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2-D Simultaneous Measurements of Velocity and Diameter of Diesel Spray Droplets by Novel Interferometric Laser Imaging for Droplet Sizing (ILIDS) Method

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Abstract : The characteristics of Diesel spray droplets, such as the velocity and the diameter were simultaneously measured by using an improved Interferometric Laser Imaging for Droplet Sizing method. The experiments were carried out using an accumulator-type unit injector system and a constant-volume vessel. Two dimensional cross-section photographs of sprays were also taken using a double-pulsed Nd-YAG laser sheet and a linear array CCD camera. As a result, interesting relations between the droplets diameter and the velocity were found.

Key words : Diesel Spray, Velocity, Diameter, 2-D measurement, ILIDS

1. Introduction

Diesel engines are superior in respects such as the fuel-economy and the durability in comparison with gasoline engines, and they are widely used as prime movers of commercial automobiles and ships. On the other hand, a social demand of harmful diesel engine emissions reduction has motivated for the global environment protection. Recently, to meet stringent emissions regulations, combined technologies such as retarding injection timing, high-pressure injection, EGR and turbo-charging are employed. Evaporation promotion of fuel, quick mixture formation of fuel evaporation, and enhanced entrainment are important for diesel spray combustion.

It is very difficult to make "well" mixture as the density of air at injection timing is very high by turbo-charging. Thereby, the development of an injector for "well" air-fuel mixture is required. A lot of studies have been made on Diesel Sprays[1], [2]. Spray characteristics, such as the penetration, the dispersion angle and the concentration of mixture have been widely examined. However,

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information such as the droplet size, the velocity and the spatial distribution of droplets are not measured for Diesel sprays.

Therefore, in this study, the authors have examined the possibility of an application of an improved ILIDS (Interferometric Laser Imaging for Droplet Sizing) technique to Diesel sprays that can acquire the droplet velocity and the diameter size simultaneously for the first time.

2. Measuring principles of ILIDS

The interferometric imaging technique is a method that examines the interference of scattering light from a single spherical droplet. The defect of the conventional ILIDS method is difficult to distinguish overlapped interference images by droplets. In order to overcome this problem, lenses compressing images are set between a collecting lens and an image plane. And the circular images are concentrated together with fringes retaining the information for circle diameter and involved fringe numbers.

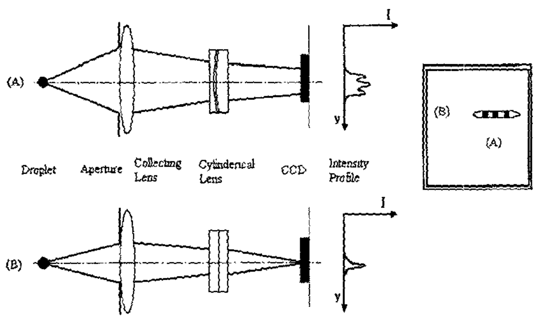


Fig. 1 Schematic of the receiving optics by orientation and image.

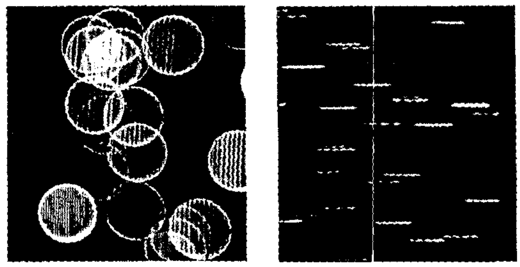


Fig. 2 An Example of a portion of the measured interferometric image a conventional technique (A) and a new ILIDS technique (B)

The interferometric image is generated by the scattered light of external reflection, p_0, and nth order refraction of particles illuminated by coherent laser source. The intensity of a pair of scattered lights, p_0, and p_1, is much stronger than that of p_2 and the highest order refraction using homogeneous illumination. The intensity ratio between p_0, and p_1 is approximately equal to unity around the scattering angle $\theta = 73$ deg. Therefore, this particular scattering angle, depending on the polarization of the laser light source, give the maximum amplitude of interference signal.

Equation (1) describes the relation between the droplet diameter, d, and the number of fringes, N, presented by Hesselbacher et al[3].

$$d = \frac{2\lambda N}{\alpha} \cdot \frac{1}{\cos\frac{\theta}{2} + \frac{m\sin(\theta/2)}{\sqrt{m^2+1-2m\cos(\theta/2)}}} \quad (1)$$

where, λ is Laser wavelength, α and θ are collecting and off-axis angles, respectively, m is the relative refractive index.

