Flame Propagation in the Mixture of Gaseous Fuel and Spray under Microgravity

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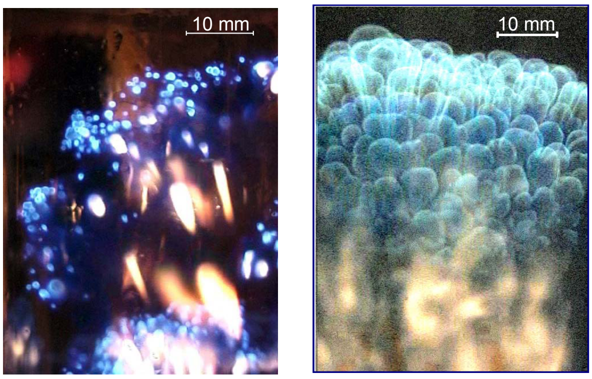
Abstract

Flame propagation experiments of n-octane spray were performed in microgravity to investigate the flame propagation mechanism of volatile fuel sprays. N-decane spray mixed with small amounts of methane was also used as a fuel to simulate the flame propagation of volatile fuel sprays. Microgravity experiments were made at Japan Microgravity Center (JAMIC) in Hokkaido, Japan, which is a drop-shaft of test duration of 10 s and a microgravity quality of 10^{-5} g. Spray was dispersed uniformly into an acrylic propagation tube with an inner diameter of 62 mm and a length of 535 mm, and after 5 s in microgravity, a quiescent spray was formed in the tube without sedimentation of droplets. Just after the Sauter mean diameter (SMD) and spray concentration were measured by a laser droplet analyzer, the spray was ignited at the open end of the tube by an electrically heated nichrome wire.

We obtained the variation of the flame propagation speed with the SMD and the

concentration in the previous paper [1], showing that the flame speed of n-octane spray was three or four times as fast as that of n-decane spray for whole SMD ranges. As shown in Fig.1, direct photographs of propagating flame showed that there was a big difference between the flame shape of n-octane and that of n-decane spray. The flame front of n-decane spray consisted of many spherical envelope flames surrounding each droplet, as shown in Fig.1 (a). On the other hand, the flame front of n-octane spray had the uneven flame surface, that is, comparatively large spherical flames were connected each other like a string of beads. In the case of n-octane, pre-vaporization occurred due to high volatility before ignition, and the equivalence ratio of fuel vapor and air mixture is around 0.60 or more at the atmospheric pressure and room temperature, which equals or exceeds the lean flammability limit. Therefore, the flame could propagate through the n-octane vapor. Due to this reason, the difference of the flame propagation appeared. Therefore, it is important to investigate how the flame propagation is affected by a vaporized fuel in spray. We proceed to another experiments using n-decane mixed with small amounts of methane as fuel vapor in microgravity.



(a) n-decane spray (b) n-octane spray

Fig.1 Photographs of the propagating flame front in microgravity

The total equivalence ratio of n-decane and methane mixture was kept constant and the concentration of methane was changed by use of an air-methane-blast atomizer. Figure 2 showed the variation of the flame speed with the concentration of methane. The total equivalence ratio was 0.90 ± 0.05 and SMD was 100 ± 7.5 μm. The concentration of methane was varied from 0 vol.% to 9 vol.%.

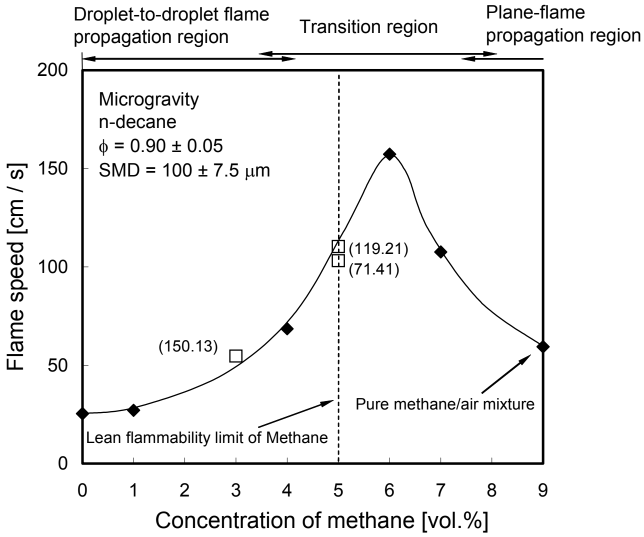


Fig.2 Variation of flame speed with the concentration of methane

The results showed that, when the concentration of methane increased, the flame speed increased first and had a maximum around 6 vol.%, and then decreased. From the observation of direct images of the propagating flames, we can reasonably divide into three flame propagation regimes as shown on the top of Fig.2. Since the flammability limit concentration of methane is 5 vol.%, flame can propagate through the methane-air mixture basically with equivalence ratios larger than 5 vol.%. When the concentration of methane is less than 5 vol.%, flame propagation must be augmented by a small amount of methane even if the premixed flame cannot be independently established, as shown in Fig.2. This still corresponds to the so-called "droplet- to-droplet flame propagation region", as well as the case of less volatile sprays. When the premixed flame with the concentration of methane over 5 vol.% can propagate by itself and droplets still exist in this combustible gas mixture, it is suggested that the surface of the premixed flame is transformed into an uneven surface and the flame speed must increase. However, the premixed flame of methane and air with less spray should have the proper burning velocity of methane and air. That is the reason why there exists a maximum flame speed in Fig.2. It is, therefore, important to examine the effect of droplets in fuel vapor on a shape distortion of the flame sheet.

An experimental study, to observe the behavior of laminar flat flame passing through a single fuel droplet suspended by a fine SiC fiber, was conducted. Laminar flat flame is propagated through a lean homogeneous propane-air mixture from the top to the bottom of the tube. The distortion of the propagating flame shape is observed and the variation of the flame speed is measured.

The results showed that the propagating flame was transformed into a convex flame toward the unburned gas and the flame speed was increased, when the flame passed through the droplet. The increase rate of the flame speed was decreased, as the equivalence ratio of propane-air mixture increased and therefore the flame speed increased, but it remained nearly unaffected by the droplet diameter in the experimental limited range of the droplet diameter.

[1] Nunome, Y., Kato, S., Maruta, K., Kobayashi, H. and Niioka, T., Proc. Combust. Inst. 29: (in print)