Time series measurement of fuel film adhering to model cylinder wall

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The purpose of this research is to know the fuel spray adhesion thickness and amount on the cylinder wall of a model engine. Laser Induced Fluorescence (LIF) method is applied to measure the adhesion film thickness. The calibration method for absolute measurement by LIF has been proposed for better accuracy. The technique is able to correct the influence of light source irregularity by using the reference fluorescent intensity. In the study, time series measurement is tested by using the LIF and a high-speed video camera. The results show that the time series data of the adhered fuel spray thickness distribution and its amount.

1. Introduction

In a gasoline engine, the adhesion of gasoline droplets to the wall is an undesirable phenomenon that causes unburned HC and oil dilution [1][2]. Johnen and Hang [3] measured the thickness of fuel adhesion to the wall using a fiber LIF method. Takahashi et al. [4] measured the thickness of adhesion fuel to the wall in the suction port and in the cylinder by an improved fiber LIF method that a used single fiber. Iida et al. [5] carried out point measurements of the thickness of fuel adhering to a wall in time series using an LIF method. As the fiber LIF method is a point measurement, it is insufficient for evaluating the distribution and behavior of adhering fuel. On the other hand, the measurement of the amount of fuel adhering to a wall was tested by Yaoko et al. [6]. They measured the amount of adhered fuel using an electronic balance. The experiment was successfully carried out. However the results were obtained on a flat plate test piece. Thus, the application of this method in an actual engine cylinder would be difficult.

In this study, the time-series thickness of adhered fuel is measured using a combination of the LIF method and a high-speed video camera. To improve the thickness measurement accuracy of adhering fuel, a calibration method with a reference image is proposed. The obtained thickness is converted to the amount of fuel adhering in the cylinder. The time-series data of the thickness and amount of adhering fuel are discussed in connection with the experimental results.

2. Proposed calibration method [7]

Fluorescent light intensity from thin liquid film with a fluorescence dye can be given by as follows:

$$I = Q\, I_0\{1 - \exp(-\varepsilon' ct)\}, \qquad (1)$$

where I is the fluorescent light intensity, Q is the quantum efficiency of a fluorescent material, I_0 is the incident light intensity of the light source, ε' is the molar absorption coefficient, c is the molar concentration of a fluorescent material, t is thickness of the solvent. The film thickness can be obtained from the fluorescence light intensity from eq. 1. Equation 1 also indicates the intensity of the fluorescence light depends on that of light source. This causes the measurement error in the absolute measurement of film thickness. The authors have proposed the calibration method by using a solid plate including fluorescent materials. The intensity from a fluorescent plate I_{ref} is expressed as follows:

$$I_{ref} = Q_f\, I_0\{1 - \exp(-\varepsilon_f' c_f t_f)\} \qquad (2)$$

The variables in eq. 2 are explained as same as those of eq. 1. When temperature change is neglected, these are treated as constants. Then, eq. 2 is expressed as

$$I_{ref} = A\, I_0. \qquad (3)$$

Where A is a constant which is independent from the conditions. Using above relationship, the following equation is obtained:

$$I/I_{ref} = Q\{1 - \exp(-\varepsilon' ct)\}/A \qquad (4)$$

This equation shows I/I_{ref} depends on Q, ε', c and t. Because Q and $\varepsilon'$are characteristic value of fluorescence dye, only t becomes variable when c is constant. Using eq. 4, thickness of liquid film can be obtained.

3. Experimental methods and conditions

To examine the relationship between I/I_{ref} and the thickness t, a calibration test is carried out. Perylene ($C_{20}H_{12}$), which is used as the fluorescent dye, is dissolved by toluene, and mixed with n-heptane which is the main test fuel. The concentration of perylene is 0.4 g/dm^3. This is the ratio of the concentration of saturated solution to fuel. UV LED (Nichia Corporation NSPU510CS×92, emission peak wavelength: 375 nm) is applied as a light source. The calibration curve is obtained by a preliminary test. The calibration curve is obtained from test with 9 pieces of test object which has known liquid film thickness.

