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Spray and flame characteristics of wall-impinging diesel fuel spray at different wall temperatures and ambient pressures in a constant volume combustion vessel

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ABSTRACT

The qualitative mixture concentration distributions and the flame characteristics of wall-impinging diesel fuel spray at different wall temperatures and ambient pressures were investigated in a high-temperature high-pressure constant volume combustion vessel. The techniques of laser induced exciplex fluorescence (LIEF) and flame natural luminosity imaging have been used to visualize the liquid and vapor phases of the spray and the flame development process respectively. Results reveal that, as the wall temperature increases, the vapor-rich field extends to the region close to the wall and the area of high vapor fluorescence intensity increases. However, the wall temperature only has a little influence on the liquid phase of the spray. The flame luminosity intensity increases and the ignition delay decreases as the wall temperature increases. Cases at higher wall temperature show more soot emissions, higher soot formation and oxidation rate. In the condition of P_a = 4 MPa, the fuel has evaporated completely before impinging on the wall. The flame area and height at different wall temperatures are nearly the same. The ignition position is observed near the impingement point. However, in the condition of P_a = 2 MPa, there are some liquid phase of the fuel impinging on the wall. The flame area and height increase as the wall temperature increases. The ignition position is always observed in the wall jet region. The distance between ignition position and the axis of the spray decreases as the wall temperature increases.

1. Introduction

Combustion inside internal combustion engines (IC engines) is a complex turbulent process inside a limited space. Spray-wall impingement of direct injected fuel often occurs in small-bore IC engines. As for direct injection gasoline or diesel engines, the fuel film formed on the wall after spray-wall impingement increases the mixture concentration near the wall, reduces the temperature of the mixture near the wall with the film evaporation, which leads to the generation of soot, unburned hydrocarbon (UHC) and carbon monoxide (CO) [1–4]. As a result, there exists excessive equivalence ratio region and low temperature region near the wall, which plays a significant role in affecting the thermal efficiency of IC engines and leading to the generation of incomplete combustion products.

The impact of the spray-wall interaction has become a significant subject for many researchers during the past few decades, including mixture formation [5–11], combustion and emissions [1,12–20]. The spray-wall interaction has a complex influence on mixture formation. Katsura et al. [5], Arcoumanis and Chang [6] focused on the features and the droplet size of the wall-impinging sprays under non-evaporation conditions. They found that small droplets were observed in the head vortex region. Senda et al. [7], Bruneaux [8], Zhang et al. [9] studied the wall-impinging sprays under evaporation conditions and learned that there was a low mixture concentration near the spray tip region. In addition, Cossali et al. [10], Mohammadi et al. [11] realized that the ambient gas entrainment was enhanced by spray-wall interaction. Meanwhile, combustion process and emission formation are affected significantly by spray-wall interaction. Combustion process of wall-impinging spray was studied by Dec and Tree [1], Kitasei et al. [12], Le et al. [13] in diesel engines. They found that the spray-wall impingement increased soot emissions. The low-temperature and high-temperature reactions occurred simultaneously in the head vortex region. Moon et al. [14], Gao et al. [15] and Wang et al. [16] concentrated on the influence of different types of nozzles on the wall-impinging spray flames. They concluded that both the group-hole nozzles and micro-hole nozzles improved combustion conditions and reduced soot emissions. Wang et al. [16] and Li et al. [17–19] confirmed that spray-wall impingement deteriorated the combustion

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significantly in comparison with the free spray flames, which generated more UHC and soot emissions. However, Pickett and Lopez [20] observed that soot levels were obviously lower in a wall-impinging spray flame compared to a free spray flame, which was contrary to some researchers' results [16–19]. The differences of the wall temperature among the above researches may be the reason. The wall temperature was far lower than the ambient temperature in Pickett and Lopez's work, while other researchers kept the wall temperature the same as the ambient temperature. In fact, there exists a considerable temperature gradient from high temperature gas to low temperature wall in the region near the wall inside actual engines. Different wall temperatures will certainly influence the combustion process of wall-impinging sprays. But there are few researches on the combustion characteristics of spray-wall interaction at different wall temperatures.

Therefore, in this paper, the effects of different wall temperatures on the qualitative mixture concentration distributions and the flame characteristics of wall-impinging diesel fuel sprays were investigated. In addition, this research also attempted to investigate the influences of the ambient pressure on the wall-impinging diesel spray concentration distributions and flame behaviors.

