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The investigation about the effects of thermal stratification in combustion chamber on HCCI combustion fueled with DME/*n*-Butane using Rapid Compression Machine

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ABSTRACT

The HCCI combustion mode poses its own set of narrow engine operating by knocking. In order to solve this, inhomogeneity method of mixture and temperature is suggested. The purpose of this research is to get fundamental knowledge about the effect of thermal stratification on HCCI combustion of DME/*n*-Butane–air mixture. The temperature stratification is made by buoyancy effect in combustion chamber of RCM. The analysis items are pressure, temperature of in-cylinder gas and combustion duration. In addition, the structure of flames using the two dimensional chemiluminescence's images by a framing camera are analyzed. Under stratification, the LTR starting time and the HTR starting time are advanced than that of homogeneous. Further, the LTR period of homogeneous conditions became shorter than that of the stratified conditions. With the case of homogeneous condition, the luminosity duration becomes shorter than the case of stratified condition. Additionally, under stratified condition, the brightest luminosity intensity is delayed longer than at homogeneous condition.

1. Introduction

Homogeneous Charge Compression Ignition (HCCI) combustion is the process in which a homogeneous pre-mixture is auto-ignited through compression. The unique property of HCCI makes possible the combustion of very lean or dilute mixtures. As a result, the combustion temperatures become low, which dramatically reduce engine-out NO_X emissions. Also, unlike the conventional diesel combustion, the charge is well mixed, that means PM emissions can be very low, while still providing high diesel like efficiencies. Moreover, dilution levels are high enough that the engine is operated essentially un-throttled, which results in significantly reduced pumping works [1,5,14]. In spite of those advantages, HCCI engine has a high pressure-rise rate (PRR) during combustion, making it critical to the high-load operating limit of this engine by knocking. At high-load HCCI operation is typically limited by an excessive PRR during combustion and the resulting engine knock [4,13]. The maximum PRR depends on the peak pressure. In order to solve this, it was suggested to use mixture inhomogeneity method [3,8,15,9] and thermal stratified method [10,16,11]. These inhomogeneities are qualities of real engine from several sources, such as; uncompleted fuel/air mixing, fuel boiling point, EGR, heat transfer on cylinder wall, and gas flow. Because these various factor effects on HCCI combustion, it is impossible to check combustion phenomena quantitatively. The purposes of this research are to get fundamental knowledge about the effects of thermal stratification and fuel strength stratification on HCCI combustion using Rapid Compression Machine (RCM).

2. Experimental method

2.1. Rapid Compression Machine

The combustion chamber of the Rapid Compression Machine (hereafter RCM) used in this study is shown in Fig. 1. This equipment is duplicated single diesel type compression cycle after the combustion process, which is carried out in the environment of constant volume – high temperature and high pressure. The advantages of making fundamental investigation of HCCI combustion in a RCM, rather than in a reciprocating engine, arise through the simplification of the mechanical system. For example, the gaseous charge permitted in a RCM is premixed at molecular level, is similar to engine with a normal intake system for vaporizing liquid fuels. Moreover, it was recently found that chemiluminescence at the condition of existence of residual gas is different from the condition of nonexistence of residual gas [7]. The areas in which chemiluminescence does not occur are not observed. Because the combustion chamber lies in the horizontal direction, the temperature distribution is easily made by buoyancy effect. The interaction between the chemistry and the temperature field resolved from

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Nomenclature

P	pressure (MPa)
PRR	pressure rise rate (MPa/ms)
RCM	Rapid Compression Machine
T	temperature (K)
t	time (ms)

Subscripts

HTR	high temperature reaction
LTR	low temperature reaction
c	combustion
0	initial time
$t_{\mathrm{LTR\ start}}$	LTR starting time
$t_{\mathrm{LTR\ end}}$	LTR end time
$t_{\mathrm{HTR\ start}}$	HTR starting time
$t_{\mathrm{HTR\ 50\%}}$	HTR 50% time
$t_{\mathrm{HTR\ end}}$	HTR end time
t_{shoot}	HTR shooting time

this distribution is fundamental to the understanding and interpretation of the performance of fuels in engines. Furthermore, there is no previous cycle, which could reduce effects of residual gas and lubrication oil that can be ignored. Figs. 1 and 2 and Table 1 show the specification of an optically accessible RCM. This RCM can be separated by driving parts and the combustion chamber. With the driving parts, air–hydraulic pressure were used to drive the RCM. Air pressurizes the accumulator and trigger. Pressures of the accumulator reach 0.24 MPa and the tester opens the trigger. After trigger time that is about 1 s, the aluminum plate and piton body are moved by the trigger air.

