September, 21st - 24th 2014
FLAME STRUCTURE 2014
8th International Seminar on Flame Structure

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Berlin Institute of Technology (TU Berlin)

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Propagation Characteristics of Hydrogen-Air Deflagration in a Closed Vessel

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ABSTRACT
Propagation characteristics of hydrogen-air deflagration need to be understood for the accurate risk assessment. Especially, flame propagation velocity is most important factor. Propagation velocity of spherical flame has been estimated based upon the propagation velocity of flat flame; however, existing method is not enough to estimate the actual propagation velocity because cellular flame front is formed in hydrogen-air premixed flame. In this study, we investigated the propagation characteristics of hydrogen-air deflagration in explosion tests using a closed vessel which has large windows. Explosion tests were conducted at atmospheric pressure and room temperature and in the range of equivalent ratio from 0.4 to 1.0. Propagation velocity was obtained from flame radius which was measured directory in Schlieren images. From the results, it was indicated that the propagation velocity in hydrogen-air deflagration is accelerated owing to developing of cellular flame front in a huge space.

INTRODUCTION
For a risk assessment of combustible mixture, a flame propagation velocity is most important factor and needs to be estimated accurately. Propagation velocity of spherical flame was derived from the propagation velocity of flat flame, considering the effect of thermal expansion. Actually, in a premixed flame of hydrogen-air, cellular flame front is formed owing to intrinsic instability. (ref.1, 2) The flame front area of a cellular flame is larger than the area of a smooth flame, and the propagation velocity of the cellular flame is higher than that of the smooth flame. In a huge space, the propagation velocity of the cellular flame more increases owing to the fact that cellular flame front develops with increasing of the spherical flame radius. Therefore, the existing estimation method of flame propagation velocity is not enough to assess accurately the risk of the hydrogen-air mixture. In order to take appropriate measures for the safety, propagation characteristics of hydrogen-air deflagration need to be understood. Previously, the hydrogen-air deflagration in a large closed vessel has been investigated. (ref.2, 3) However, propagation velocity of the flame could not be measured directly from observed flame because of small windows. In this study, the propagation velocity was obtained directly using a closed vessel which has large windows.

APPROACH
We conducted explosion tests in a closed vessel in order to investigate propagation characteristics of hydrogen-air deflagration. Closed vessel has ignition plugs and four quartz windows. The volume of the vessel is about 73 litters, and the diameter of the windows is 300mm. Propagation phenomena was observed by Schlieren photography (Mizojiri SL-350) using a high speed video camera (Photoron SA-X). The overview of the experimental setup is illustrated in Fig.1. Explosion tests were conducted at atmospheric pressure and room temperature. Hydrogen-air mixture was spark ignited at the center of the vessel by the ignition plugs, and Schlieren video and pressure profile were obtained. In order to clarify the influence of equivalent ratio on propagation velocity, hydrogen-air mixtures were tested in the range of equivalent ratio, ϕ, from 0.4 to 1.0. Further, the Schlieren video was analyzed, and radiuses of the spherical flames were obtained from the each frame of the video.

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RESULTS AND DISCUSSION

Shrieren photographs obtained in the explosion experiments are shown in Fig.2. In the both cases of ϕ =1.0 and 0.5, cellular flame fronts were observed and wrinkles at the flame front increased with increasing of flame radius. Comparing between the case of ϕ =1.0 and 0.5 at same diameter, the flame front in the case of ϕ =0.5 has more wrinkles and larger concave/convex than the case of ϕ =1.0. In Fig.3, experimental propagation velocities, u_b, in the both cases of ϕ =1.0 and 0.5 were plotted as solid line. In order to compare the experimental propagation velocities with laminar burning velocities, propagation velocity of smooth flame front, u_L, was calculated at the both equivalent ratio by multiplying laminar burning velocities by the thermal expansion ratio. The calculated propagation velocities of smooth flame front are rendered as dashed line in Fig.3. As shown in Fig.3, experimental propagation velocities increase with increasing of radius. The ratios of the experimental propagation velocity to the calculated propagation velocities of smooth flame front, u_b/u_L, are summarized in Fig.4. The u_b/u_L increased with decreasing of equivalent ratio and with increasing of flame radius as shown in Fig.4. The u_b/u_L increases with developing of the cellular flame front. This fact shows that the u_b of the cellular flame becomes higher than the u_L owing to the larger flame front area of the cellular flame than the smooth flame.

CONCLUSION

We conducted explosion tests of hydrogen-air mixture in the closed vessel and observed the propagation phenomena by Schieren photography. From the 300mm diameter windows, large spherical flames were observed successfully by Schieren photography. The cellular flame fronts developed with increasing of flame radius and with increasing of equivalent ratio. Also, the u_b/u_L is increased with increasing of flame radius and with decreasing of equivalent ratio. Therefore, these results indicate that the propagation velocity, u_b, in hydrogen-air spherical deflagration should be accelerated owing to developing of a cellular flame front in a huge space.