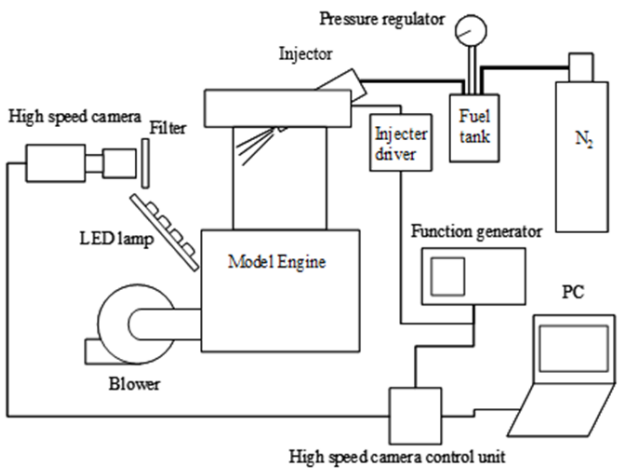

Figure 1 Experimental apparatus

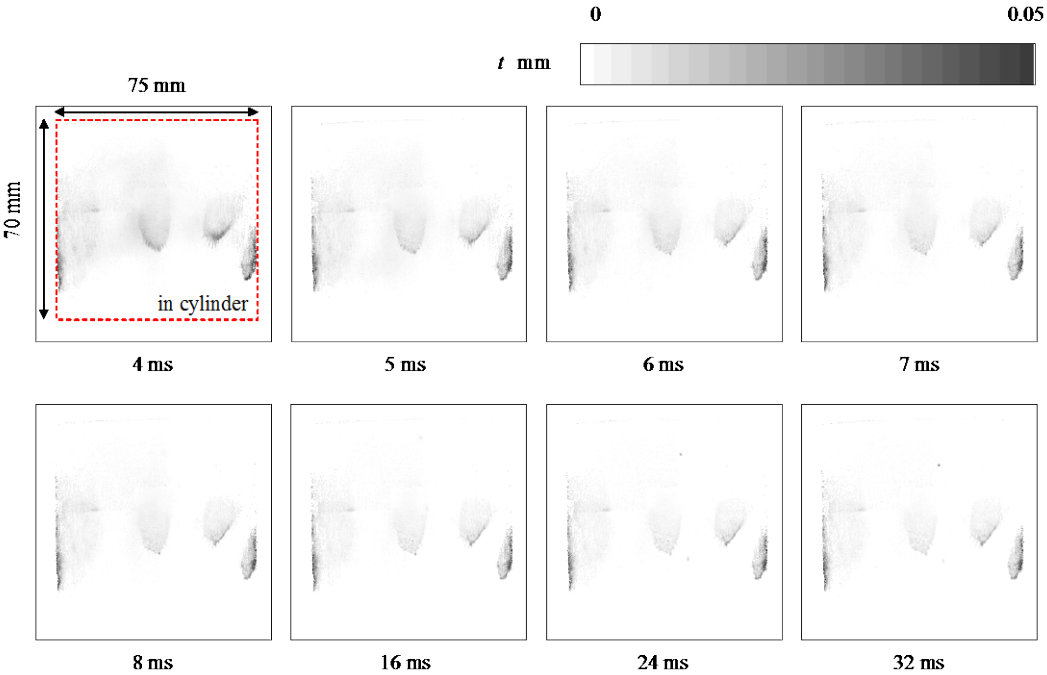

Figure 2 Fuel thickness distribution (injection duration: 1.5ms)

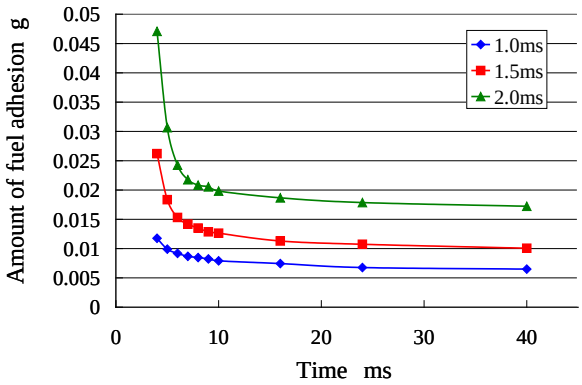

Figure 3 Time series results of fuel adhesion mass

The experimental apparatus is shown in Figure 1. A model engine with acrylic cylinder with 75 mm in bore is used. The fuel is kept in fuel tank with 10 MPa. Injection durations of 1.0, 1.5, and 2.0 ms are tested. The adhered fuel on the inner surface of the cylinder wall can be observed from outside of the model engine. A high-speed video camera (Phantom v710, picture resolution: 1280×800, frame speed: 1000 fps) obtains the fluorescence images.

4. Results and discussions

An example of experimental results of fuel film thickness distribution is shown in figure 2. The results are obtained under the condition of 1.5 ms injection duration. The first frame of the picture when the spray tip reaches the wall surface is set to 0 ms. Thick adhered fuel film areas which are represented by dark gray color can be observed. The fuel thickness at the outer edge of the spray impinging area is thicker than that at the center. The change in the thickness with time is recognizable until 7ms. For example, the thin adhered fuel can be observed between the main spray impinging areas at 4 ms. The fuel at these areas disappears or becomes thinner at 5 ms. This result is mainly caused by fuel evaporation. The change in the adhering fuel thickness becomes small after 7 ms.

The amount of fuel adhering to the wall surface is shown in figure 3. The vertical axis of the figure is the amount of fuel adhesion (g) and the horizontal axis is the time which is the same as that in figure 2. The amount of adhered fuel rapidly decreased until 7 ms in all injection durations. After 7 ms, the change in the adhesion fuel amount becomes small. As mentioned before, the main reason for this decrease is fuel evaporation. After 7 ms, fuel evaporation ceases in this experiment.

5. Summaries

In this research, a method to correct the light source unevenness in the LIF method using fluorescent plate is proposed. Time series thickness and amount of adhered fuel to the cylinder wall of the model engine is measured. The results show that the proposed LIF method is useful tool for evaluate the fuel film behavior.

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