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Simultaneous capture of liquid length of spray and flame lift-off length for second-generation biodiesel/diesel blended fuel in a constant volume combustion chamber

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HIGHLIGHTS

- Simultaneous capture of the liquid length of spray and flame lift off length.
- First time to visualization research the interaction between flame and liquid phase.
- Combustion of second-generation biodiesel/diesel blended fuel was studied via OH*.
- Ambient oxygen concentration has little impact on the LL under reacting condition.

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ABSTRACT

Simultaneous imaging of OH* chemiluminescence and Mie scattering of fuel spray have been performed under reacting conditions in a constant volume combustion chamber aimed for a second-generation biodiesel/diesel blended fuel. Mie scattering of 532 nm laser light technique was used for the liquid fuel measurement. In order to remove the interference signal from soot radial, filtered Mie scattered light from the fuel droplet was recorded with a charge coupled device (CCD) camera. The spray liquid length and the flame lift-off length for this high cetane-number fuel were investigated under different ambient gas conditions (temperature, density, oxygen concentration) and injection pressure. Experiments showed that the spray liquid length under the reacting condition was shorter than that under non-reacting condition. The flame lift-off length was significantly influenced by the ambient gas temperature, density, oxygen concentration and injection pressure, while the spray liquid length was slightly affected by the injection pressure and oxygen concentration. The overlap between liquid fuel and combustion flame easily happened at high temperature, high oxygen concentration, and low injection pressure conditions.

1. Introduction

Aimed at the global energy crisis and environment issues, the combustion and emission characteristics of the internal combustion engine have been widely studied during the past years for continuous reduction of fuel consumption and exhaust emissions. Spray combustion is a major part of the working cycle for both the diesel engine and the advanced GDI (Gasoline Direct Injection) engine [1]. Generally speaking, conventional diesel engines have relatively high thermal efficiency but on the other hand, it also produces relatively high emissions of NO_X and soot. Recently the low temperature combustion (LTC) has been put forward and widely investigated and then been believed to be a valid way to reduce the NO_X and soot emissions simultaneously. Cooled exhaust gas recirculation (EGR) coupled with the injection strategies was adopted in the LTC mode to achieve the low flame temperature and good premixed combustion.

On the other side, all kinds of alternative renewable fuels, such as natural gas, hydrogen, bio-alcohol and ethanol, Dimethyl Ether, biogas and biodiesel, have been another good choice to meet the challenge of the energy crisis and environment pollution. Among all these alternative renewable fuels, biodiesel has attracted much more attention because it can be directly used in existing diesel engines with little or no modifications at all. And it is also the most

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representative fuel since it is produced from biological feedstock [2–5]. In many countries, the first-generation biodiesel whose main composition is Fatty-Acid Methyl Esters (FAME) has already been used in diesel engines with lower emissions. However, in recent years, the first generation biodiesel, FAME, has been found more and more drawbacks, such as using edible oils as a feedstock for oil production, low-oxidation stability, low heating value, high acidity and corrosivity and high viscosity, which has largely prevented its' further application to diesel engines. While, the second generation biodiesel totally different from the FAME generated by catalytic hydrodeoxygenation process with free of sulfur, oxygen, nitrogen and aromatics was found more appropriate and promising using in diesel engines because of a better oxidation stability, similar chemical composition with traditional fossil diesel, negligible acidity and corrosivity, High heating values and abundant non-edible feedstock [6–8]. However, little optical experimental research about the combustion characteristics of this second generation biodiesel has been performed.

The maximum axial penetration distance of liquid phase fuel for the diesel spray, named as liquid length (LL) is an important parameter which has a great influence on the combustion and emission characteristics. Proper LL contributes to a good fuel-air mixing, while too long LL may lead to a liquid fuel impingement on the piston bowl walls, which may largely increase the soot emission and reduce the engine efficiency [9,10].

