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Macroscopic spray characteristics of kerosene and diesel based on two different piezoelectric and solenoid injectors

Wenbin Yu, Wenming Yang *, Kunlin Tay, Balaji Mohan, Feiyang Zhao, Yunpeng Zhang

Department of Mechanical Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore 117575, Singapore

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ABSTRACT

In this study, the behaviours like injection momentum and spray characteristics for piezoelectric and solenoid injectors were compared. With piezoelectric injector, the macroscopic spray characteristics of kerosene and diesel were investigated. The characteristic like spray penetration, spray velocity, spray angle and air entrainment were used to understand the fuel spray behaviours. The result shows that the piezoelectric injector has the advantage of faster injection response and needle opening than the conventional solenoid injector, which will enable precise and rapid injection control and must be beneficial to air–fuel mixing before ignition in a real engine. Due to the lower value of viscosity in kerosene, the injection durations for kerosene are longer than diesel. Also longer injection intervals will be needed for kerosene to realize multiple injections. Kerosene has shorter spray penetration and lower spray velocity compared with diesel, while the spray angle of kerosene is larger than diesel. Entrained air mass is a typical trade-off result of comprehensive influence of spray penetration, spray angle and charge density. Kerosene sprays get more entrained air than diesel, which means the usage of kerosene has advantage in fuel–air mixing.

1. Introduction

After the concepts of low temperature combustion (LTC), premixed charge compression ignition (PCCI) with diesel [1–3] and partially premixed combustion (PPC) with gasoline [4], researchers have proposed to integrate the advantages of gasoline and diesel fuels to get lower emissions while maintaining high thermal efficiency, dual-fuel reactivity controlled compression ignition (RCCI) [5,6] and blend fuel premixed compression ignition [7,8] are typical representatives. Most recently, a concept called wide distillation fuel (WDF) was proposed, which refers to fuels with distillation range from initial boiling point of gasoline to final boiling point of diesel. As one kind of WDF, kerosene is getting more and more researchers' attention. The measured physical and chemical properties of kerosene indicate that the density, viscosity and cetane number vary between those of diesel and gasoline, while the heat value is higher than both diesel and gasoline fuel.

Also, after the Second World War, the idea of using a single military fuel was conceived to simplify the logistic supply chain for petroleum products, which has been called single fuel concept (SFC). Kerosene, which had been used as an aviation fuel, has been considered as the SFC. Actually, quite a number of researchers have investigated the effect of kerosene in diesel engines [9–13], and it was found that kerosene, as a substitution for diesel, showed no critical limitation [9–13].

However, most studies performed so far have focused on emission measurements, which give little information about macroscopic spray characteristics for kerosene, especially by a piezoelectric injector. In this paper, based on a piezoelectric injector, the spray characteristics of kerosene are studied and compared to the conventional diesel fuel. The characteristic like spray penetration, spray velocity, spray angle and air entrainment were used to understand the fuel spray behaviours.

2. Experimental setup

Fig. 1 shows experimental set up, including constant volume spray chamber (CVSV), fuel supply and injection system, visualization system and an intelligent control system. In order to reproduce the condition in the engine combustion chamber, very high ambient density in constant volume spray chamber can be realized for spray characteristics study. For spray dynamic measurement, the constant volume spray chamber is developed to allow optical access to the whole injected fuel sprays. The ambient pressure can be up to 6 MPa under room temperature and inert nitrogen gas was used to pressurize the chamber. By changing the ambient

* Corresponding author.