Before reaching TDC, the piston bodies decelerate due to the oil and air damper and then come to a halt. However, its compression speed is low. The maximum speed of the base engine is 400 rpm; the average speed during base engine piston compression is 320 rpm. The quartz window at the cylinder head and the fuse box make the optical measurement possible. The piston stroke for compression is 692.3 mm, the compression ratio is 14.6:1 and the compression duration is 200 ms. The combustion chamber has the diameter of 145 m, surrounded with 48 mm deep pancake type bowl area. The final combustion chamber volume was about 7.93×10^{-4} m^3. The combustion chamber wall and the air supply line are heated to control the initial temperature of fuel–air mixture. In-cylinder gas pressure is measured using piezoelectric pressure transducer (Kistler model 6123) with charge amplifier, and is recorded on a computer with data logger (TEAC DRX-2a) after amplification through charge amplifier (Kistler model 5001). The displacement of piston is measured using a rotary encoder (Onosokki Inc. RP-432Z) attached in the piston body. The history of combustion volume and the in-cylinder gas pressure can be calculated from the measured displacement and the in-cylinder gas pressure. The P–V diagram can be drawn by a pressure history. The combustion chamber lay in the horizontal direction, the temperature distribution created vertical direction. At the combustion chamber and cylinder head, the cylinder head was fitted with quarts window (145 mm (diameter) × 40 mm (thick)). This window could take the chemiluminescence imaging by head view of the chamber cross-section.

2.2. In cylinder gas temperature distribution

To investigate the spatial temperature distribution in the combustion chamber of RCM, a thermocouple type temperature measurement has been used. Seven thermocouples can measure the seven points temperatures simultaneously. Fig. 3 and Table 2 show the in-cylinder gas temperature measurement device. These

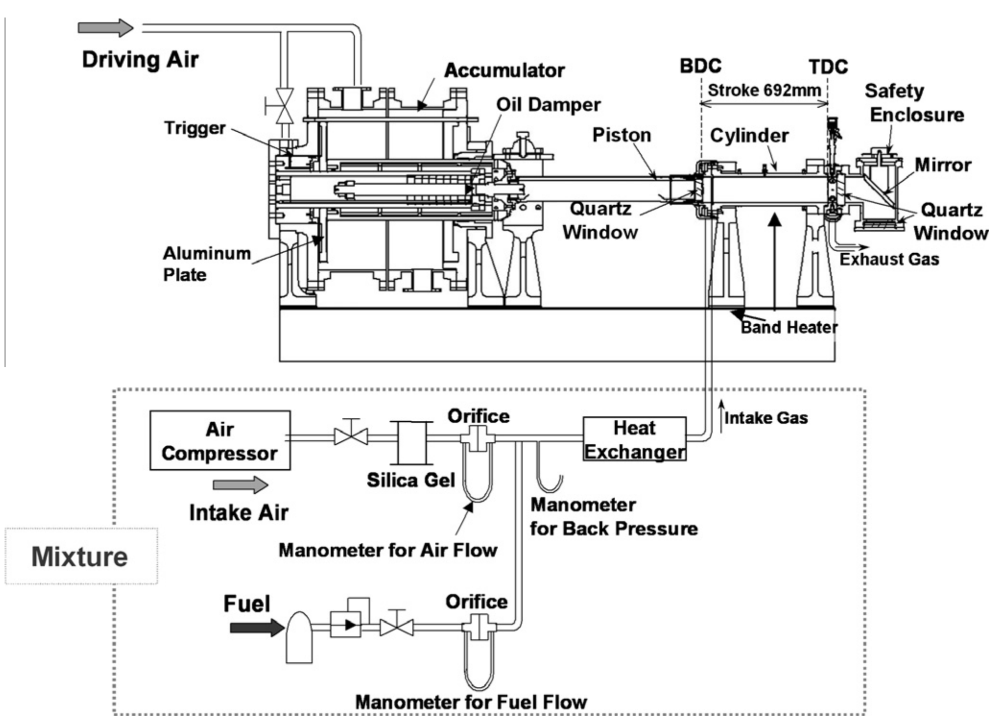

Fig. 1. Rapid Compression Machine.