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Experimental study on microscopic and macroscopic characteristics of diesel spray with split injection

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HIGHLIGHTS

- Near-field spray were characterized by ultra-high speed imaging.
- Far-field spray were characterized by high speed imaging.
- Microscopic characteristics were studied by PDPA.
- The novelty of split-injection strategy was investigated.

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ABSTRACT

The microscopic and macroscopic characteristics of diesel spray with split injection strategy were systematically investigated by employing ultra-high speed imaging in the near-field, high speed imaging and Phase Doppler Particle Analyzer (PDPA) techniques. It was found that for single injection there were four stages for the development of spray penetration, largely depending on injection pressure and ambient pressure. With split injection strategy, the "wake driving force" caused by higher speed of the wake of the first injection than that of periphery gas tended to distort the second split injection, whereas the 'air driving force' caused by the first split injection tended to make the second plume symmetric. Furthermore, the second split injection showed lower macroscopic penetration and spray area during the initial stage but higher macroscopic penetration and spray area at the later stage than the first injection. In addition, higher injection pressure lead to better dispersion and smaller droplets. The strong collision (both primary collision and secondary collision) caused larger droplets for split injection than for single injection. Lower effective injection pressure due to lower injector opening for split injection strategy was believed to be partly responsible for the larger droplet sizes.

1. Introduction

Multiple injection strategy tends to present better spray quality and better engine combustion performance compared with single injection [1–4]. The macroscopic spray characteristics of split injection however are thought to be complicated due to various factors involved. It was pointed out that the features of split injection strategy are special [5]. For instance, the mutual influences of split injections lead to strong unstable motion as the split injections develop, huge vortexes are enhanced by the boosted air entrainment and the coming split plumes penetrate into the former ones.

Basing on various tests with split injection strategy, Kourosh [6] reported that the first injection plume shared great similarities to the single injection plume whereas the second plume presented obvious distinctions compared with single injection. The second injection penetrated faster than the first one and the velocity difference was more apparent at the late stage of the injection. However, when the dwell period was sufficiently long, no velocity difference was found. It was argued that "cavity mode wake effect" and "wake impingement" were the two mechanisms that caused the higher penetration velocity for the second injection event.

For microscopic characteristics, the size and velocity of droplets can be employed to denote the atomization quality. The evaporation of spray greatly depends on droplet sizes. The spray tip presents the smallest droplets because of strong air interaction, while the tale shows the largest drops resulting from low velocity [1,2,7]. The coalescence and collision of droplets at the further positions along the plume lead to an increase of Sauter mean diameter (SMD) [1,8,9]. It is well known that enhanced atomization under high ambient pressure leads to smaller SMD [9,10]. This is

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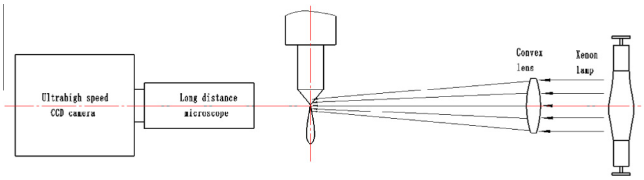

Fig. 1. The layout of the primary breakup setup.

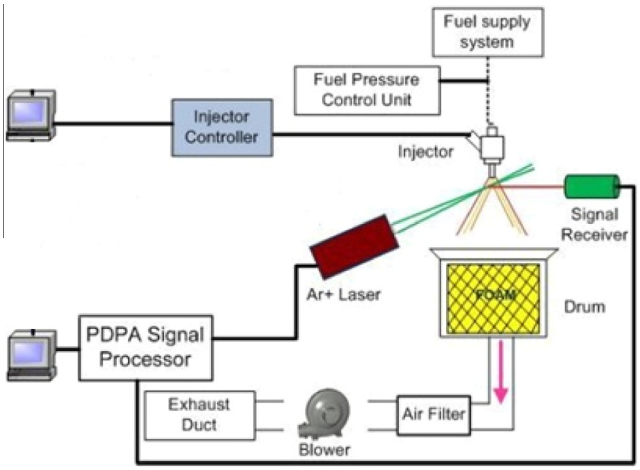

Fig. 3. Set up for PDPA (adapted from [11]).

because the effects of raised back pressure in terms of boosting the break up outbalance the effects of coalescence. Many studies also show that high viscosity and surface tension cause large SMD [10].

