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Flame temperature distributions of biodiesel fuel in a single-cylinder diesel engine

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ABSTRACT

An experimental investigation was conducted on the effect of injection timings and pressure on flame temperature of biodiesel. To estimate flame temperatures accurately during the combustion processes, an optical HSDI diesel engine composed of an endoscope and a high-speed CCD camera was used. In addition, the AVL-ThermoVision software allowed measurement of discrete flame temperatures from images taken during the combustion processes. NOx and soot concentration, which are directly related to the flame temperature, were also measured using exhaust emission analyzers, in order to study the correlation between emissions characteristics and the temperature under various injection timings.

The results of this study show the characteristics of flame temperature values and distribution for biodiesel and ULSD fuel owing to the difference of their physical properties and injection strategies. Additionally, the study of high pressure injection was performed under the same conditions. When the injection pressure increased, more homogeneous combustion was observed.

Nomenclature

ATDC	after top dead center
BMEP	brake mean effective pressure
BTDC	before top dead center
CA	crank angle
CI	compression ignition
deg.	degree (°)
DI	direct injection
DOHC	double-overhead cam
ECU	engine control unit
EGR	exhaust gas recirculation
HSDI	high speed direct injection
PDPA	phase Doppler particle analyzer
$P_{inj.}$	injection pressure
SMD	Sauter mean diameter
SOI	start of injection
TDC	top dead center
ULSD	ultra-low-sulfur diesel

1. Introduction

Compression ignition (CI) engines have been widely used in a variety of vehicles, from high-duty trucks to light-duty vehicles such as passenger cars. Recently the demand for diesel-fueled CI engines is increasing due to their higher power output and fuel economy compared to gasoline engines. However, combustion using diesel fuels results in noxious exhaust emissions such as carbon monoxide (CO), carbon dioxide (CO_2), unburned hydrocarbon (UHC), and nitrogen oxides (NOx). To reduce the pollutant emissions of diesel engines, biodiesel has been extensively used as an alternative fuel in CI engines. Biodiesel has many benefits as an alternative fuel for CI engines, such as lower UHC, CO emissions. In addition, due to its oxygen content, biodiesel has reduced soot emissions compared to regular diesel fuel [1–5,8].

Due to these attractive advantages, a lot of research on the effects of biodiesel combustion has been conducted, using various methods. Wang et al. [6,7] studied about spray characteristics of biodiesel fuels under ultra-high injection pressure and investigated the effects of biodiesel physical properties on spray and combustion, experimentally and analytically. Lee et al. [8] performed spray and combustion tests on biodiesel-blended fuel. They observed the distribution of SMD and spray tip penetration under a variety of injection pressures using the PDPA system. In combustion tests, they measured the in-cylinder pressure and heat release rate at various injection conditions for blended fuels. Zhang et al. [9] investigated the effect of

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Table 1
Specifications of the test engine.

Description	Specification
Engine type	DI diesel engine (NA[a])
Cylinder number	1
Bore × stroke	85 mm × 90 mm
Displacement volume	510 cm^3
Compression ratio	17.1
Valves	DOHC 4
Injection system	Common-rail
Injection hole number	5
Nozzle diameter	0.18 mm
Spray angle	142°

[a] NA: Naturally-aspirated.

biodiesel-blended fuel on the NOx emissions. They found the main factors affecting NOx formation under various operating conditions such as the variation of the load, the number of injections, the injection timings, and the EGR rate.

A lot of research focuses on NOx emissions for biodiesel fuel because there is generally an increase in NOx emissions when using biodiesel [4–11]. Due to the fact that flame temperature is a considerable influence on the formation of NOx emissions [12], many researchers have tried to control for the flame temperature using various parameters. Measuring the flame temperature is important but it is difficult and complex so that flame temperature has been inferred from the heat release datum in many cases. To evaluate the flame temperature exactly, state-of-the-art measurement equipment has been introduced into the present study. Visualization system has also been developed to measure spray characteristics [13–16] and flame temperature during the combustion process. In general, combustion visualization uses the natural luminosity imaging technique, which is widely employed for studying the combustion process [17–20]. However, although it is difficult to acquire the precise flame temperature using this technique, it is possible to observe the flame distribution during combustion.

