COMBUSTION CHARACTERISTICS OF LEAN PROPANE-AIR MIXTURE BY USING HIGH IGNITION ENERGY

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Abstract

Experiments have been carried out to examine the combustion characteristics of propane-air mixtures under normal gravity and microgravity conditions by using high ignition energy in a combustion tube. The microgravity technique achieved in a freely falling chamber is employed because the realizations of symmetrical flame propagations in a tube are possible. Experimental condition for the initial mixtures corresponds to room temperature and 0.1 MPa and the fuel used is propane of 99.9% purity.

The main conclusions are as follows: (1) The flame speed monotonically decreases with decreasing the equivalence ratio under normal gravity and microgravity. (2) The probability of the irregular flame propagation for both fuels under microgravity are larger than that under normal gravity at same equivalence ratio. (3)The range of distance of flame propagation under normal and microgravity conditions by using high ignition energy can possible to distinguish.

1. Introduction

Experiments on combustion of extremely lean mixtures in the vicinity of flammability limits by using high ignition energy have acquired importance from the viewpoint of safety engineering in space [1] and development of new kinds of combustion having low fuel consumption and low emissions [2]. Furthermore, the determination of propagation limits under normal gravity and microgravity are very important for active control of safety engineering [3-8]. In fact, the values of these propagation limits are needed not only from the standpoint of design of many combustion systems including safety problem, but also in view of the combustion theory. From view point of this, in the previous investigations[1,9-11], experiments had been carried out with extremely lean, quiescent propane-air mixtures to examine the behavior of irregular flame propagation and to examine the lean limits of flame propagation in a tube under microgravity.

As the next step, an experiments have been carried out with extremely lean, quiescent propane-air mixtures by using high ignition energy to examine the combustion characteristics under normal gravity and microgravity conditions for propagation limit and the probability of the irregular flame propagation distance of flame propagation in a tube. The microgravity technique achieved in a freely falling chamber is employed because the realizations of symmetrical flame propagations in a tube are possible. Experimental condition for the initial mixtures corresponds to room temperature and 0.1 MPa and the fuel used is propane of 99.9% purity. Experiments are conducted in the drop shaft operated by Micro-Gravity Laboratory of Japan and Hosei University drop tower where the acceleration level inside the combustion device is of the order of 10^{-5}g. The observation time of microgravity is about 1-4 sec.

2. Experimental apparatus

The experimental apparatus and procedure are similar to those described in the previous reports [1]. The experimental equipments under normal gravity consist of a combustion tube, an igniter, a delay circuit and an exhaust system(Fig. 1 and Fig.2). The combustion tube was mounted in each direction (upward, downward and horizontal) at each experimental conditions. The falling assembly for microgravity experiment measuring 400 × 400 × 800 mm and weighing about 80 kg(Fig. 3). A glass tubes are changeable from 20 to 70 mm in internal diameter and 630 mm (short type) or 1500 mm (long type) in length is mounted horizontally inside the falling assembly. A set of CCD video and a still camera, an ignition system, a delay circuit and a battery constitute the remaining part of the assembly. The travel time of the flame front is tracked by video cameras located at different axial stations from ignition point.

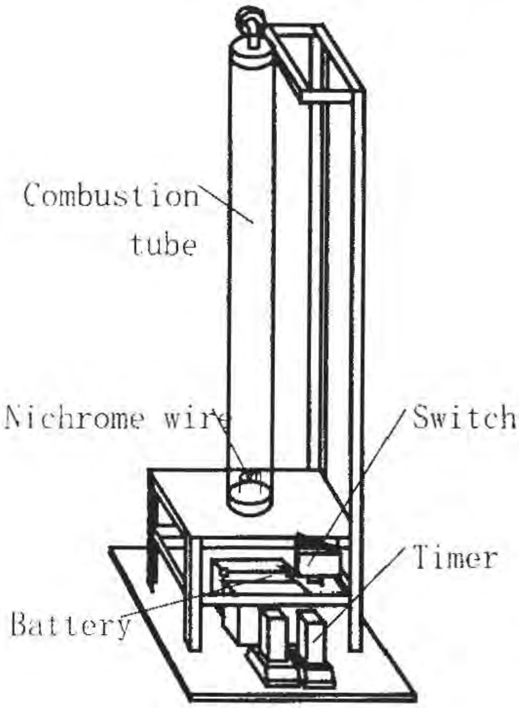

Fig. 1. Experimental apparatus(Normal gravity)

