figure 4 shows the comparison of pressure in the cylinder in each fuel. The ignition timing was earliest with gas oil, median with the mixed fuel, and latest with A-heavy oil (Marine diesel oil) as it can be seen in this figure. It is probable that the combustible mixture formation acts according to a low boiling point of DME in conjunction with the excellent atomization characteristics. It is obvious that the ignition delay becomes shorter with mixing DME. The pressure curve ranging from the fuel injection start (17°B.T.D.C) to the ignition shows higher value in the case of DME composite fuel. It is thought that injected DME evaporates rapidly, and it raises the pressure in the combustion chamber.

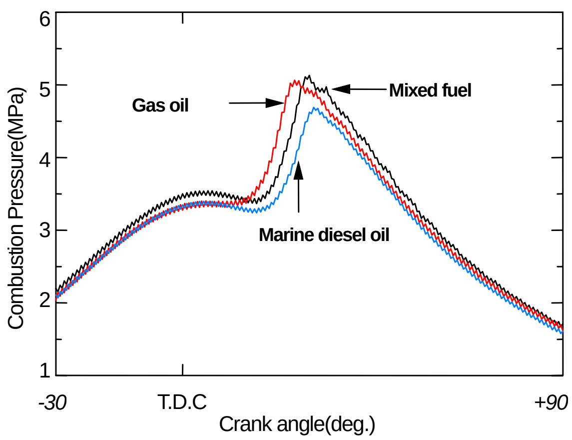


Fig.4 History of Combustion Pressure

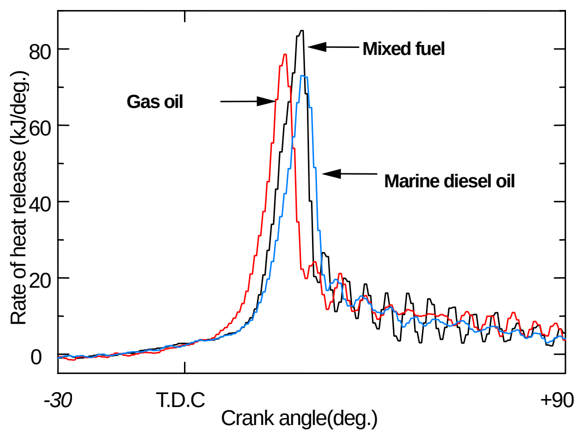


Fig.5 History of Heat Release Rate

It is shown that the pattern of the rate of heat release is similar between each fuel from Figure 5. However, the heat generation at the premixed combustion period is growing because the mixed fuel is later in the ignition compared to gas oil. In addition, the mixed fuel is slightly shortening in the combustion period compared with A-heavy oil (Marine diesel oil). It is thought that it is because the combustibility of the post-burning period improved due to containing oxygen in the molecular and the better atomization of DME. Figure 6 shows the ignition delay. Figure 4 and Figure 5 were the data of the load

49%(about 3.5kW), and the ignition delay was defined from the injection timing (17°B.T.D.C) of the experiment engine to rapid standing up time in the graph of the rate of heat release.

Figure 7 is a comparison of the NOx concentration in each fuel. The result was obtained that the NOx slightly decreases in the case of mixed fuel. This is thought to be a decrease of thermal NOx by the flame temperature falling due to the evaporation of DME. It was also slightly low compared with another fuel for the exhaust temperature.

The CO_2 concentration is shown in Figure 8 and the O_2 concentration is shown in Figure 9. The mixed fuel has lowered in each load though A-heavy oil (Marine diesel oil) and gas oil are almost same levels in the exhaust of CO_2. On the other hand, the exhaust density of O_2 has risen compared with gas oil and A-heavy oil (Marine diesel oil). It is thought that more amounts of the fuel are needed for the case of mixed fuel to obtain the same level of engine load due to smaller calorific value. Moreover, the mixed fuel needs smaller amount of air compared with A-heavy oil (Marine diesel oil) 100% and gas oil 100%, because it contents the oxygen molecule of about 35% in the composition. Therefore, it is guessed that the excess air ratio in the combustion chamber has been becoming small for the mixed fuel compared with A-heavy oil (Marine diesel oil) and gas oil.

