A STUDY OF COMBUSTION MECHANISM OF PROPAINE-AIR MIXTURES NEAR THE IGNITION LIMIT UNDER MICROGRAVITY

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Abstract. The present experiments have been carried out with quiescent very lean propane-air mixtures for examining the lower limits of flame propagation, lower limits of ignition and minimum flame speed under microgravity. The drop shaft operated by the Micro-Gravity Laboratory of Japan (MGLAB) was used in order to produce microgravity conditions. Duration of microgravity conditions was about 4.5 s. The main conclusions are as follows:
1) microgravity experiments make possible to determine the true values of the flame propagation limits; 2) the equivalence ratio at the propagation limit is lower under microgravity conditions than that under normal gravity.

1. Introduction

Experiments on combustion of very lean mixtures in the vicinity of lower propagation limits are very important from the viewpoint of development of the combustion system for low fuel consumption and low emissions with high load engines. However, accurate data on combustion characteristics of such mixtures are scarce due to difficulties inherent in conventional measuring techniques under normal gravity. It is well known that the flame behavior is strongly influenced by buoyancy under normal gravity. This influence is more pronounced near the lower propagation limits where flame speeds are very low. Consequently, the data such as flame speed and propagation limits of extremely lean mixtures obtained by conventional measuring techniques under normal gravity are suspect.

Thus, the present experiments have been carried out with quiescent very lean propane-air mixtures for examining the lower limits of flame propagation, lower limits of ignition and minimum flame speed under microgravity.

The drop shaft operated by the Micro-Gravity Laboratory of Japan (MGLAB) was used in order to produce microgravity conditions.

2. Experimental apparatus and procedure

Figure 1 shows a falling assembly. The falling assembly is used to observe the behavior of flame propagation into extremely lean mixtures in long tube. The assembly measures 400×400×800 mm and weighs about 80 kg. It contains a glass tube, a CCD video cameras, 35-mm camera, ignition system, delay circuit and battery for ignition. The glass tube of 70 mm in internal diameter and 630 mm in length is mounted horizontally inside the falling assembly. The fuel-air mixtures in the glass tube are ignited at one end by a heat nichrome wire and immediately after ignition, that end is kept closed till the end of combustion process.
The travel time of flame front is tracked by CCD video cameras located at different axial stations from the igniter (Fig. 2).

The experiments are carried out at an initial temperature of 293 K and initial pressure 0.1 MPa. Propane used as a fuel was of 99.9% purity. A mixture of 79% nitrogen and 21% oxygen by volume is used as a substitute for air.¹,²

Fig. 1. Falling assembly
3. Results and discussion

Figure 3 shows the flame shape of propane-air mixtures near the lower propagation limit under normal and microgravity conditions, respectively. From this figure, it can be seen that the distortion of flame shape from axial

![Normal gravity](image1.png) ![Microgravity](image2.png)

*Fig. 3. Flame shape*
symmetry is evidently due to the marked influence of buoyancy at normal gravity condition. On the other hand, under microgravity an axially symmetric flame propagation is possible throughout the combustion process in a tube. So it makes possible to determine the true values of the flame propagation limits from the microgravity experiment. Figure 4 shows that the typical example of irregular flame shape of extreme lean propane-air mixtures under microgravity. From this figure it can be seen that the flame shapes are very irregular owing to extreme lean state of mixtures under microgravity. In these experiments, irregular flame shapes were observed for equivalence ratio $\varphi = 0.35-0.55$. For more extremely lean mixtures ($\varphi = 0.15-0.30$) and over the rich side ($\varphi > 0.60$) one can not observe the irregular flame propagation in these experiments. This fact indicated that the irregular flame propagation occurs due to decreasing flame temperature, that is an instability of thermal diffusivity and molecular diffusivity in the preheat zone at the flame front.

Figure 5 shows that the behaviors of ignition of extremely lean propane-air mixtures under microgravity. It can be seen from this figure that under microgravity the ignition was observed at equivalence ratio of about $\varphi = 0.15$. Furthermore, in these experiments, it was also observed that the flame propagation was possible up to the end of the combustion tube for propane-air mixtures at as low equivalence ratio as $\varphi = 0.20$ under microgravity.
For more extreme lean mixtures of equivalence ratio less than $\phi = 0.15$, the flame propagation can not be observed at half length (300 mm) of combustion tube under microgravity (Extinction). These observation imply that the equivalence ratio at the propagation limit under microgravity is lower than that under normal gravity. $^3$, $^4$ This fact denotes that the lower limits of flame propagation are influenced by the heat loss to walls of the combustion tube.

Figure 6 shows that the flame speed versus the equivalence ratio under microgravity. This figure has been drawn to study the minimum value of flame speed of extremely lean propane-air mixtures under microgravity conditions at 293 K and 0.1 MPa. This figure results show that the flame speed monotonically decreases with decreasing the equivalence ratio and assumes a value of 11.5 cm/s at an equivalence ratio of $\phi = 0.15$. 

Fig. 5. Behavior of ignition (Microgravity)
Figure 7 shows the influence of radiation from wall on flame speed at constant equivalence ratio ($\phi = 0.25$) under microgravity. This experiment has been carried out to insert the different paper at through the half area of combustion tube from the ignition side to the end of side. Where, Silver:aluminium paper, White:white paper and Black:black paper were used. It can be seen from this figure that the flame speed a little increases with increasing the rate of radiation of the wall, the maximum difference is about 5% at the center of combustion tube. Later near the end of combustion tube that effect is a negligible.
4. Conclusions

This experiment have been carried out with quiescent very lean propane-air mixtures for examining the lower limits of flame propagation, lower limits of ignition and minimum flame speed under microgravity. The main conclusions are as follows:
1) microgravity experiments make possible to determine the true values of the flame propagation limits 2) the equivalence ratio at the propagation limit is lower under microgravity conditions than that under normal gravity 3) minimum value of flame speed is about 11.5 cm/s at the equivalence ratio of about $\phi = 0.15$ under microgravity 4) the influence of radiation from the wall on the flame speed is very small under microgravity.

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References