

A Study of an HCCI Engine Operating on a Blended Fuel of DME and Methane

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ABSTRACT

In this study, experiments were conducted using a blend of two types of fuel with different ignition characteristics. One was dimethyl ether (DME) that has a high cetane number, autoignites easily and displays low-temperature oxidation reaction mechanisms; the other was methane that has a cetane number of zero and does not autoignite easily. A mechanically driven supercharger was provided in the intake pipe to adjust the intake air pressure. Moreover, flame light in the combustion chamber was extracted using a system for observing light emission that occurred in the space between the cylinder head and the cylinder and in the bore direction of the piston crown. The results of previous studies conducted with a supercharged HCCI engine and a blended fuel of DME and methane have shown that heat release of the hot flame is divided into two stages and that combustion can be moderated by reducing the peak heat release rate (HRR).

As a result of this experiment, the shape of the heat release in hot-flame being greatly influenced by the equivalence ratio change. It is inferred from the results that engine operation should be possible in the high load region while avoiding the occurrence of knocking.

INTRODUCTION

The growing severity of global environmental issues in recent years, including air pollution and the depletion of fossil fuels, has made it necessary for internal combustion engines to achieve higher efficiency and lower exhaust emission levels. Homogeneous Charge Compression Ignition (HCCI)⁽¹⁾ engines have been the subject of extensive interest and research as a combustion system capable of attaining higher efficiency and cleaner exhaust emissions for meeting these requirements. HCCI engines can achieve lean combustion that exceeds the lean flammability limit. In addition, the fuel concentration distribution in the cylinder shows less nonuniformity because a premixed mixture of fuel and air is inducted into the cylinder. These characteristics support high efficiency while simultaneously reducing particulate matter (PM) and nitrogen oxide (NOx) emissions to attain cleaner exhaust

gas⁽²⁾. However, when the ignition timing is advanced, HCCI combustion proceeds rapidly and tends to result in knocking⁽³⁾⁽⁴⁾ or other abnormal combustion conditions. Conversely, because combustion is induced by autoignition, retarding the ignition timing tends to result in misfiring, as a sufficient increase in temperature is not obtained by compression of the mixture by piston motion. These are HCCI combustion issues that have yet to be resolved.

This study investigated methods of moderating HCCI combustion for the purpose of suppressing knocking and other undesirable combustion characteristics during high-load operation. Methods of moderating the combustion process include the application of supercharging or the use of a blended fuel composed of components having different ignition characteristics. Our previous studies have shown that the use of a blended fuel of dimethyl ether (DME) and methane⁽⁵⁾, which have different ignition characteristics⁽⁶⁾, along with the application of supercharging results in two-stage heat release that is effective in suppressing the peak heat release rate⁽⁷⁾⁽⁸⁾. The present study focused on the overall equivalence ratio in a supercharged HCCI engine⁽⁹⁾ when operated on a two-component fuel blend. An investigation was made of the effect of two-stage heat release on moderating the hot flame.

Table 1 Test engine specifications

4-cycle Air-cooled Diesel Engine	
Number of Cylinders	1
Bore × Stroke	76 × 66 mm
Displacement	299 cm ³
Compression Ratio	11.5 : 1
Engine Speed	1400 rpm
Valve Arrangement	OHV
Valve Overlap	0 deg.

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EXPERIMENTAL EQUIPMENT AND PROCEDURE

A schematic diagram of the experimental system used in this study is shown in Fig. 1. The specifications of the test engine are given in Table 1. A four-cycle air-cooled single-cylinder diesel engine was used that was operated at a constant engine speed of $N = 1400$ rpm. The intake air temperature⁽¹⁰⁾ was varied by means of a heater and an intercooler installed in the intake pipe, and the intake air pressure was varied by using a mechanically driven supercharger. The tappet clearance was adjusted so that there was zero valve overlap in order to minimize the amount of fresh air that was blown out through the exhaust valve by supercharging. A quartz crystal pressure transducer was installed in the cylinder head to measure the cylinder pressure.

A quartz window was provided near the top of the cylinder block for observing the combustion flame in the cylinder. As illustrated in Fig. 2, combustion flame light⁽¹¹⁾ in the bore direction was extracted, introduced into a monochromator via an optical fiber cable and separated at a wavelength of 395.2 nm. This wavelength is part of the bandwidth that displays a continuous spectrum of strong light emission produced by the recombination reaction of carbon monoxide (CO) and oxygen (O) atoms and known as CO-O glow. These atoms are the principal components of the light emission that occurs in hot flame reactions⁽¹²⁾. The separated light was detected using a photomultiplier in order to obtain the light emission intensity.