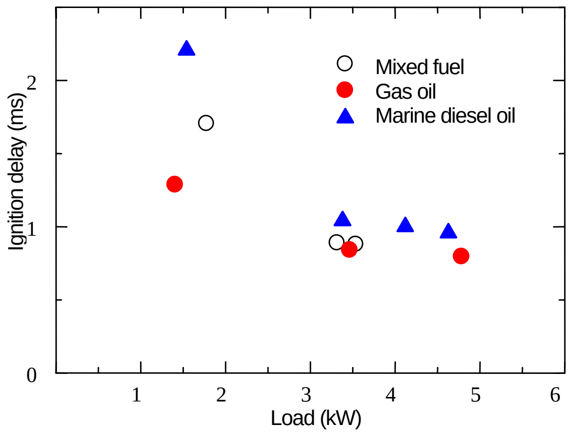


Fig.6 Ignition Delay

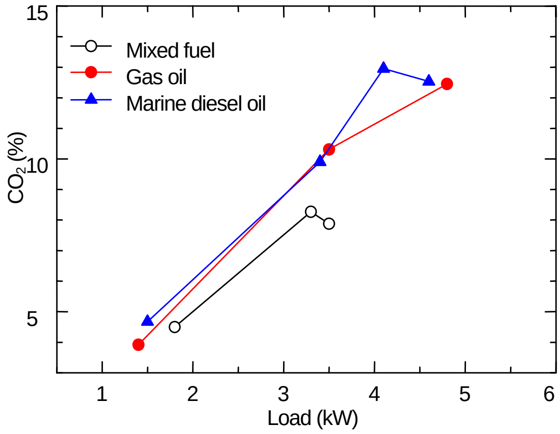


Fig.8 CO_2 Concentration in Exhaust Gas

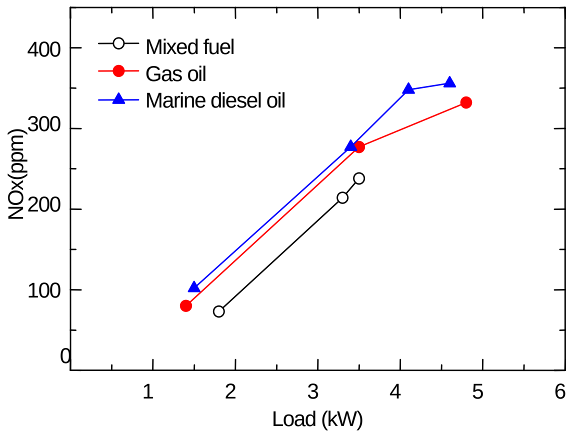


Fig.7 NOx Concentration in Exhaust Gas

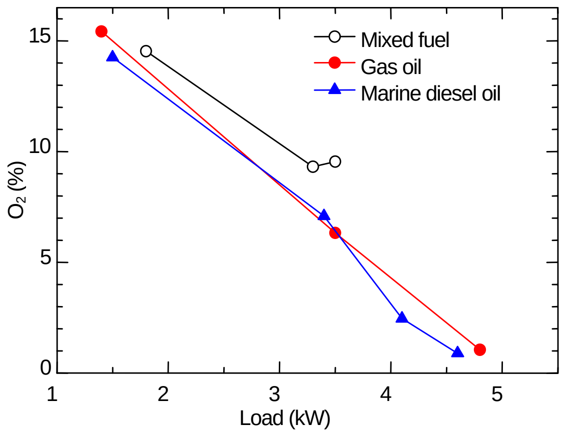


Fig.9 O_2 Concentration in Exhaust Gas

After running for a short time, the test engine has stopped in this experiment with the mixed fuel pressurizing to 1.1MPa. This is because DME causes the decompression boil in the state below the maximum vapor pressure along with the rise of the temperature of the engine, and the vapor lock happened in the fuel pump. Actually, the bubble was confirmed while running the engine in the upper part of the fuel pump.