ACKNOWLEDGEMENTS

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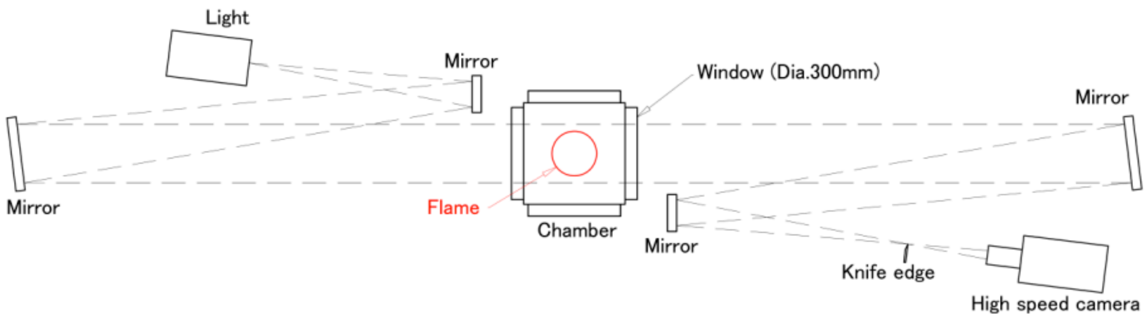

Fig.1 Experimental setup

	r = 40mm	r = 80mm	r = 120mm

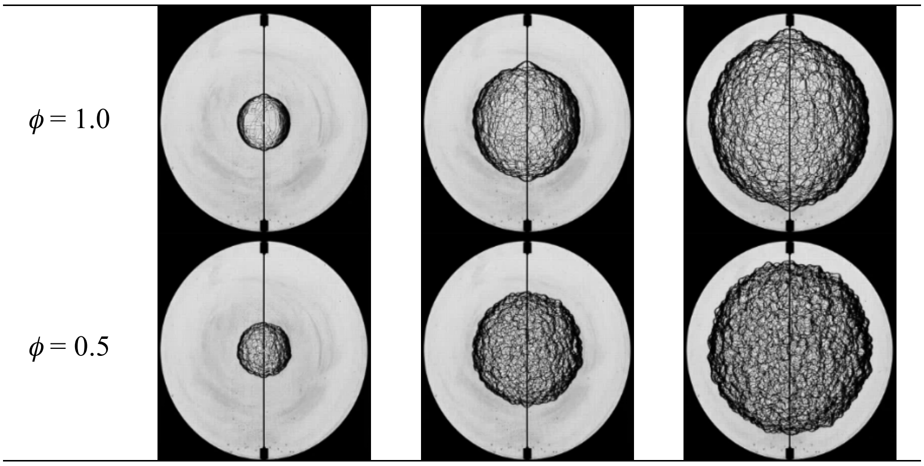

Fig.2 Schlieren photograph at $\phi = 1.0$ and 0.5

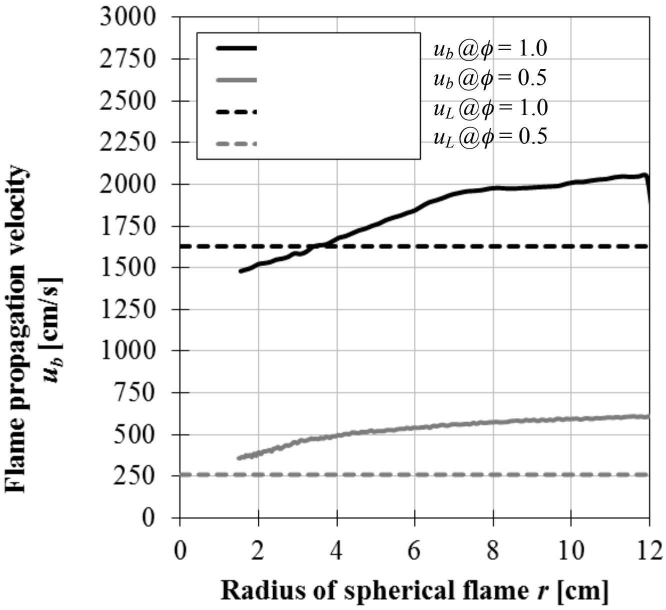

Fig.3 Profile of flame propagation velocity at $\phi = 1.0$

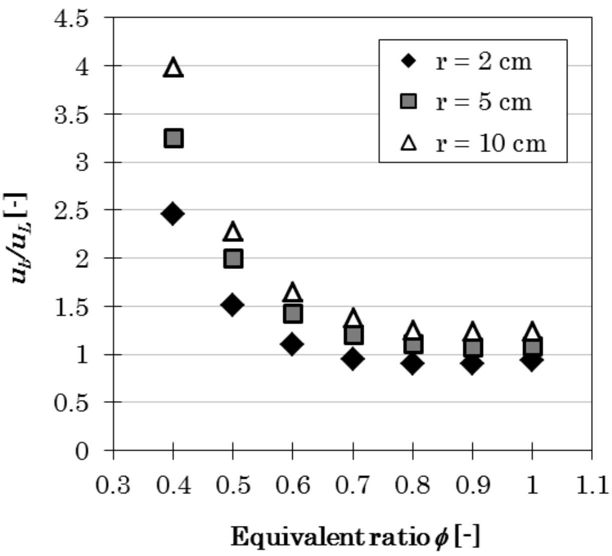

Fig.4 Ratio of experimental propagation velocity to calculated propagation velocity

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