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Effects of valve events on the engine efficiency in a homogeneous charge compression ignition engine fueled by dimethyl ether

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ABSTRACT

Combustion characteristics of a homogeneous charge compression ignition (HCCI) engine were investigated with regard to the residual gas, i.e. internal exhaust gas recirculation (IEGR), by changing the intake and exhaust maximum opening points (MOP) and the exhaust cam lifts. Three different exhaust camshafts were used and had 2.5 mm, 4.0 mm and 8.4 mm exhaust valve lift. In-cylinder gas was sampled at the intake valve immediately before ignition to measure the IEGR rate. The heat release, fuel conversion efficiency and combustion efficiency were calculated using the in-cylinder pressure and composition of exhaust gases to examine the combustion features of the HCCI engine. The negative valve overlap (NVO) was increased as exhaust valve lift was reduced. Longer NVO made an increased IEGR through exhaust gas trapping. The IEGR rate was increased as the exhaust valve timing advanced while it was affected more by exhaust valve timing than by intake valve timing. Combustion phase was advanced by lower exhaust valve lift and early exhaust and intake MOP. It was because of higher amount of IEGR gas and effective compression ratio. The fuel conversion efficiency with higher exhaust valve lift was higher than that with lower exhaust valve lift. The late exhaust and intake MOP made the fuel conversion efficiency improve.

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1. Introduction

Dimethyl ether (DME) is being considered as an alternative fuel for the compression ignition (CI) engine because of its soot-free combustion [1,2]. Huang et al. [3] reported that the injection duration with DME is a longer than that with diesel. And they found DME engine had lower peak pressure and noise than diesel engine through the study about CI engine fueled with DME compared to that with diesel. Yoon et al. [4] compared the effect of pilot injection on DME CI engine with diesel engine and reported that the pilot injection in DME engine made hydrocarbon (HC) and carbon monoxide (CO) reduce without increasing nitrogen oxides (NOx) emission while the pilot injection in diesel engine made nitrogen oxides increase. DME is a liquefied gas with similar handling characteristics to those of liquefied petroleum gas (LPG) [5] and can be produced from natural gas, coal, methanol, and biomass [6]. DME is a high cetane-numbered fuel similar to diesel, has no double C–C bonds, and contains oxygen molecules (around 35% by mass), which oxidize intermediate soot product. This fuel is easily evaporated and mixes well with air so that rich regions are avoided, leading to soot-free combustion. With a properly designed DME injection and combustion system, NOx emissions can also meet ultra low emission vehicle (ULEV) limits [7]. An engine can be operated more quietly using DME because the ignition delay of DME in a CI engine is shorter than that of diesel, resulting in rapid premixed burning. Under the usual engine operating conditions, the evaporation rate of DME is two or three times faster than that of diesel [2,8–10]. It is one of the reasons why many researchers apply DME to HCCI engine.

The homogeneous charge compression ignition (HCCI) combustion is a promising concept for applications in future automobile engines and stationary power plants. HCCI engines breathe a premixed air/fuel mixture as in a spark ignition (SI) engine, and ignition occurs without a spark plug as in a CI engine [11]. NOx and particulate matter (PM) are reduced in HCCI engines due to a lower combustion temperature and a well-mixed air/fuel mixture [11,12]. However, HCCI engines have high HC and CO emissions, which are the result of a low combustion temperature [11]. CO

Abbreviations: AC, alternating current; ATDC, after top dead center; BDC, bottom dead center; BTDC, before top dead center; CAD, crank angle degree; CI, compression ignition; CO, carbon monoxide; CO_2, carbon dioxide; DME, dimethyl ether; DOHC, double overhead camshaft; FCE, fuel conversion efficiency; GC, gas chromatograph; HC, hydrocarbon; HCCI, homogeneous charge compression ignition; IEGR, internal exhaust gas recirculation; IVC, intake valve close; IVO, intake valve open; $IMEP_{gross}$, gross indicated mean effective pressure; MOP, maximum opening point; NOx, nitrogen oxide; NVO, negative valve overlap; LPG, liquefied petroleum gas; O_2, oxygen; SI, spark ignition; PM, particulate matter; TDC, top dead center; ULEV, ultra low emission vehicle.

