Studies on the Acceleration Effect of Fuel Droplets Monodispersed in a Premixed Gas on Combustion

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Purpose and Background

Our group has performed fundamental studies on spray combustion using a static homogeneous fuel spray as a simple model of real sprays. From those studies, it was found that the flame speed of homogeneous fuel sprays exceeds that of the premixtures of the same equivalence ratio in certain spray conditions. The purpose of this project is to understand the acceleration mechanism of fine fuel droplets in the flame propagation of homogeneous sprays. The effects of the fine fuel droplets on flame propagation were investigated experimentally using microgravity conditions. From the viewpoint of the application of findings to internal combustion engines, it is most important in this project to check whether the increase in the flame speed leads to the increase in the heat release rate or not.

Experimental method

A rapid and uniform temperature drop of saturated fuel vapor-air mixtures has been employed to generate a homogeneous spray. Figure 1 shows a schematic diagram of the combustion chamber. Homogeneous sprays were generated and ignited in the combustion chamber (inner diameter: 40 mm, height: 40 mm). The ignition wire was located at the center of the combustion chamber. The pressure in the combustion chamber just before ignition (= P0) was 0.2 MPa for all experiments. The Sauter mean diameter was used as the mean droplet diameter dm and shadowgraphy was applied to observe flame propagation.

Results and discussion

Figure 2 shows flame propagation behavior of a homogeneous fuel spray. After an ignition delay, the flame started to propagate at 1.5 ms. Wrinkles appeared at about 3 ms and grew. Since wrinkles do not appear for premixture flames, it can be supposed that fuel droplets in the spray induced the wrinkles.

Fig.1 Combustion Chamber.

Fig.2 Flame propagation behavior in a homogenous spray
Figure 3 shows the effect of the mean droplet diameter on the flame speed when total equivalence ratios $\phi_t$ are 0.8, 0.9 and 1.4. Liquid equivalence ratio $\phi_l$ was fixed at 0.2 for $\phi_t = 0.8$ and 0.9, and at 0.25 for $\phi_t = 1.4$. The flame speed at 10 mm in the flame radius was used as a characteristic flame speed of homogeneous sprays. In the case of $\phi_t = 0.8$, the flame speed increases as the increase in $d_m$, and then decreases. In the case of $\phi_t = 0.9$, the flame speed takes two local maximum values. In the case of $\phi_t = 1.4$, the flame speed decreases and then increases. The slip velocity (relative velocity between droplets and unburned gas) and the evaporation rate of fuel droplets have strong effects on the flame speed. The dependence of the flame speed on $d_m$ is determined by the dependences of those effects on $d_m$.

Figure 4 shows the effect of $d_m$ on the maximum burning pressure. The vertical axis is nondimensionalized with $P_0$. In the case of $\phi_t = 0.8$ and 0.9, the maximum burning pressure of homogeneous sprays exceeds that of premixtures in the region of $d_m < 50 \mu m$. The dependence of the maximum burning pressure on $d_m$ is qualitatively similar to that of the flame speed. This fact means that the increase in the flame speed leads to the decrease in the burning time, consequently to the decrease in the heat loss. The region of $d_m > 25 \mu m$ for $\phi_t = 1.4$ is exceptional. Although the flame speed increases as the increase in $d_m$, the maximum burning pressure decreases. Large $d_m$ leads to slow evaporation of fuel droplets. It is supposed that, in the region of $d_m > 25 \mu m$ for $\phi_t = 1.4$, flames propagate selectively through the mixtures far from the droplets because the equivalence ratio of such mixtures are close to the initial gas equivalence ratio ($\sim 1.15$). The results suggest that temperature decrease due to the selective flame propagation is the cause of the decrease in the maximum burning pressure.

It was confirmed that the combustion of lean fuel vapor-air mixtures can be accelerated by the replacement of fuel vapor with fine droplets. This combustion technique can be useful for the acceleration of the combustion in lean combustion engines. Long-term microgravity experiments will provide us the better understandings on the homogenous fuel spray combustion because it is possible to generate a spray which consists of large droplets. The knowledge between single droplet combustion and spray combustion is still necessary to construct the more general predictive model of spray combustion.

**Publication List (Oral Presentation)**