The leakage of the fuel in the influence of poor lubricity in DME (wear-out of the nozzle needle and the plunger) was not seen. It is thought that the viscosity increases by the mixture with A-heavy oil (Marine diesel oil). However, it is necessary to examine for further parameters such as a change in mixing ratio and a longer operation duration.

5. Conclusion

It is concluded that the ignition of fuel became better in case of mixing DME and A-heavy oil (Marine diesel oil) due to its higher cetane number and better fuel atomization. The viscosity of mixed fuel also becomes higher. Thus, it is assumed that the leakage of fuel will be minimized due to the mixing of DME with A-heavy fuel oil (Marine diesel oil).
But in this study, the experimental data was limited to a small range. The running time duration of test engine was also very short. For further study, the pressure of mixed fuel must be raised and cooling of the fuel pump will be needed. Moreover, a mixing ratio of DME and A-heavy oil (Marine diesel oil) should be varied with longer test time.

6. Acknowledgment

Authors would like to express special thanks to the Ministry of Education for giving the grant in aid (Young Research (B), 14750726) to conduct this study.

References

(1) Ichikawa et al., Technology in Usage of Natural Gas, NTS, (2001), pp.477-478, pp.482-485.
(2) Kajitani, Journal of JIME, Vol.37 No.2, (2002-2), pp.86-92.

Question and Answer

Question 1

In the diagram of the ignition delay of each fuel, it is compared based on the time duration. How will it be when it is compared based on the crank angle?

Answer 1

It is shown that the ignition delay based on the crank angle indicates same trend, since the engine speed was kept constant for all experimental conditions. The ignition delay based on the time is shown in Figure A-1.

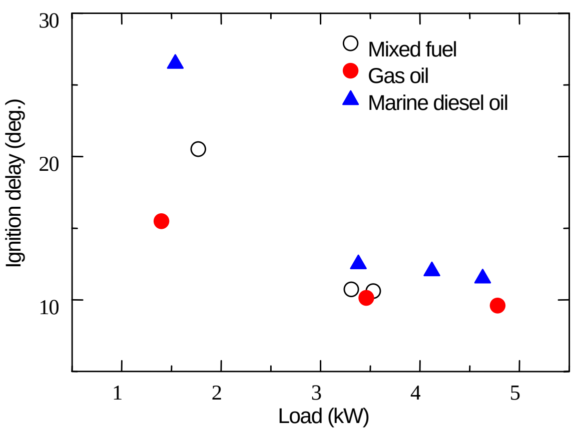


Fig.A-1 Ignition Delay Based on Time Duration

Question 2

As the demerit of DME, it is noted that the deterioration of the seal materials such as rubbers exits. Is there any deterioration or erosion in your experiments?

Answer 2

The deterioration of flow valve was observed, and it was replaced with the chemical-resistant valve (Kalrez). However, about other parts, such as a fuel pump, it has not checked yet. Although it is expected by having mixed A-heavy oil (Marine diesel oil) that the degree of degradation becomes loose, as long as DME is mixed, degradation is considered to be not avoidable for the present condition.

Question 3

Do you think that DME is dissolving in A-heavy oil (Marine diesel oil) completely under these conditions? (At the atmospheric temperature and pressure, the ethanol can dissolve in A-heavy (Marine diesel oil) while the methanol does not dissolve and make an emulsified fuel.)

Answer 3

We think the composite fuel to be dissolution. The mixed fuel of DME and A-heavy oil (Marine diesel oil) was kept in the airtight container and there was no separating appearance at the visual check level after 24 hours.