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JAPAN'S RESEARCH ON GASEOUS FLAMES

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Introduction

Although research studies on gaseous flames in microgravity in Japan have not been one-sided, they have been limited, for the most part, to comparatively fundamental studies. At present it is only possible to achieve a microgravity field by the use of drop towers, as far as gaseous flames are concerned.

Compared with experiments on droplets, including droplet arrays, which have been vigorously performed in Japan, studies on gaseous flames have just begun. Experiments on ignition of gaseous fuel, flammability limits, flame stability, effect of magnetic field on flames, and carbon formation from gaseous flames are currently being carried out in microgravity. Seven subjects related to these topics are introduced and discussed herein.

Ignition of Gaseous Fuel (PI : M. Kono)

A methane- or hydrogen-air mixture in a cylindrical vessel with a diameter of 60 mm and a length of 16 mm was ignited by a heated metal wire, 100 μm in diameter, the temperature of which was measured by an optical pyrometer[1]. Since yields of the upward flow are due to the buoyancy before ignition in normal gravity, ignition times should increase in comparison with ignition times in microgravity. A numerical approach was also conducted for microgravity conditions.

Ignition delays due to the use of a tungsten wire for the stoichiometric methane-oxygen mixture are plotted in Fig.1, showing that ignition delays in normal gravity are quite scattered and longer than those in microgravity. For the methane-air mixture, however, there are no differences between normal gravity and microgravity. Numerical calculation showed that the ignition point in methane-oxygen is some distance from the hot wire, while ignition in methane-air occurs near the wire. This means that the buoyancy effect is stronger in the case of methane-oxygen.

Figure 2 shows the temperature histories of platinum wire for the hydrogen-air mixture. In the case of the equivalence ratio $\phi = 0.3$, there are abundant oxygen molecules around the wire, and so ignition times are shorter than those for $\phi = 1$ and the discrepancy between normal gravity and microgravity is not recognized. In the case of $\phi = 1$, however, the effect of the natural convection which supplies oxygen to the wire surface and promotes the surface reaction is quite large. Therefore, ignition takes place faster in this case.

Burning Velocity (PI : S. Okajima)

To measure the flammability limits and the burning velocities near the limits, a closed cylindrical vessel with a diameter of 116 mm and a length of 120 mm was installed in a freely falling chamber [2,3]. The burning velocities were obtained from schlieren streak photographs.

Figure 3 shows the burning velocities plotted against the equivalence ratio for methane and propane. The burning velocities were compared with those obtained by other methods, and it was concluded that the burning velocities in this experiment agreed well with those obtained by the counterflow twin-flame method [4], which will be explained in the next section.

By use of the same apparatus, cellular flames were also observed for methane and propane [5]. The authors concluded that there was an equivalence ratio which indicated the maximum probability of the appearance of a cellular flame, and that the cell structure of both fuels became fine as the initial pressure in the vessel increased.

Flammability Limit (PI : T. Niioka)

The objective of this experiment was to obtain the flammability limit and to observe the flame behavior near the limit by use of the technique of counterflow twin premixed flames, because flames in extremely low velocity fields can be stabilized in microgravity, as shown in Fig.4.

Usually, keeping the concentration constant, the counterflow velocity is increased and extinction is observed. Here, fuel concentration was decreased according to a computer-programmed control, keeping the low flow velocity constant. The most difficult point in the study of this very low speed flow is whether the flame is followed by slight flow control. Figure 5 shows that there was little difference between the equivalence ratio controlled arbitrarily and the flame interval.

Figure 6 is a plot of the equivalence ratio and the distance between twin flames versus time. In the case of methane, the twin flames approached monotonously and were extinguished after they becoming united. This proved to be true as expected. In the case of propane, however, twin flames were united and extinguished as well, although it was expected that extinction would occur when the flames were still separate, owing to the Lewis number effect.

Since sudden changes of the flame interval were always recognized in the case of propane, the location of the symbol (*) in Fig.6(b) was defined as the point of flammability limit. This is because, after this point, flames cannot maintain their self-propagation characteristics and only unstable flames can exist. The variation of the nominal stretch rate with the equivalence ratio at extinction showed that the flammability limit of the propane/air mixture was 0.50.

Blowoff Limit (PI : J. Sato)

The flow velocity gradient at the burner rim has a great effect on the blowoff condition of premixed flames. When the flow velocity of the mixture is small, however, the effect of buoyancy may also be significant, and so it is expected that there is a discrepancy between the case for that in normal gravity and for that in microgravity for a very lean or a very rich mixture. This experiment is now being conducted using methane as a fuel.

