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An optical study on liquid-phase penetration, flame lift-off location and soot volume fraction distribution of gasoline–diesel blends in a constant volume vessel

Liang Zheng, Xiao Ma [*], Zhi Wang, Jianxin Wang

State Key Laboratory of Automotive Safety and Energy, Tsinghua University, China

HIGHLIGHTS

- We studied soot formation characteristics of gasoline–diesel blends using LII–LEM.
- Liquid spray length decreases linearly with the increase of gasoline proportion.
- Lift-off length increases non-linearly with the increase of gasoline proportion.
- Peak soot concentration of G60 fuel jets decreases by 91% from that of the G0 case.
- First-soot location shifts from the jet edge (G0, G20, G40) to the jet center (G60).

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ABSTRACT

Liquid-phase penetration, flame lift-off location and soot volume fraction distribution of gasoline–diesel blended fuel jets (gasoline volume fraction 0%, 20%, 40% and 60%) were measured in a constant volume vessel to investigate the combustion and soot formation processes of the wide-distillation fuel. The test was conducted under a constant ambient condition ($T_a = 830$ K, $P_a = 4$ MPa) with fixed injection parameters ($d = 168$ μm, $P_{inj} = 80$ MPa). Mie-scatter imaging, OH chemiluminescence imaging along with coupled Laser Induced Incandescence (LII) and Laser Extinction Method (LEM) were used to investigate the liquid spray length, lift-off length and quantitative soot concentration, respectively. It was found that the increase of gasoline proportion in gasoline–diesel blends results in the following effects: the liquid spray length decreases with a nearly linear tendency while the flame lift-off length increases non-linearly; the general soot concentration decreases significantly and the initial soot-formation location moves downstream; the peak soot volume fraction decreases and the soot inception time increases; the initial soot point and the peak concentration region of soot shift from the periphery to the center of the jet. It was also found that the lift-off length, first-soot distance, peak soot concentration and soot inception time vary more significantly at higher gasoline proportions.

1. Introduction

Diesel engines are characterized by their high power output and low fuel consumption, while facing the problem of harmful emissions, particularly NOx and PM emissions. Researchers have been trying to achieve clean combustion in diesel fueled Compression Ignition (CI) engines with advanced combustion modes, in which the compromise between NOx/PM emissions and engine efficiency is a key issue [1–3].

Recent studies have shown that fuels with low Cetane Number (CN) and high volatility are more suitable for CI engines than diesel in terms of emissions [4–7]. Using blends of gasoline and diesel is one of the most practical ways to achieve these fuel properties. Gasoline–Diesel Blends (GDB), also named dieseline by Xu et al. [8], can be regarded as a representative of wide-distillation fuels [9]. The low boiling point, high volatility components can promote the fuel–air mixing and thus reduce PM emission, while components

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Abbreviations: NOx, nitrogen oxides; PM, particulate matter; CI, Compression Ignition; GDB, Gasoline–Diesel Blends; HCCI, Homogeneous Charge Compression Ignition; LTC, Low Temperature Combustion; PPCI, Partially Premixed Compression Ignition; SVF, Soot Volume Fraction; LII, Laser Induced Incandescence; LEM, Laser Extinction Method; ASI, After the Start of Injection; CN, Cetane Number; RON, Research Octane Number; MON, motor octane number; T_a, ambient temperature; P_a, ambient pressure; P_{inj}, injection pressure; d, nozzle orifice diameter.

[*] Corresponding author at: State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China. Tel.: +86 10 62772515.

E-mail address: max@mail.tsinghua.edu.cn (X. Ma).

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with high boiling point can ensure a stable auto-ignition, preventing the over fast heat release rate. As a result, investigations into the effects of GDB on the engine performance and emissions have drawn increasing attention. Previous studies showed that GDB are beneficial for such new combustion modes as Homogeneous Charge Compression Ignition (HCCI), Low Temperature Combustion (LTC) and Partially Premixed Compression Ignition (PPCI), because PM and NOx emissions can be reduced simultaneously with a reduced level of EGR [10,11] and the low emission operating regime can be widened [12,13]. An in-cylinder optical diagnostics on GDB showed that an increased lift-off length corresponded to a decreased soot production [14].

Park et al. [15] found that the droplet size of GDB decreased as the gasoline fraction increased due to the reduction in surface tension. Payri et al. [16] concluded that there is no major differences between diesel and gasoline for momentum flux, spray penetration and cone angle in non-evaporative conditions. However, the injection rate for diesel is higher than that of gasoline, while the needle closing speed for diesel is lower, due to the larger density and viscosity. Kim et al. [17,18] studied the spray and combustion of gasoline and diesel fuels in a constant volume chamber and also in an optical accessible CI engine. It was found that, compared with diesel, gasoline presents significantly shorter liquid penetration length, narrower spray angle, longer lift-off length and lower combustion luminosity in evaporative conditions. Currently, the fundamental research on GDB spray and combustion (including pure gasoline) are still limited.