Although the impact of dwell and fuel quantity ratio between injections on the spray characteristics has been widely studied, the effects of injection pressure and back pressure on the interaction between split injections are still not clear. The primary breakup characteristics when split injection strategy is employed is thought to be important for the spray macroscopic characteristics but have not been sufficiently studied. In addition, microscopic characteristics (droplet size and velocity) with split injection strategy also require deep study to explore the novelty of the split injection strategy. In this study, to systematically study the characteristics of split injection strategy, the primary breakup in the near field was studied with ultrahigh speed imaging technique by using a long distance microscope. The macroscopic characteristics were then investigated with high speed imaging and the microscopic characteristics were finally probed with PDPA.

2. Experimental setup

The employed injector was a solenoid one which had a single hole with the diameter of 0.18 mm. The primary breakup was investigated by using ultra-high speed photography technique (Fig. 1). An ultra-high speed CCD camera completed with a highly resolved long distance microscope was employed to visualize the spray morphology. The development of spray was recorded within the view field of 2.3 mm downstream of injector. The ultra-high frame speed of the camera, 1,000,000 fps, allowed the details of the spray development to be recorded. A 500 W xenon lamp together with a convex lens was employed to sufficiently illuminate the spray. The ambient pressure was atmospheric and the ambient temperature was room temperature.

For high speed imaging technique, a high pressure vessel (11 MPa pressure limit) was employed to study the effects of the back pressure, as shown in Fig. 2. The aforementioned xenon lamp was positioned at the side window to illuminate the spray. The aforementioned CCD camera together with a 105 mm Nikon lens (aperture was set to maximum, 2.8) was located at another side window, forming a 110° angle with the side window for the xenon lamp. For high speed imaging, the frame speed of the camera was set to 63 k with the corresponding time interval between two images of 16 μs. The back pressure for high speed imaging ranged from atmospheric to 3.5 MPa (the common in-cylinder pressure for diesel engine when fuel is injected) with ambient temperature of room temperature.

The setup for PDPA is presented in Fig. 3. One PC was used to control the PDPA signal processor and the other PC was used to control the injection parameters. An air blower and a filter were employed to suck the air out so that the lab is free of contamination and safety risks. The incline angle between the transmitter and the receiver was 70°. More details about the PDPA setup can be found in [11]. In this study, the measuring positions were located along the plume axis. Data were acquired for 240 injections or 20,000 validated particles detected. The fuel was injected into atmospheric condition.

3. Test conditions and tested fuel

To study the spray characteristics of single and split injection strategies, the injection pressure varied from 60 to 120 MPa while the back pressure ranged between atmospheric pressure and

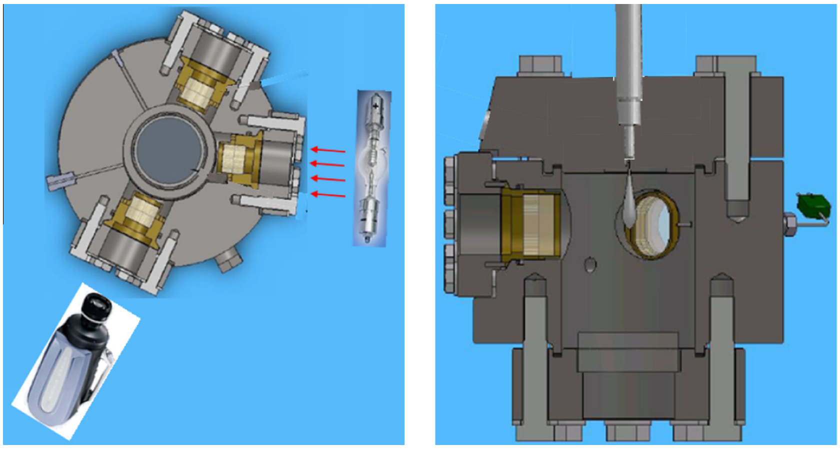

Fig. 2. Set up for the high speed imaging (adapted from [11]).