Figure 1 shows the simplified schematic of improved receiving optics, put forth by Maeda et al[4]. The imaging optics consisted of a rectangular aperture, a circular objective lens, a pair of cylindrical lenses and high resolution CCD camera.

The role of rectangular aperture in front of the objective lens as shown in Fig. 1 are to adjust the collecting angle, and to enhance the depth of focus. A pair of cylindrical lenses located between the imaging plane and the objective lens makes horizontal out-of-focus images on a focus plane. A pair of cylindrical lenses can shift along the optical axis and they enable the adjustment of the degree of horizontal defocusing.

Figure 2 shows a comparison of the obtained images between the conventional ILIDS technique (A), and improved technique (B). Both images are only portions of the captured digital images. The areas are 4x4 mm^2 within the 10x10 mm^2 matrix of the CCD receiver. In case (A), even 15 droplets make it difficult to count within the specified area. On the other hand, in case (B), more than 100 particles can be identified on the image by using the optical compression technique. And the radius of the circular images with different number of fringes in Fig. 2 are the same since the image size is correlated with the collecting angle or the aperture size, i.e., it is the number of fringe spacing that gives the droplet size. Figures 1 and 2 demonstrate the significant improvement of the present method afforded by partial compression technique.

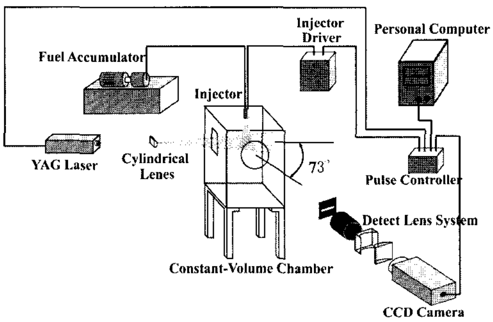


Fig. 3 Experimental apparatus of the ILIDS.

Table 1 Experiment conditions.

Injection system	Accumulator type unit injector
Nozzle	Single hole nozzle
Fuel	JIS #2 diesel oil
Orifice diameter (mm)	0.244
Injection pressure (MPa)	50
Ambient pressure	Atmospheric pressure
Ambient temperature	Room temperature

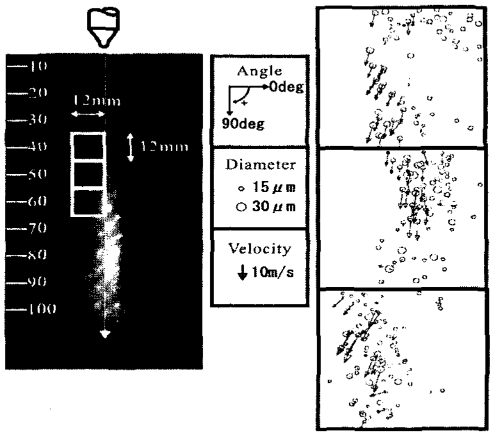
3. Experimental apparatus and method

The experimental device and an outline of the optical systems are shown in Fig. 3. Fuel injections were made inside a chamber with quartz windows[5]. Free sprays were formed using a unit-type injector. The injection rate form is almost a top-hat shape. Experimental conditions are shown in Table 1. The injection and ambient pressure are set at 50 MPa and atmospheric pressure, respectively. Injection duration was set at 3 ms and measurement field was chosen at 4-6 cm from the nozzle-tip. Measurements were made at 1.5 ms after end of injection.

The optical system is almost similar to a PIV system. The laser source is a double-pulsed Nd:YAG laser (wavelength 532 nm, pulse width 5 ns, output power

50 mJ/pulse and a highest repetition frequency of 30 Hz). The time interval of two shots was set to 3 μs. The measurement area of a frame is 12x12 mm. Measurement frames are shown in Fig. 4(a). The scattering and the collecting angles were set up at θ=73deg and α=7.3deg, respectively.

A digital 10 bit (1018x1008 pixel) CCD camera was used for acquisition of images. The obtained images were continuously accumulated in the memory of PC and processed using a commercial software developed by KANOMAX Inc., to analyze the position of each droplet, droplet-size, and its velocity.



(a) (b)

Fig. 4 Measurement regions in spray photograph (left hand) and samples of the measured results (right hand) of validated droplets diameter and velocity distribution.