In this study, the liquid-phase penetration, lift-off length and Soot Volume Fraction (SVF) distribution of GDB (gasoline volume fraction 20%, 40% and 60%) and the reference diesel were measured in a high-temperature high-pressure constant volume vessel, providing a comprehensive understanding of the combustion and soot formation characteristics of GDB. The effects of fuel volatility and reactivity on soot formation characteristics were also analyzed.

2. Experimental setup

2.1. Constant volume vessel

The experiments were carried out in a high-temperature high-pressure constant volume combustion vessel. The cross section of the vessel is depicted in Fig. 1. Optical access is provided by four quartz windows at each side, 100 mm in diameter and 70 mm thick. The volume of the chamber is 0.017 m^3, including the volume of heating cartridges which are installed at the bottom of the chamber. The power of the heating cartridges is 2.6 kW in total. An injector was mounted at the top of the chamber. More information of the constant volume vessel system can be found in a previous paper [19].

2.2. Optical setup

Several optical diagnostics were employed in the measurements: Mie-scatter imaging for liquid-phase penetration, OH chemiluminescence imaging for flame lift-off length, and Laser Induced Incandescence (LII) coupled Laser Extinction Method (LEM) for soot concentration distributions.

Fig. 2 shows the schematic of the optical setup for LII–LEM and OH chemiluminescence imaging. For LII measurements, the frequency-doubled (532 nm) output of a Nd:YAG laser (Quantel Brilliant B) was used. The laser beam (280 mJ per pulse, 10 Hz) was converted into a 50 mm wide, 1 mm thick laser sheet, and then directed into the vessel, passing through the axis of the fuel jet. The laser sheet has a one-dimensional Gaussian spatial profile. The spatial average laser fluence was about 0.3 J/cm^2, above the threshold (0.2 J/cm^2 for 532 nm excitation) of the "plateau region". Hence the LII signal is nearly independent of laser fluence variations and the impact of laser attenuation can be effectively reduced [20].

The incandescence signal was captured by an intensified CCD camera (Lavision Intensified Relay Optics + Imager QE) with a 90 mm lens. The camera gate was set to 55 ns and was started coincident with the Nd:YAG laser pulse. The filters used were a 440 nm short-pass filter and a 410 nm band-pass filter (FWHM 50 nm). For each fuel, natural soot luminosity images were also

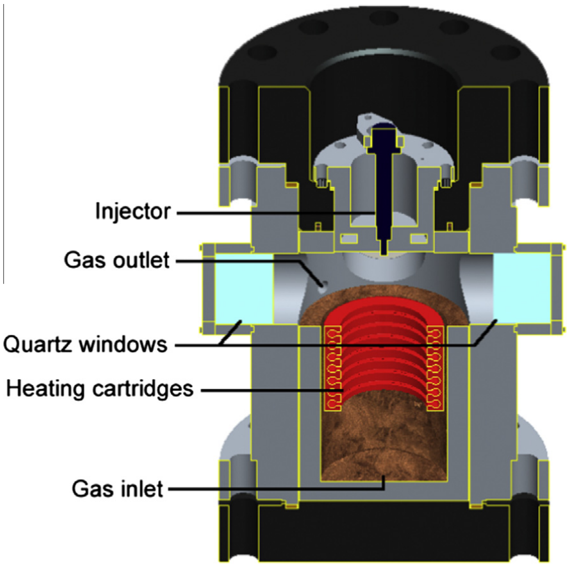

Fig. 1. Sketch of cross section of the constant volume vessel.

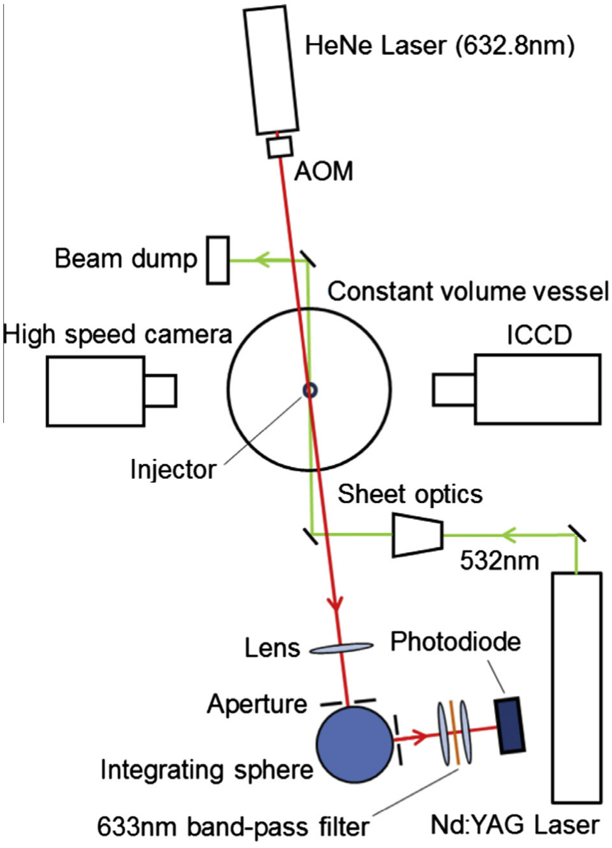

Fig. 2. Sketch of the optical setup.