Effect of Ambient Pressure on Spreading flame over Wire Insulation under Opposed Flow Condition

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対向空気流中電線被覆上燃え拡がり火炎に及ぼす圧力影響について

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1. Introduction

In a spacecraft, ignition of electrical wires can often be the starting point for a fire, and subsequent flame spread over the wire insulation can result in a catastrophic situation. To ensure the fire safety in spacecraft, there are several researches of wire combustion in microgravity. Takahashi et al. conducted experiments to get the Limiting Oxygen Concentration (LOC) using Nickel-Chrome (NiCr) and copper core wires insulated with polyethylene under opposed air flow conditions[1]. Also, Mizutani et al. conducted experiment to get the LOC using copper core wires insulated with fire-resistant material ethylene-tetrafluoroethylene (ETFE) under same condition[2]. However, there is limited research of spreading flame over electrical wire under various pressure in microgravity[3] even though spacecraft wire may occur in different condition from standard atmospheres[4].

The present paper investigates the effect of pressure on LOC of a flame spreading over a polyethylene insulated NiCr wire in microgravity. It also compares the data obtained with normal gravity in order to evaluate the influence of gravity.

2. Experimental Configuration Figure

Figure 1 shows the experimental setup for the parabolic flight tests and the ground tests.

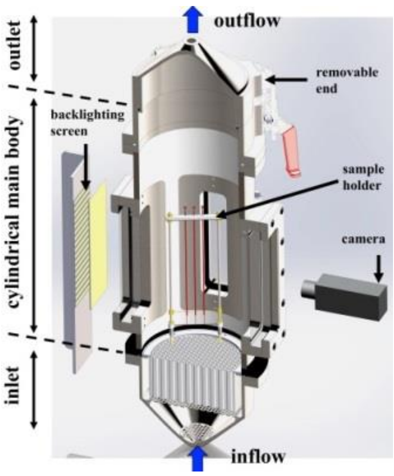

Fig. 1 Schematic cut of the experimental setup

In the combustion chamber, the oxidizer flow entered from the bottom and was vented at the top. Oxygen concentration in the oxidizer flow could be adjusted from 0 to 21 % by mixing of air and nitrogen gas. The external flow velocity inside the chamber was always set to 10 cm/s and pressure could be adjusted from 0.5 to 1.4 atms. Two cameras were set to capture detailed live information. One camera captured direct flame emission and the other one imaged the flame before a backlighting screen to evaluate the burning rate of molten insulation as well as flame absorption. A detailed description of the experimental design and method is given by Citerne et al.[5].

Every sample holder had a wire coated with 130 mm of polyethylene. In this study, a polyethylene insulated NiCr wire were used. The core diameter was 0.5 mm and the insulation thickness was 0.3 mm. For the ignition procedure, an 8 mm coil made from 0.5 mm diameter Kanthal wire was set to encircle (6 times) the downstream end of the sample wire, and the coil produced approximately 94 W for 8 seconds. The ignition sequence was initiated before the start of the microgravity period, so that the actual ignition occurred during microgravity. The microgravity environment was therefore carried out during parabolic flights (on board of the Novespace A310 airplane), which enabled microgravity conditions for about 22 seconds for each parabola.

3. Result

In this study, when a flame is sustained during the whole microgravity period of each experiment, it is considered as a "propagation" scenario. When the flame is not sustained during the whole period of microgravity, it is considered an "extinction" scenario. Near the LOC condition, propagation flame was too dim to capture the visible camera. So, we judged the propagation and extinction using the movement of molten insulation in the flame using backlighting camera. Then, the LOC is assumed to exist between the maximum extinction case and minimum propagation case.

Figure 2 and Figure 3 show the LOC of spreading flames over wire insulation in microgravity and normal gravity under different pressure conditions. This was single run experiment. Each plot shows one experiment. An open circle corresponds to flame propagation conditions, and a cross shows flame extinction conditions. Also, solid line shows the LOC boundary expected from experimental result. In both gravity case, the LOC decreased as pressure increased. Also, the LOC of microgravity is about 2 % smaller than that of normal gravity in terms of minimum LOC value.