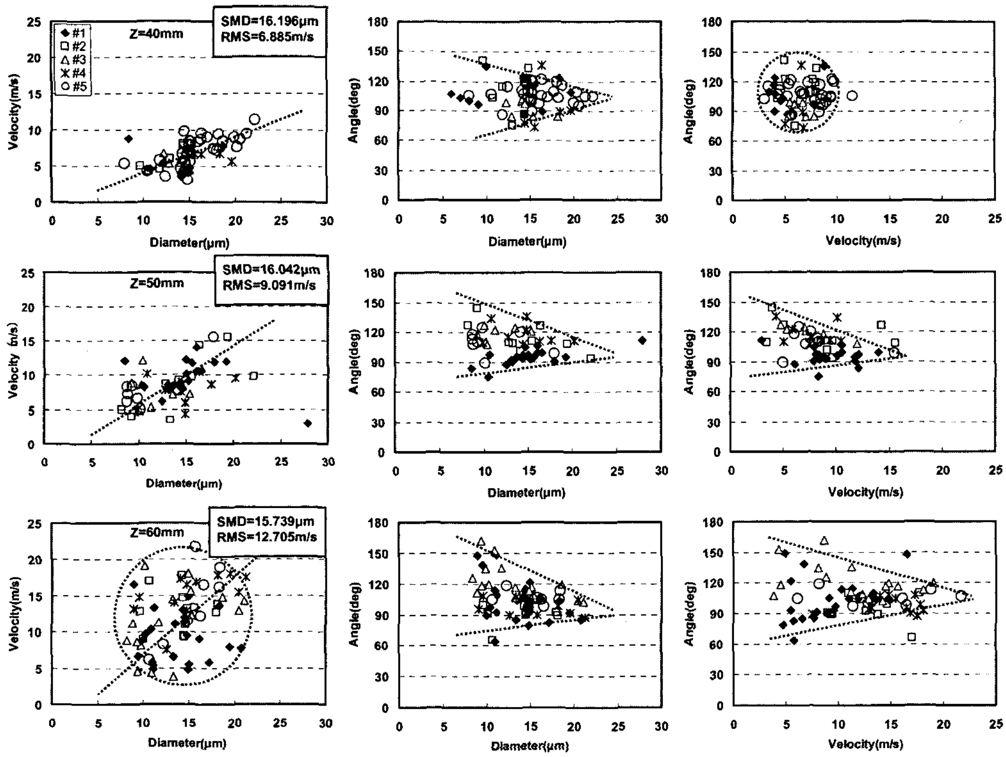


Fig. 5 Relations between velocity, diameter, or angle of velocity for five experimental shots.

4. Results and discussion

Examples of typical results are shown in Fig. 4(b). The circles and arrows show the diameter and the velocity, respectively.

The results measured at z=40 mm, 50 mm and 60 mm with an injection pressure of 50 MPa are shown in Fig. 6. Five shots data in each frame (noted as # 1-5) are indicated. SMD and RMS values of droplets velocity in each frame are also calculated. SMD values are almost the same among the three positions. however, RMS of velocity is larger in the downstream.

At z=40 mm, a correlation between the velocity and the diameter was found. At z=50 mm, the gradient of correlation (shown in broken-line) becomes large, while the scatter of data also becomes large. At z=60 mm, the same tendency was found.

As the measurement timing was set at 1.5 ms after end of injection, the effect of injection becomes weak in the upstream, thereby the gradient of correlation becomes small in upstream. Meanwhile, as the turbulence generated by injection and accompanying vortices are weak in the upstream, the scatter of data also becomes small.

Regarding the correlation between the velocity angle and the diameter, small droplets indicate a large scatter of the angle in each position, since small droplets are subject to be affected by the motion of vortices.

Regarding the correlation between the angle and the velocity, the droplets with small velocity indicate a large scatter of angle, as they have small diameter and tend to move on the motion of vortices.

5. Summary

In order to obtain a detailed information on Diesel sprays, an improved ILIDS system was applied for the first time. In three frames having 12x12 mm size located 40, 50, 60 mm downstream of nozzle-tip were chosen. Measurements were made at 1.5 ms after end of injection with a pressure of 50 MPa. Consequently, the following conclusions were obtained.

(1) Correlations between the velocity and the diameter were found. The scatter of data became large in the downstream as the effect of turbulence is larger in the downstream.

(2) Correlations between the angle of velocity and the diameter were examined. The smaller droplets indicated a larger scatter of angle as they can move subject to the ambient vortices.

(3) Correlations between the angle and the velocity were also examined. The droplets with smaller velocity indicated a larger scatter of angle as they have smaller diameter and tend to move on the ambient gas motion of vortices.

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