Another major parameter that influences the combustion and emissions formation processes is the flame lift-off length (LOL), which is defined as the farthest upstream location of high temperature combustion. Proper LOL can promote the air entrainment of the jet more sufficiently and make the engine have a good combustion and low soot, HC emissions [10–12]. Many researches have been employed on the LL and LOL. Experiments and numerical studies show that injection pressure, ambient density and ambient temperature all have significant influences on the spray vaporization under diesel engine conditions, but most of the experiments were just conducted under normal atmospheric temperature (298 K) called a non-evaporating condition [13,14]. Some researchers also studied the spray characteristics at evaporating condition with a higher ambient gas temperature but no oxygen presence just nitrogen inside [15,16]. And the researches of the LL under reacting conditions (i.e. combustion conditions) with oxygen conducted are very little. Guillaume et al. measured the LL of diesel sprays under reacting conditions in an optical DI diesel engine and found that the fresh air close to the injector tip is the main part of the air entrainment into the jet which controls the LL [9]. Ma et al. studied the liquid-phase penetration (i.e. LL), flame lift-off location and soot volume fraction distribution of gasoline-diesel blends in a constant volume vessel and found that the liquid spray length influenced by the proportion of the gasoline in the fuels, so did the LOL [17]. More experiments were conducted to have a full insight into the spray combustion just with LOL as a medium instead of the LL. Chartier et al. investigated the influence of inter-jet spacing on the LOL for quasi-steady jet and found that the inlet temperature and inter-jet spacing had a strong interaction [18]. Siebers et al. studied the oxygen concentration effects on the LOL and found that the soot formation was essentially dominated by the air-fuel ratio which largely influenced by the location of the flame LOL [11]. Similar investigation was done by Idicheria and Pickett [19]. It was also found that LOL had a significant correlation with the ignition delay [20], and the lift-off stabilization is essentially determined by the auto ignition [21].

The LL is an important factor which affects the LOL. Meanwhile, the LOL also influences the LL. However, the relation between LOL and LL under reacting conditions is not very clear, because the visualization of the LL under reacting condition is really difficult. The soot radiation illumination is so strong that the liquid phase and the flame can't be distinguished exactly [17,20,22,23].

In this work, under low ambient oxygen concentration conditions, the LL and flame LOL were measured in a constant volume combustion chamber simultaneously under reacting conditions using second-generation biodiesel/diesel blended fuel. To get an accurate and effective LL, the LL was tested with the Mie scattering of 532 nm laser technique specially. LOL was measured via OH* chemiluminescence with an intensifier charge coupled device (ICCD) camera.

2. Experimental setup

2.1. Facilities

A high-temperature high-pressure optical constant volume combustion vessel which is able to simulate a wide range of thermodynamic conditions was used in this experiment. The schematic diagram is depicted in Fig. 1. The facility mainly includes five parts: gas intake system, exhaust system, electrical heating system, water cooling system and electrical control system. The high-pressure gas was initially inflated in the chamber (0.012 m^3) and heated by the electrical heater installed in the bottom, the gas temperature in the vessel was controlled by adjusting the electrical heater power. There are four round quartz windows at the four faces of the vessel and each of them is 100 mm in diameter and 70 mm in thickness for getting the optical access. A single-hole diesel injector with 0.18 mm in diameter was mounted at the top of the chamber. The electrical control system is a closed loop system which adjusts both the pressure in the chamber and the power of heater to obtain the expected operating conditions meeting the experimental request. This rig can work in closed circuit to observe spray evolution and combustion process either in a standard air atmosphere or with different oxygen concentration. The steady thermodynamic condition within the chamber allows a better and easier control of the test conditions.

A high pressure common rail system of Bosch was used in this experiment. The rail pressure of this common rail system can be up to 180 MPa, and can be controlled by ECTEK Calibration System. A single-hole injector with orifice diameter of 0.18 mm was used. The orifice length-to-diameter ratio is 5.36. For the injector is solenoid-activated, it opens and closes rapidly (<100 μs) and have a constant injection rate throughout the injection period. The energizing time can be set from 0 ms to 10 ms by the ECTEK Calibration System.

2.2. Optical method for LL measurements

Mie-scattering is believed to be a valid approach for measuring the LL. This technic needs a light source, a white light or a monochromatic light produced by an LED or a laser system. During the combustion, the soot particles have strong radiation, so most experiments were performed under non-combustion conditions and then the interference by the signal from the natural flame illumination can be avoided. Thomas Hülser et al. measured the LL under reacting conditions with Mie-scattering using a white light and found that the measurement was not precise [20]. To solve these problems, Mie scattering of laser-light was applied in some researches [9,24,25]. In these studies, a 532 nm or 448 nm laser was used as a light source and a corresponding wavelength band pass filter (BPF) was mounted in front of camera to isolate the elastically scattered light from other sources. In this paper, as shown in Fig. 2, the fuel liquid phase was imaged via Mie scattering of 532 nm laser sheet light but not beam light. The laser light was pumped from a 10-Hz frequency-doubled Nd: YAG laser with