Diffusion Flame (PI : J. Sato)

Methane is issued from a tube with an inner diameter of 5 mm, and an airflow nozzle with a diameter of 54 mm is constructed in a concentric configuration. The thickness of the fuel burner rim is 0.1 mm to avoid the effect of turbulence at the rim. In normal gravity, flickering of the diffusion flame with a frequency of about 10 Hz was observed at a fuel velocity of 25.5 cm/s when the outer airflow is stopped.

Switching from this condition in normal gravity (Fig.7(a)) to the same condition in microgravity, the flame shape changed as shown in Fig.7(b), (c) and (d), in that order, within one second. Since air is not supplied by natural airflow convection and is transferred only by diffusion, the flame becomes weak and only blue flame exists around the burner port, as shown in Fig.7(d). It can be seen in Fig.7(d) that the diffusion flame developed below the burner port owing to the downward diffusion of methane.

In the present study, only the diffusion flame was observed, but in the next step, the turbulent flame will be observed to determine the contribution of natural convection to the turbulent diffusion flame. In addition, we plan to study the effect of air temperature on the diffusion flame.

The Effect of Magnetic Field (PI : K. Ito)

Oxygen molecules are paramagnetic, and therefore the transport of oxygen should be influenced by a magnetic field. The objectives are not only to investigate the combustion mechanism in a magnetic field but also to promote combustion, for example, by utilizing the change of the flame shape.

A butane diffusion flame was established on a circular tube with an inner diameter of 0.6 cm. The tube was made of copper so as to be independent of magnetic field. Figure 8 shows the arrangement of the burner, the flame(R) and the magnet (A), the magnetic force (H) of which had a certain distribution. Butane was chosen as the fuel.

A comparison of the flame shapes is shown in Fig. 9. Standardizing flame (A) in normal gravity and without magnetic field, totally, flames (B, C) without magnetic field changed more drastically, while flames (A′, B′, C′) with magnetic field did not change much. Actually, it was not possible to establish a flame in microgravity (C), although it was possible to sustain a flame if the field was magnetized (C′). This means that the effect of the magnetic field on oxygen transport is very strong and that the flame shape is not greatly affected by natural convection.

Carbon Formation (PI : K. Ito)

From a circular tube with a diameter of 0.6 cm, butane was flowed out and ignited in a stagnant oxidant atmosphere. The fuel flow rate was 0.3 through 1.2 cm^3/s. Figure 10 is a schematic representation of what the flame looked like from above.

Large particles of soot with a diameter of over 100 μm were formed in 50% oxygen air, which was 200 to 500 times greater than the case in normal gravity. The carbon zone is located in a ring-shaped region on the top of a spherical diffusion flame, as seen in Fig.10(b).

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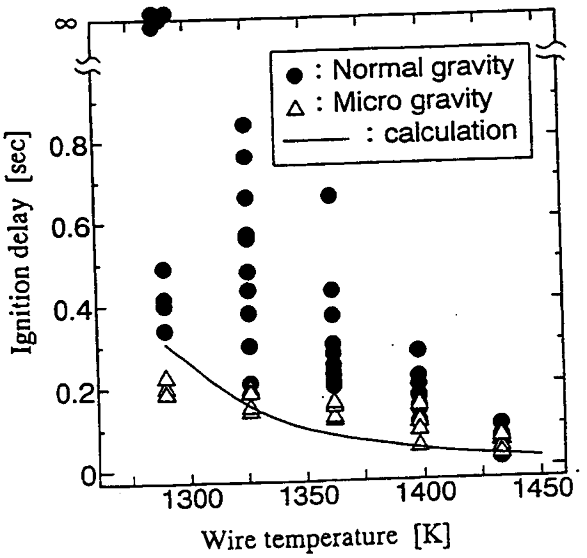


Figure 1. Comparison of ignition delay times of a stoichiometric methane-oxygen mixture in normal gravity with such times in microgravity.

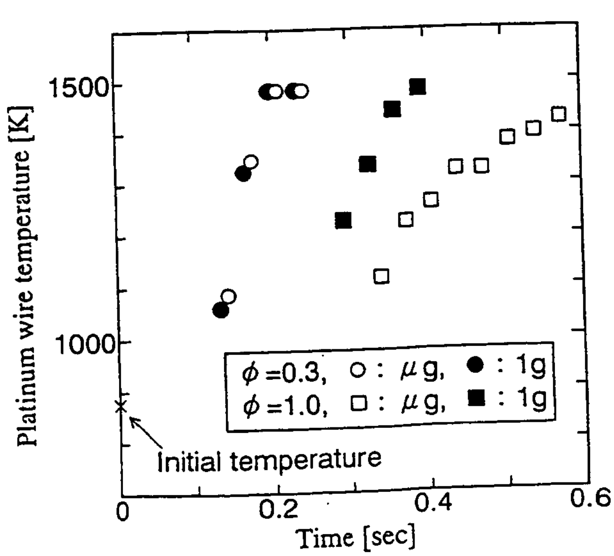


Figure 2. Histories of platinum wire temperature for a hydrogen-air mixture.