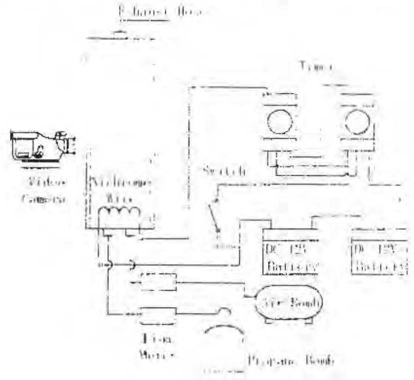

Fig. 2. Control system

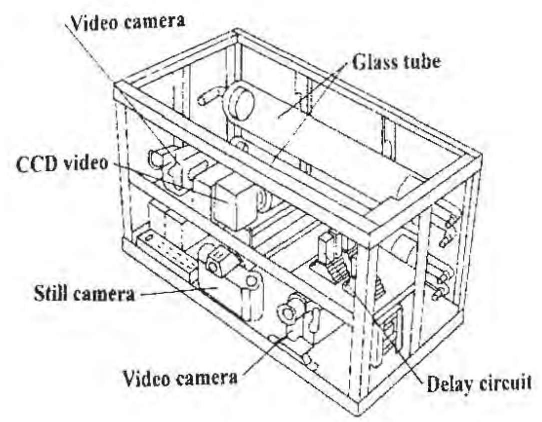

Fig. 3. Experimental apparatus(Microgravity)

Typical examples of direct color photographs of the flame propagation near the lean limit of inflammability of propane-air mixtures under normal and microgravity are shown in Fig. 4. The flame shapes near the lean limit mixtures of upward, downward and horizontal propagations under normal gravity are subjected to a marked influence of buoyancy effect. On the other hand, under microgravity axially symmetric flame propagation is possible throughout the combustion process in a tube.

3. Results and discussion

(a) Upward propagation (b) Downward propagation (c) Horizontal propagation (d) Microgravity

Fig. 4. Flame shape (C_3H_8, ϕ=0.52)

0.000[sec] 0.033[sec] 0.067[sec]

Fig. 5. Irregular flame shape (C_3H_8, microgravity, ϕ=0.4)

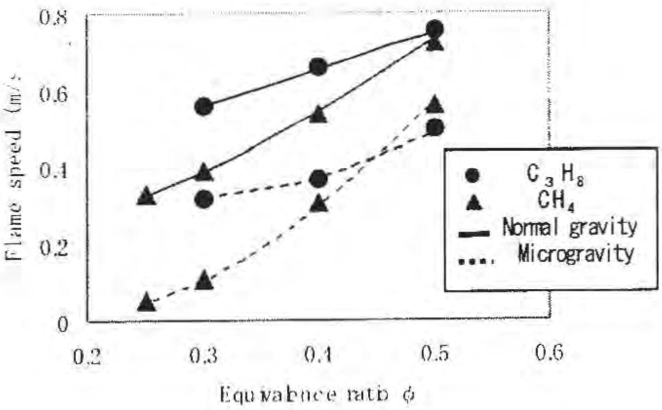

Fig. 6. Flame speed

Figure 5 shows the irregular flame fronts of cellular nature observed in a narrow range of 0.30≦ ϕ ≦0.50 under microgravity. The flames do propagate over the entire length yielding repeatable flame speeds. At ϕ <0.30 or ϕ >0.50, no irregular flame fronts are observed. It is well documented in literature that spontaneous cellular instability primarily occurs in fuel-oxidizer mixtures when the Lewis number (α/D α :thermal diffusivity, D: molecular diffusibity) of the deficient species is smaller than some critical value. Rich mixtures of heavy fuels or lean mixtures of light fuels are often found to exhibit cellular instability. In conformation to this, rich mixtures(ϕ >1.5) of propane-air do show such instabilities. However, lean side cellularity in Fig. 5, irregular flame fronts in lean propane-air mixtures under microgravity (ϕ =0.48) a heavy fuel like propane is rather unusual.