The purpose of this study is to investigate the effects of biodiesel fuel on combustion characteristics and exhaust emission characteristics compared with diesel fuel under various injection strategies. To observe combustion phenomena precisely, a visualization system, including a micro CCD camera, is introduced. For combustion imaging, bottom view images are widely used because the system is easier to install. However, there have been several challenges including speed limitations, hence a large number of studies have been conducted under lower engine speeds [20]. In the present study, to overcome

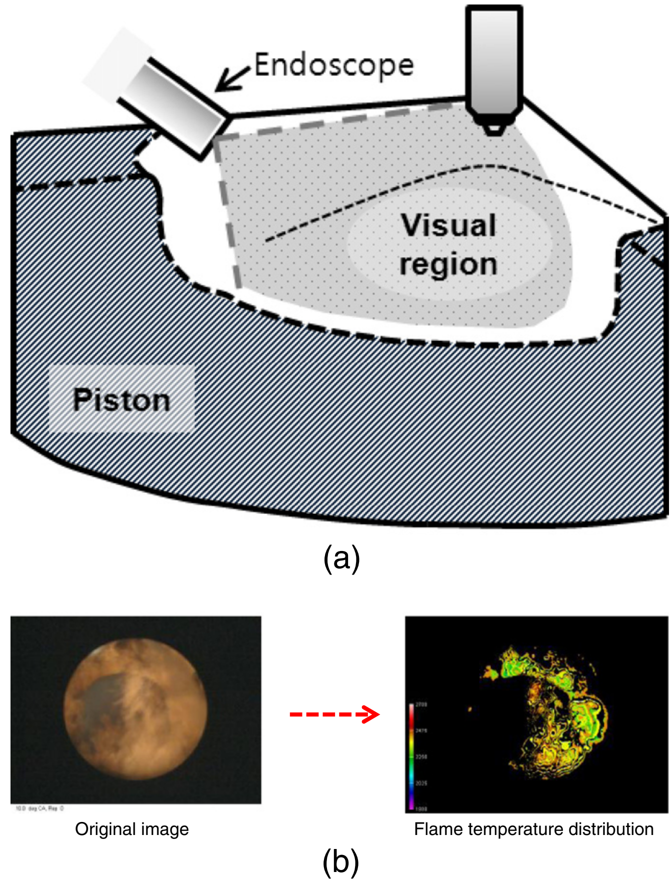

Fig. 2. (a) Visual region of endoscope. (b) Converted flame temperature distribution from an original image.

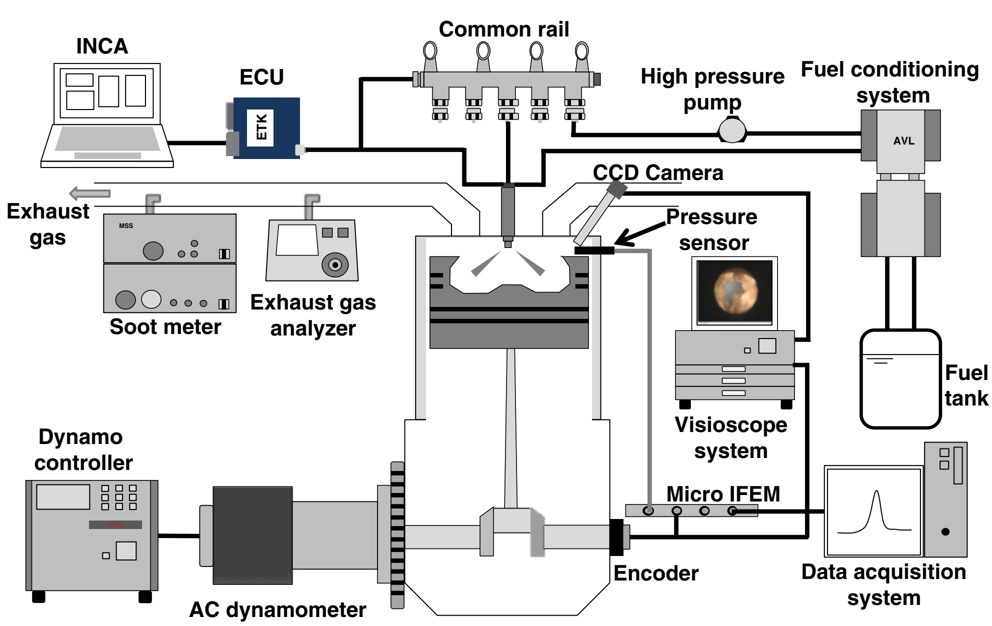

Fig. 1. Schematic diagram of a single cylinder test engine using an exhaust gas analyzer.