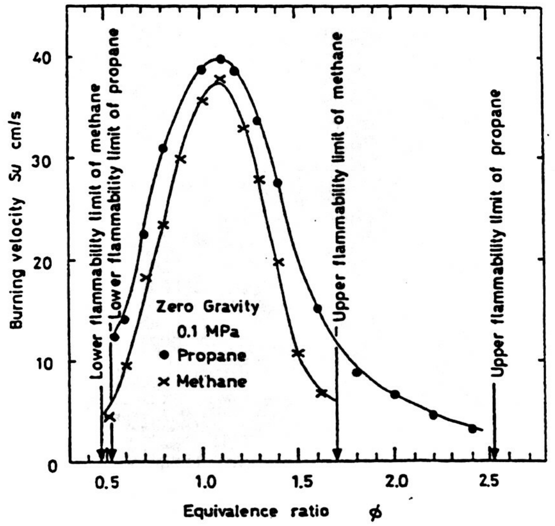


Figure 3. Burning velocities versus equivalence ratio for propane- and methane-air.

Figure 4. Direct photo of twin flames in a low velocity counterflow field in microgravity.

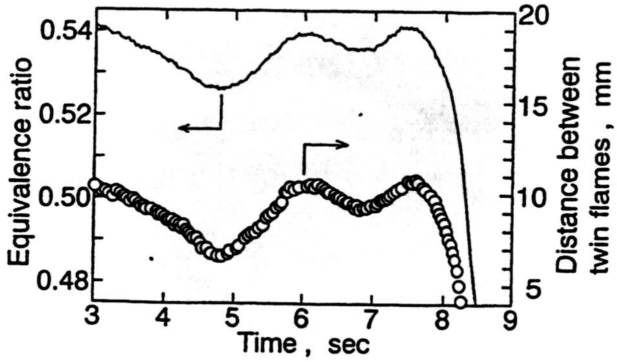


Figure 5. Variation of twin flame distance with time when the equivalence ratio was changed arbitrarily.

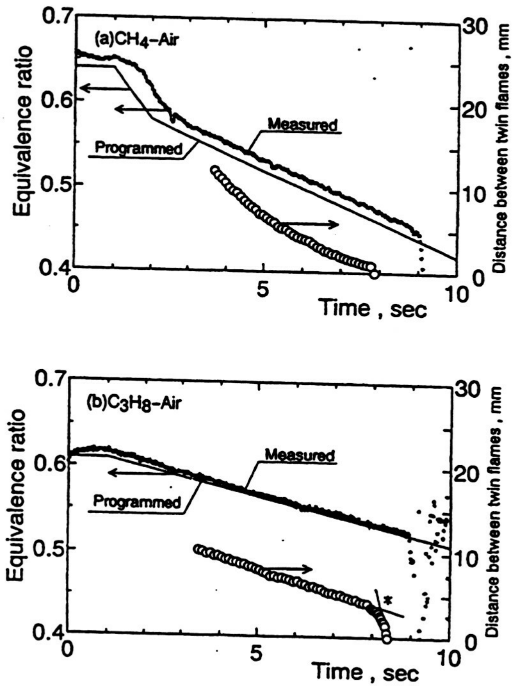


Figure 6. The variation of twin flame distance with time for methane (a) and propane (b).