2. Experimental apparatus, methods and conditions

2.1. Experimental apparatus and methods

The experiments were conducted in a high-temperature high-pressure constant volume combustion vessel. Fig. 1 shows the schematic diagram of experimental apparatus. Four hollow windows were installed at the four sides of the vessel. Three JSG1 quartz blocks with an effective diameter of 100 mm were mounted to the three windows respectively to be used as optical windows. Two opposites of them made the laser accessible. The other one was used for acquiring images by a camera. The fourth window was obstructed by a black metal block with the same size as the quartz block. An electric heater was installed in the bottom of the vessel to heat the charged gas. Before the experiments, the temperatures in the visible tested region were measured by thermocouples at different locations and the temperature is approximately uniform (773 ± 10 K) for the ambient condition. The inlet port and exhaust port were set in the bottom of the vessel. The vessel was filled with the compressed gas from high pressure gas cylinders. The injector was installed in an adapter in the center of the top lid of the vessel. A flat wall fixed perpendicular to the injector axis was located 35 mm away from the injector nozzle tip. The temperature of the wall was adjustable by the thermal oil flowing through the pipeline inside the wall. Two thermocouples were applied to measure the ambient temperature and the wall temperature respectively. The thermocouples measuring the ambient temperature were located around 25 mm above the wall surface in order to avoid interfering with the spray and flame. The thermocouples measuring the wall temperature were located inside the wall through the radial hole of the wall. The tip of the thermocouples was located at the center of the circular wall and 2 mm under the upper surface of the wall. Before the experiments, the temperatures in different radial positions of the wall, which were 0, 10, 20, 30 mm away from the center of the wall respectively, were measured in all testing conditions. The differences among them were less than 5 K.

A common rail injection system of Bosch was used to supply the constant pressure to the injector. The injector was controlled by an injection controller (EC94821ZZ, Changzhou automotive electronic systems Co., Ltd., ECTEK). The injection timing, the injection mass and the time to take the images were controlled by a delay pulse generator (DG535, Stanford, USA). The injector used in this study was a single-hole type one and the nozzle diameter is 0.14 mm.

The technique of laser induced exciplex fluorescence (LIEF) has been used to visualize the liquid and vapor phases of the spray. Two-dimensional images presenting the qualitative concentration distribution of the liquid and vapor phases were obtained simultaneously. This technique was first applied by Melton [21] and has been successfully utilized in optical engines [22–28] and combustion vessels [29–31]. In

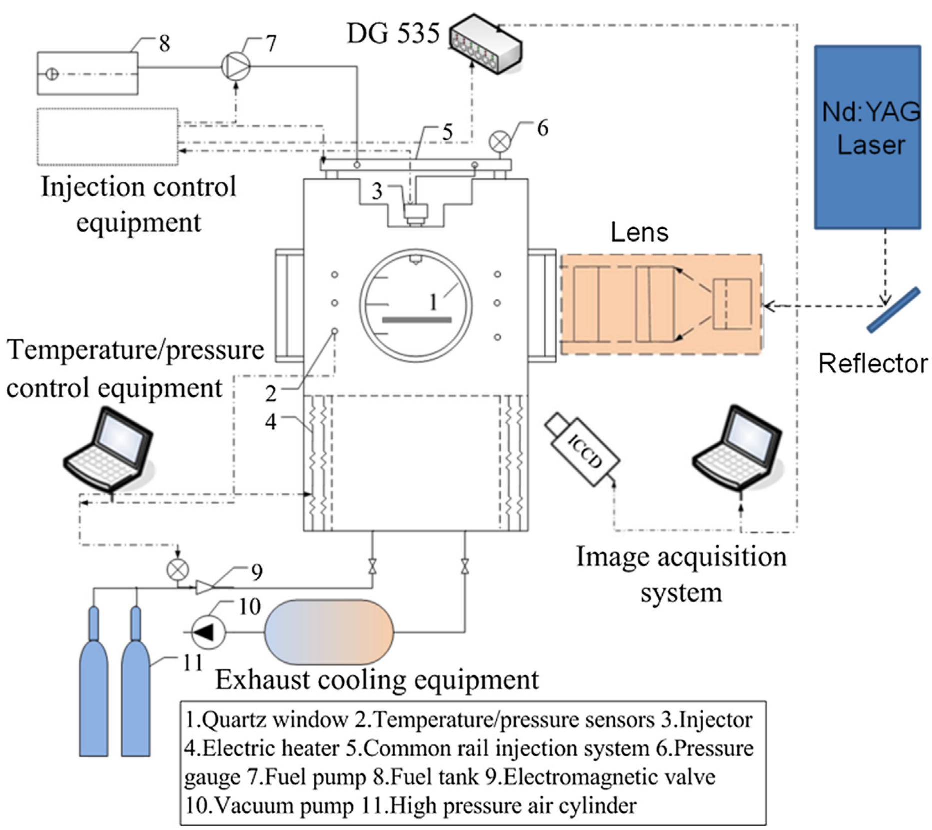

Fig. 1. Schematic diagram of the experimental apparatus.