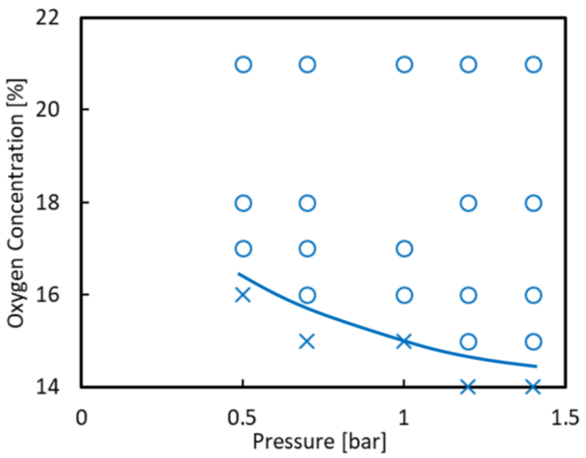

Fig. 2 LOC of microgravity (10 cm/s)

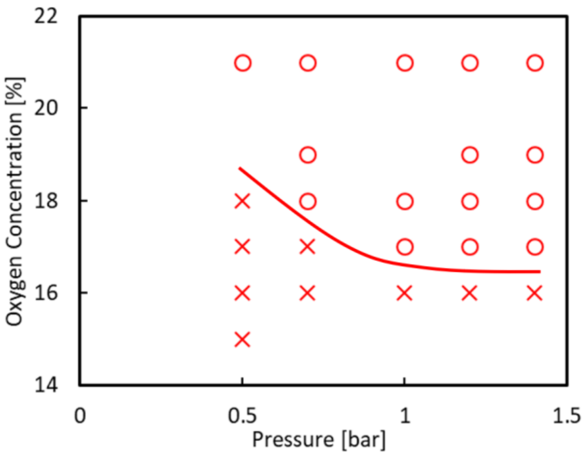

Fig. 3 LOC of normal gravity (10 cm/s)

4. Discussion

4.1 Effect of pressure

To consider the flame spreading over wire, the length of preheat zone and stand-off distance is important index. As external pressure decreases, the length of preheat zone and stand-off distance increase because thermal diffusivity increase as pressure decrease. And increasing stand-off distance of spreading flame over wire insulation cause the decreasing of heat input from flame to wire insulation. Also, increasing of length of preheat zone cause increasing of radiation loss from wire surface. Finally, these effects cause the increasing of LOC under small pressure.

4.2 Effect of gravity

In the microgravity condition, natural convection reduced, and this causes the decrease of relative flow velocity. In the normal gravity condition, the relative flow is equal to the sum of external flow velocity and natural convection and flame spread rate. However, in the microgravity condition, the relative flow is only the external flow velocity and the flame spread rate. Because of the existence of natural convection, heat loss because of natural convection was occured. Therefore, the LOC in microgravity is smaller than that in normal gravity. Also, molten ball is another reason. The molten ball fell in normal gravity but never fell in microgravity and this fall makes the extinction easier.

5. Conclusion

The present work investigated the effect of pressure on Limiting Oxygen Concentration (LOC) of a spreading flame over PE insulated NiCr wire in normal and microgravity. The main conclusions of the present study may be summarized as follows:

(1) According to the flammability tests, LOC decrease as pressure increased in both gravity case, because flame enlarged in low pressure and reduced the heat input from flame and increase of radiation loss from wire surface.

(2) The LOC of microgravity is smaller than that of normal gravity because of natural convection.

These results provide insight into the mechanism of extinction limit of flame spread over wire insulation, especially the effect of pressure on the extinction limit, which will be useful for establishing reliable fire safety standard for spacecraft.

Acknowledgments

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