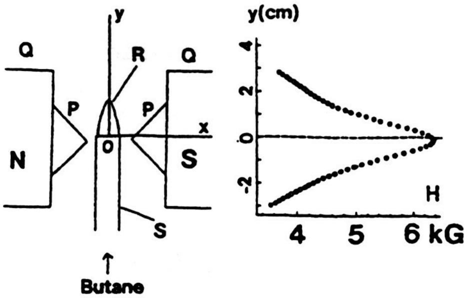
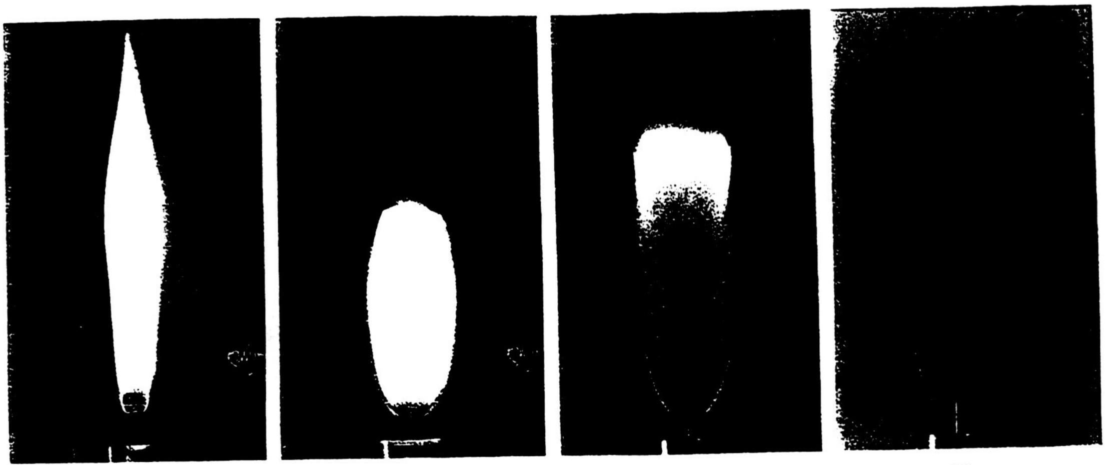


Figure 8. Arrangement of experimental apparatus for a flame in a magnetic field.



(a) (b) (c) (d)

Figure 7. Diffusion flame of methane without forced convection of air. (a) in normal gravity, (b) about 0.3 sec after drop, (c) about 0.6 sec after drop, (d) about 1 sec after drop.

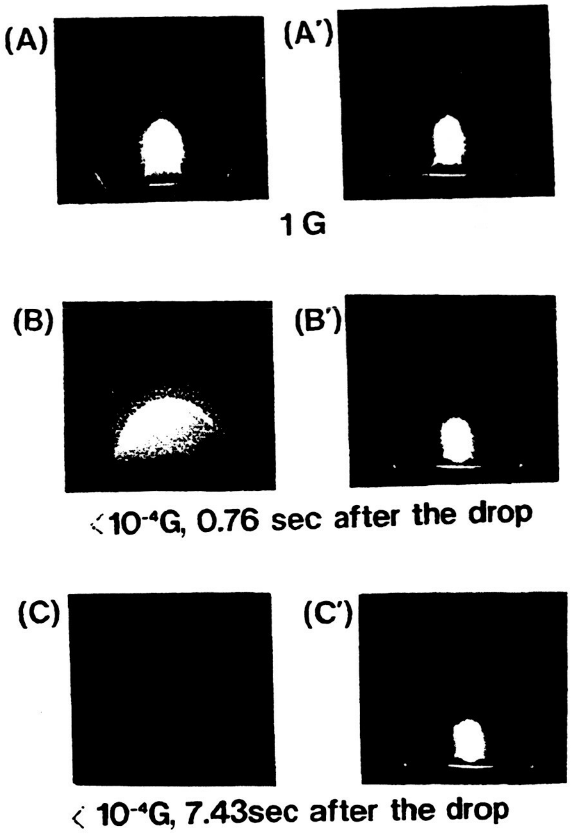


Figure 9. Flame shape changes in a magnetic field.

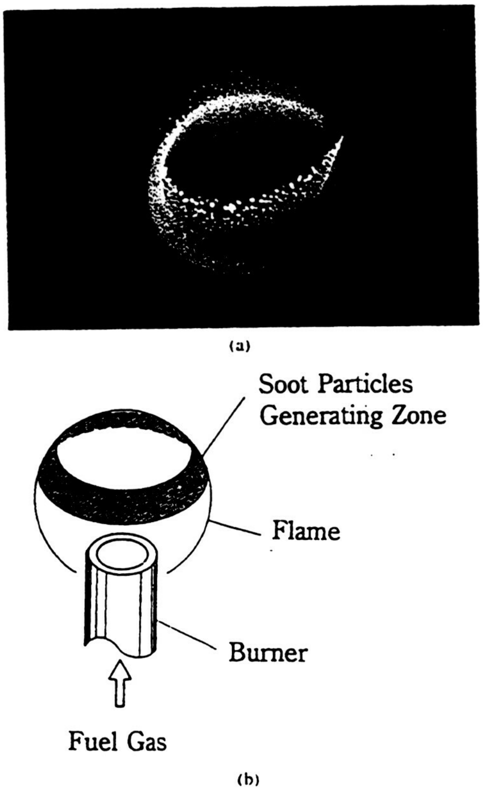


Figure 10. Picture of a flame with luminous spots taken from above the flame under microgravity (a) and schematic representation of the formation region.