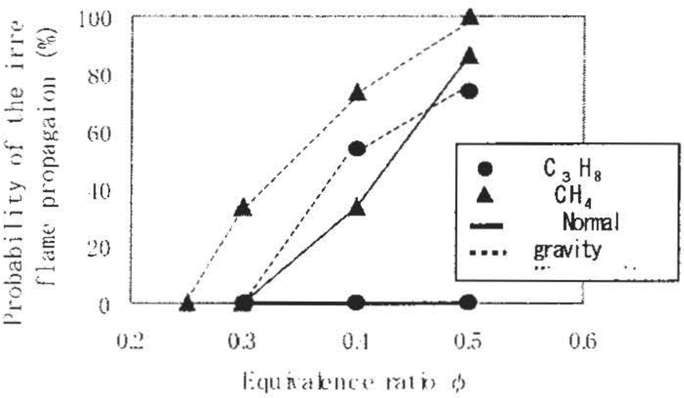

Fig. 7. Probability of the irregular flame propagation

The fact that this instability is repeatable and restricted to a narrow range of ϕ is even more intriguing.

Figure 6 shows the average flame speed of methane-air and propane-air mixtures against equivalence ratio under normal and microgravity conditions, respectively. As seen from this figure, it can be seen that the flame speed monotonically decreases with decreasing the equivalence ratio under normal gravity and microgravity. Furthermore, the flame speed under microgravity is smaller than that under normal gravity at same equivalence ratio.

Figure 7 shows the probability of the irregular flame propagation(%) of methane-air and propane-air mixtures under normal and microgravity conditions, respectively. It is found from this figure that the probability of the irregular flame propagation for both fuels under microgravity are larger than that under normal gravity at same equivalence ratio.

Figure 8 shows the distance of flame propagation of propane-air mixtures against equivalence ratio as a function of direction of flame propagation. Where the distance of flame propagation was defined the length of which the flame propagation was observed until this distance from ignition point. From this figure it can be seen that the range of distance of flame propagation under normal and microgravity conditions can possible to distinguish under follows: Range Ⅰ: the flame propagation was observed under normal and microgravity conditions (Distance of flame propagation: over 1500 mm, Flammability), Range Ⅱ: the flame propagation was influence by gravity condition (Distance of flame propagation:1)microgravity, less than 600 mm 2) normal gravity, less than 1500 mm), Range Ⅲ: under microgravity the flame propagation was observed ((Distance of flame propagation:1)microgravity, over 1500 mm, 2) normal gravity, less than 1000 mm), and Range Ⅳ : the flame propagation was not observed under normal and microgravity conditions (Without flammability limit under normal and microgravity conditions).

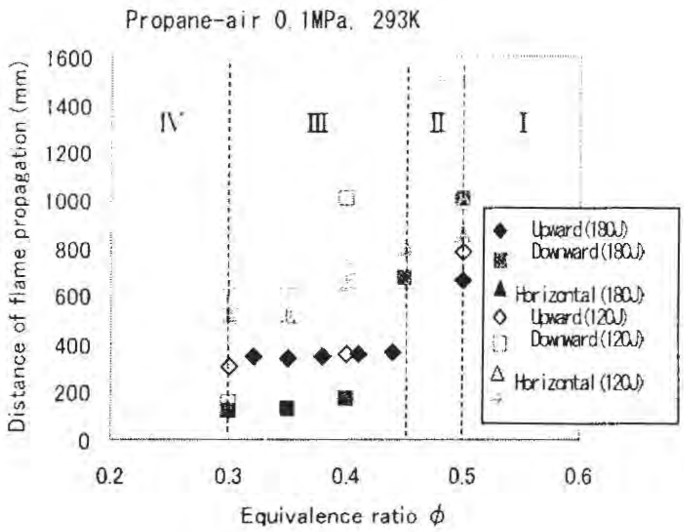

Fig. 8. Distance of flame propagation (C_3H_8)

4. Conclusions

Experiments have been carried out with extremely lean, quiescent propane-air mixtures to examine the influence of flame propagation direction under normal gravity and microgravity conditions on propagation limit and distance of flame propagation in a tube. The experimental results show that (1) The flame speed monotonically decreases with decreasing the equivalence ratio under normal gravity and microgravity. (2) The probability of the irregular flame propagation for both fuels under microgravity are larger than that under normal gravity at same equivalence ratio. (3)The range of distance of flame propagation under normal and microgravity conditions can possible to distinguish under follows: Range I : the flame propagation was observed under normal and microgravity conditions (Distance of flame propagation: over 1500 mm, Flammability), Range II: the flame propagation was influence by gravity condition (Distance of flame propagation:1)microgravity, over 1500 mm, 2) normal gravity, less than 1500 mm), Range III: under microgravity the flame propagation was observed ((Distance of flame propagation:1)microgravity, less than 600 mm,2) normal gravity, less than 1000 mm), and Range IV : the flame propagation was not observed under normal and microgravity conditions (Without flammability limit under normal and microgravity conditions).

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