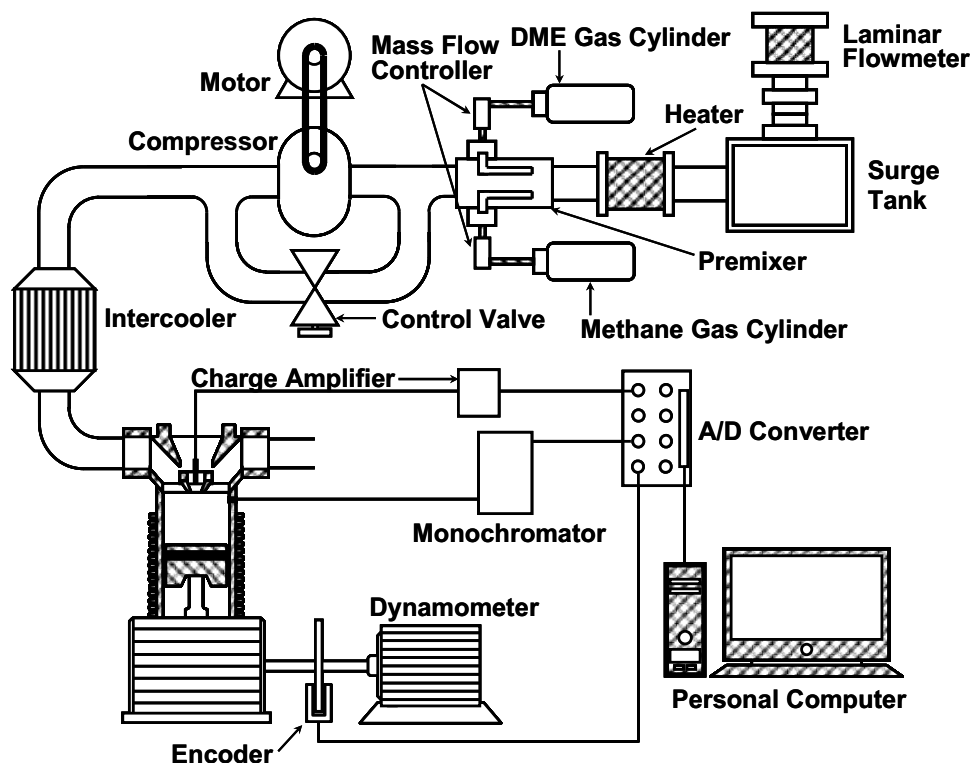


Fig. 1 Configuration of experimental equipment

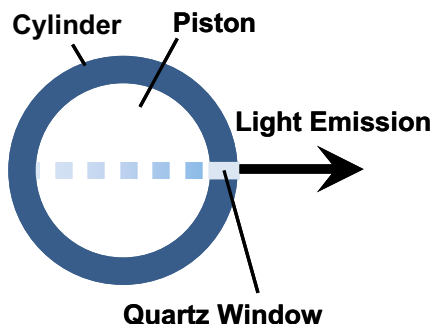


Fig. 2 Configuration of light emission measurement system

The test fuels used in this study were blends of DME and methane having the properties shown in Table 2⁽¹³⁾. Because DME has a high cetane number, it is conducive to autoignition and has a low-temperature oxidation mechanism⁽¹⁴⁾⁽¹⁵⁾. It can be synthesized from a wide variety of raw materials and tends not to produce soot when combusted. Additionally, it liquefies more easily than propane, giving it an advantage with respect to transport. Because of these features, it is expected to be used as an alternative fuel in the future.

Methane, on the other hand, has the characteristic that it does not autoignite easily because it has a cetane value of zero. It is a principal component of natural gas and is expected to be used as a fuel that produces a low level of carbon dioxide emissions. The flow rates of DME and methane were regulated by mass flow controllers. The fuels were injected into the intake pipe and premixed before being supplied to the test engine.

