Laser-induced plasma generation and evolution in a transient spray

N. Kawahara*, E. Tomita, S. Nakamura

Department of Mechanical Engineering, Okayama University, Okayama, Japan

* Correspondent author: kawahara@mech.okayama-u.ac.jp

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Introduction

In laser ignition, a flame kernel is formed as a laser-induced plasma, which is generated by focusing a high energy density pulse-laser on combustible mixture. Laser ignition has a lot of advantages over spark-plug ignition, such as selection of ignition point by setting an optical system, control of ignition energy, decrease in heat loss and interaction between a ground electrode of spark-plug and a spray due to the ignition device. However, there are few research about laser-induced plasma generation in the point where contain both gas and liquid phase like a fuel spray.

In this study, the behaviours of laser-induced plasma and fuel spray were investigated by visualizing images with ultra-high-speed cameras. Ethanol is used as fuel. Time-series images of laser-ignited flame of ethanol spray are visualized using high-speed colour camera. Effects of water content in ethanol on ignitability of laser-ignited spray flame are discussed. Status of laser-induced plasma in fuel spray is investigated with plasma temperature observed by measurement of plasma emissions using laser-induced breakdown spectroscopy (LIBS). Visualization of laser-induced plasma is observed using ultra-high-speed colour camera. Moreover, interaction between a single droplet and laser-induced plasma is investigated using levitated single droplet by the ultrasonic-levitator.

Experimental results

Fig. 1 shows the time-series images of laser-ignited ethanol spray flame under various water content conditions in ethanol. Injection pressure $P_i$ was 7MPa, the ambient temperature $T_a$ was 430K. Incident energy was $E_{in}=30mJ$ constant. Water content in ethanol was changed from 0% (dehydrated ethanol) to 50%. The laser-ignited flame of ethanol is luminous flame.

Plasma temperature of laser-ignited ethanol spray flame can be estimated as shown in Fig. 2. Appropriate water content in ethanol can affect better ignitability due to higher plasma temperature and volume expansion in combustion. However, higher water content causes lower ignitability of laser-ignited spray flame due to lower plasma temperature. At each droplet position (DP), the laser was shot into the droplet, and the process was observed by the high-speed camera, as shown in Fig. 3. In DP=1mm, the laser into the droplet after through the focal point. The plasma generated in the air contacted with the droplet, therefore the droplet was exploded from inside. In DP=−4mm, the lens focal point locates behind the droplet. The plasma beam was refracted by the droplet and the focal length became shorter than the original focal length of the convex lens, therefore the droplet was exploded from inside. We can see the droplet was exploded from the backward or behind in DP=−18mm. This result also supports the lens effect of the droplet.