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Nomenclature

Symbols

C	carbon
L2.5	exhaust camshaft which has 2.5 mm valve lift and 140 crank angle degree valve open
L4.0	exhaust camshaft which has 4.0 mm valve lift and 180 crank angle degree valve open
L8.4	exhaust camshaft which has 8.4 mm valve lift and 228 crank angle degree valve open
m_{fuel}	dimethyl ether mass
P	cylinder combustion pressure
Q_{ch}	fuel chemical energy release
Q_{ht}	heat transfer energy
Q_{LHV}	lower heating value of the fuel
Q_{HV_i}	Lower heating value
V	cylinder volume
W_i	work done on the piston
x_i	mass fraction
$(\bar{x}_{CO_2})_C$	CO_2 mole-concentration in the sampled gas
$(\bar{x}_{CO_2})_E$	CO_2 concentration in the exhaust gas
γ	specific heat ratio
η_c	combustion efficiency

Subscripts

a	air
f	fuel

emission is an index of incomplete combustion [13] originating from the lack of oxidation reaction during the expansion stroke. The HCCI engine uses spontaneous ignition, which is governed primarily by chemical kinetics with the premixed air/fuel mixture during the compression process. The basic characteristics of the HCCI engine, such as its low cyclic variation and flame propagation, have been studied by previous researchers [14,15]. Its high combustion pressure and high rate of pressure increase are due to simultaneous auto-ignition and limited engine operation [11,16]. Jang et al. [17] showed the improvement of DME HCCI engine performance by direct injection and exhaust gas recirculation.

Internal exhaust recirculation (IEGR) gas, i.e. residual gas from previous cycle, has a high temperature and can promote the auto-ignition in HCCI engines [18–20]. Studies have assessed the combustion characteristics of gasoline fuel in an HCCI engine by adjusting the compression ratio variation, intake temperature, and negative valve overlap (NVO) [16,19]. The in-cylinder charge temperature increases as IEGR rates increase, which is the reason why the auto-ignition timing is advanced in HCCI engines. In these systems, heat release rates are lower on account of the larger amounts of exhaust gas retained in the cylinder because the gas acts as a dilutant [21,22].

This study examined the effects of intake and exhaust maximum opening points (MOP) and exhaust valve lift on DME HCCI combustion. The effects of the exhaust valve profile and the intake and exhaust valve timing on the IEGR rate and HCCI combustion fueled by DME were investigated. Measurement of the IEGR rate was performed through an in-cylinder gas sampling method. The heat release, combustion efficiency, and fuel conversion efficiency were analyzed to compare the effects of the intake and exhaust valve timing and of three different exhaust camshafts on the combustion features and efficiency.

2. Experiments

2.1. Experimental apparatus

Fig. 1 shows a schematic diagram of the experimental apparatus used in this study. The detailed specifications of the test engine are presented in Table 1. The engine was a four-stroke, water-cooled, single-cylinder double overhead camshaft (DOHC) engine. The engine speed and load were controlled by an alternating current (AC) dynamometer (82 kW, Unico Co.). DME fuel injector (Denso Co.) was placed upstream – 30 cm away from the intake port – to

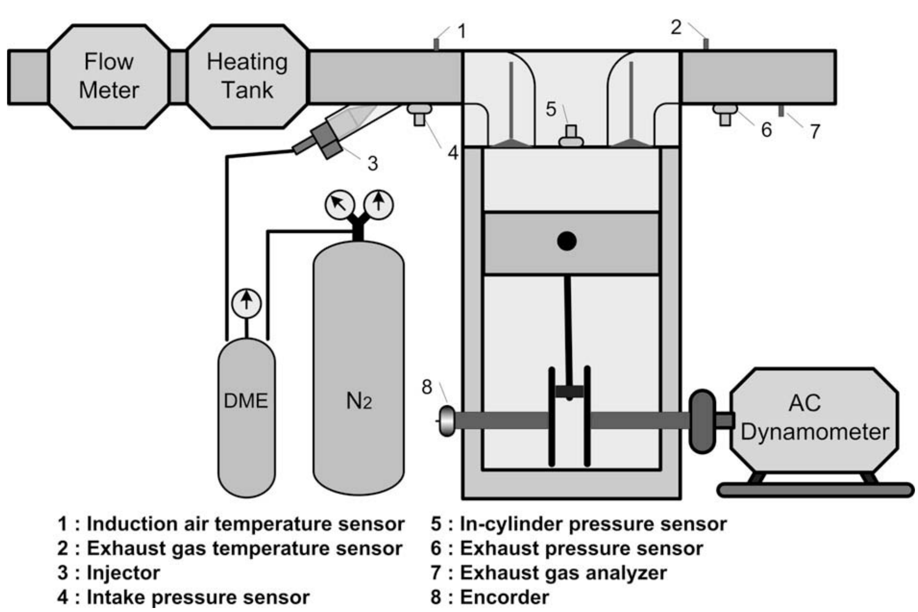

Fig. 1. Intake and exhaust valve profile.

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