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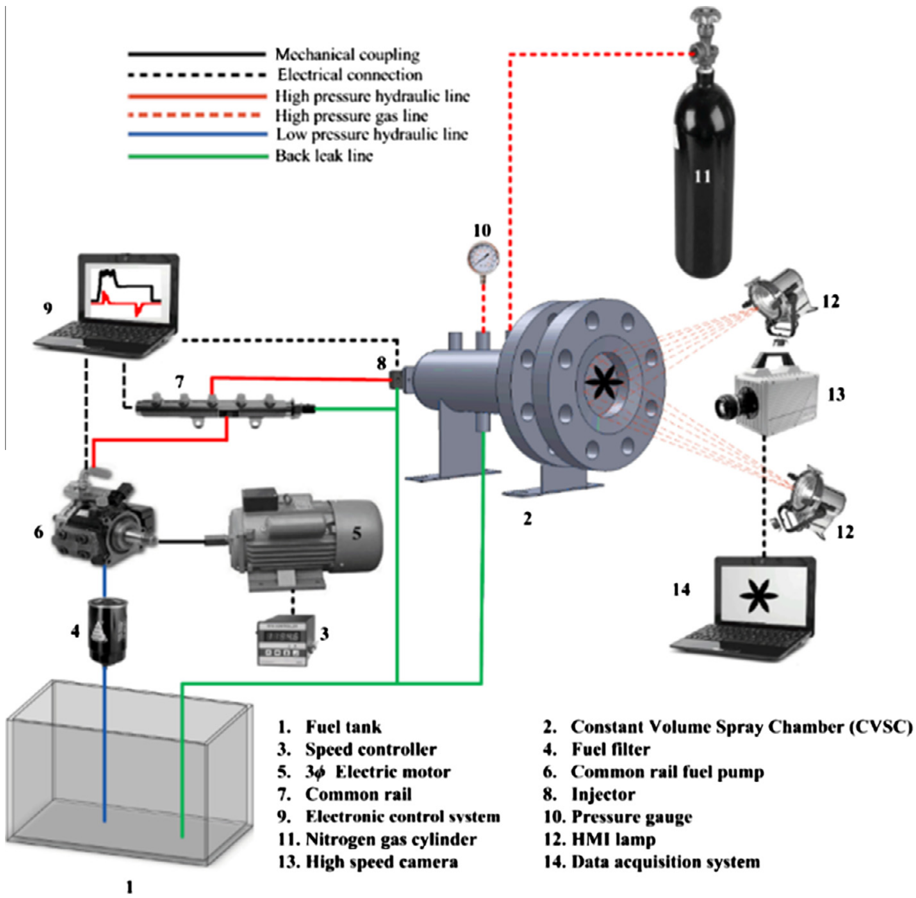

Fig. 1. Schematic of spray visualization experimental setup.

pressure, the charge density inside the chamber can be varied in accordance with the will. The chamber has a volume of 6 L. The diameter and the thickness of the optically polished quartz glass window are 150 mm and 60 mm.

A built-in-house control system for spray test was established, which is with the embedded FPGA real-time technology. Based on the control system, the excitation current and voltage can be flexibly and accurately adjusted to adapt most kinds of injectors (driven by solenoid or piezoelectric valve) and high pressure fuel pumps to realize adjustable injection timing, injection duration, injection rate, common rail pressures and multiple injections. A multifunctional data acquisition system was also established to collect experiment data such as transient and averaged spray momentum, injection rate, fuel pressure, fuel injection quantity, injection duration, and energizing current profile.

The fuel supply and injection system consists of fuel injectors, common rail, high pressure fuel pump, electric motor for driving fuel pump and high pressure fuel lines. The highest common rail pressure can be adjusted up to 200 MPa. In this study, a piezoelectric injector was used for spray study. And also the comparison between piezoelectric injector and conventional solenoid injector was carried out. The specifications of the injectors are shown in Table 1.

Table 1
Specification of injectors.

Energizing type	Solenoid	Piezoelectric
Number of holes	7	8
Angle of the spray (°)	154 ± 5	154 ± 5
Orifice diameter (μm)	138 ± 5	138 ± 5

A Photron Fastcam SA5 high speed camera was used for spray visualization. The camera sensor is 12 bit monochrome with a spatial resolution of 20 μm pixel with a minimum exposure time of 1 μs. The images are captured at 20,000 frames per second with a maximum spatial resolution of 832 × 448 pixels and temporal resolution of 50 μs. A Nikon lens (Nikkor AF 28-85 mm f/1:3:5-4:5) is installed in the high speed camera with C-mount adapter. A 400 W Hydrargyrum medium-arc iodide (HMI) lamp is used to provide illumination and also a high speed electronic ballast is equipped to limit current and voltage.

In order to quantify the macroscopic spray characteristic like spray penetration, spray velocity and spray angle, a post processing for the raw spray image was conducted in this study. The processing of spray image is similar to the one which authors used before [14–16]. Fig. 2(a) and (b) shows the processing of spray image. Firstly, the background was subtracted from the original spray images to eliminate some uniform illumination and isolate the spray. Then, the isolated images are coloured for further processing. After that, the isolated and coloured spray images are subjected to thresholding. Finally, the while/black coloured thresholding images are used for edge detection. Similar method was used by Delacourt et al. [17].

The spray momentum measurement was similar to Payri et al. [18], and the method is shown in Fig. 3. Based on principle of conservation of momentum, the momentum flux from injector nozzle can be obtained from the force which is measured by force sensor (Kistler 9207). The force sensor is piezoelectric type capable of measuring force between ±50 N with sensitivity of <±0.05 N. On