EXPERIMENTAL RESULTS AND DISCUSSION

EFFECT OF DME/METHANE BLENDED FUEL ON MODERATING COMBUSTION UNDER A LOW SUPERCHARGING PRESSURE WITH METHANE'S SHARE OF THE INJECTED HEATING VALUE BEING 40%

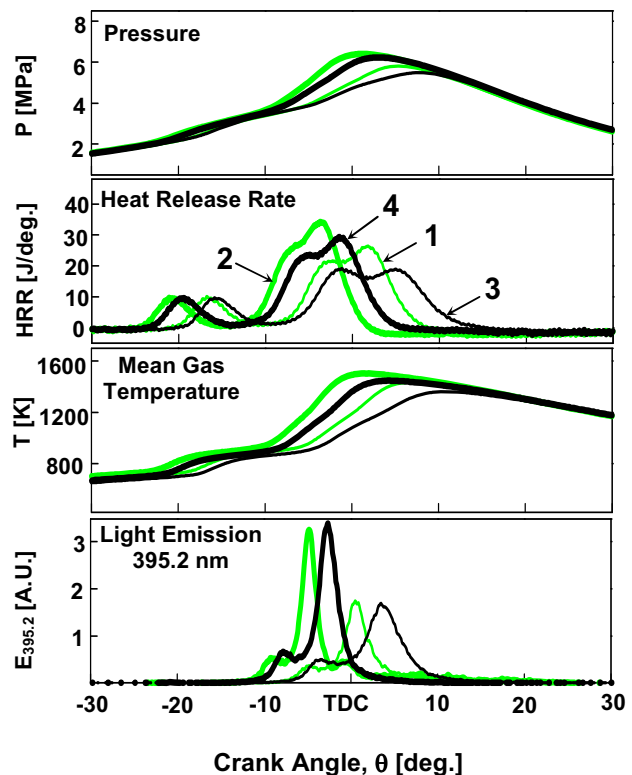
An experiment was conducted in which methane's share of the injected heating value γ_{CH_4} was kept constant at 40%, and the ignition timing was varied by varying the intake air temperature under an intake air pressure of $P_b = 140$ – 160 kPa. Figure 3 shows the results measured for two total equivalence ratios of $\phi_{total} = 0.31$ and 0.34 . From the top, the figure shows the cylinder pressure P (MPa), heat release rate HRR (J/deg.), mean in-cylinder gas temperature T (K), and light emission intensity $E_{395.2}$ at a wavelength of 395.2 nm as a function of the crank angle θ (deg.) along the horizontal axis.

Under a condition of a retarded ignition timing (waveforms 1 and 3 in Fig. 3), the HRR waveforms clearly show that heat release of the hot flame occurred in two stages under both equivalence ratios. With an advanced ignition timing (waveforms 2 and 4 in Fig. 3), the profiles of the HRR waveforms of the hot flame exhibit differences ascribable to the different total equivalence ratios used. For the higher total equivalence ratio of $\phi_{total} = 0.34$ (waveform 2), the HRR waveform of the hot flame shows an increase in heat release in the latter half and the profile has nearly a single-stage heat release pattern. In contrast, with the lower total equivalence ratio of $\phi_{total} = 0.31$ (waveform 4), the HRR waveform of the hot flame displays a two-stage heat release pattern that is divided into first and second stages.

An examination of the light emission intensity waveforms measured at 395.2 nm indicates that light emission occurred in two stages at this wavelength under the condition where two-stage heat release of the hot flame occurred. This result suggests that lowering the total equivalence ratio caused the hot-flame heat release to occur at two different times, producing a first-stage and a second-stage heat release. This implies the possibility of controlling the peak HRR.

Table 2 Test fuel properties

Fuel	DME	Methane
Molecular Formula	CH_3OCH_3	CH_4
Cetane Number	>55	0
Auto-ignition Temperature [K]	623	905
Lower Heating Value [MJ/kg]	28.8	50.3
Stoichiometric A/F Ratio [kg/kg]	9	16.9
Low Temperature Oxidation Reactions	Yes	No



Engine Speed, N		1400 rpm	
Intake Pressure, P_b		140 ~ 160 kPa	
Methane's Share of Injected Heating Value, γ_{CH_4}		40%	
Ignition Timing, θ_{ign}		Retarded	Advanced
		(Intake Air temperature, T_{in})	
Total Equivalence Ratio, ϕ_{total} (Injected Heating Value, Q_{in})	0.34 (430 J/cycle)	1 (330 K)	2 (353 K)
	0.31 (425 J/cycle)	3 (333 K)	4 (353 K)

Fig. 3 Effects of ignition timing and lower equivalence ratio on moderating combustion under low supercharging pressure