EFFECT OF LOW EXTERNAL FLOW ON FLAME SPREADING OVER ETFE INSULATED WIRE UNDER MICROGRAVITY

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1. INTRODUCTION

Fire safety is one of the most important issues for manned space missions. A likely cause of fires in spacecraft is wire insulation combustion in electrical system. Regarding the wire insulation combustion it important to know the effect of low external flow on the combustion because of the presence of ventilation flow in spacecraft. Although, there are many researches on flame spreading over solid material at low external flows under microgravity [1,2], research dealing with wire insulation is very limited. An example of wire insulation combustion in microgravity is the Space Shuttle experiments carried out by Greenberg et al [3]. However, the number of experiments was very limited. Therefore, the effect of low flow velocity is still not clear. The authors have reported results on flame spreading over ETFE (ethylene-tetrafluoroetylene) insulated wire in a quiescent atmosphere in microgravity by 10 seconds drop tower [4]. The authors also performed experiments of polyethylene insulated nichrom wire combustion in low flow velocity under microgravity [5]. The results suggested that flame spread rate had maximum value in low flow velocity condition. Another interesting issue is the effect of dilution gas, especially CO_2, which is used for fire extinguisher in ISS. There are some researches working on dilution gas effect on flame spreading over solid material in quiescent atmosphere in microgravity [4,6]. However the research with low external flow is limited and, of course, the research discussing a relation of the appearance of maximum wire flammability in low flow velocity region with different dilution gas cannot be found yet. The present paper, therefore, investigates the effect of opposed flow with different dilution gas on flame spreading over ETFE insulated wire and change in the presence of the maximum flammability depending on the dilution gas type is discussed within the limit of microgravity time given by ground-based facility.

Generally, solid combustion has longer time scale than other phase fuel, especially with thick sample and/or low oxygen concentration and it is difficult to obtain reliable data in short time microgravity test. Therefore, the present work is limited to high oxygen concentration cases with thin fuel. To attain general understanding of wire insulation combustion, the test with long-term microgravity is essential. This subject is selected as a candidate of ISS flight test at IAO2000

(Effect of Material Properties on Wire Flammability in Weak Ventilation of Spacecraft (FireWIRE)) and the research is now under definition stage.

2. EXPERIMENTAL

The experiments were performed at the Japan Microgravity Center (JAMIC) 10s dropshaft and NASA's KC-135 aircraft. The detail of the setup for KC-135 test is described in Ref. [7].

Figure 1 shows the combustion chamber with flow duct used for JAMIC test. The combustion chamber is a rectangular airtight vessel, and a flow duct is installed in the chamber. The chamber has an air suction fan at the left end of the duct. The flow velocity in the duct is controlled in the range 0 to 30cm/s.

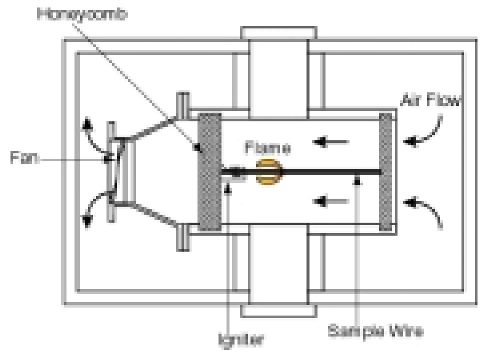


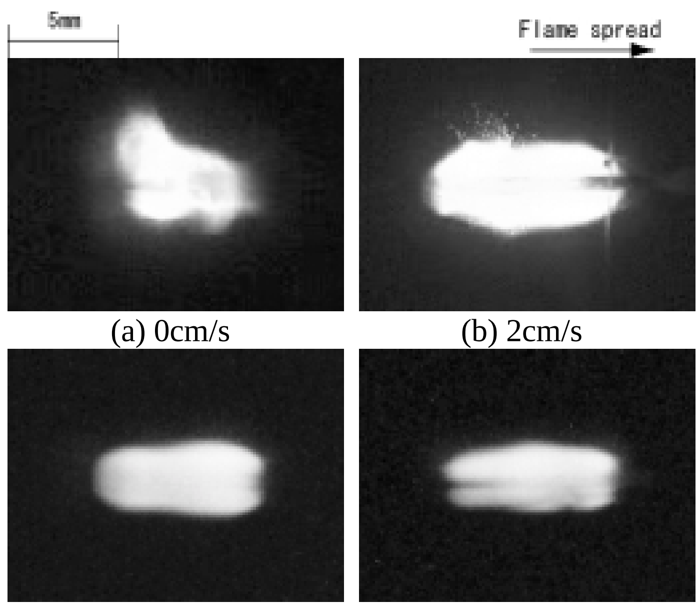
Fig.1 Out line of combustion chamber

A sample wire, which is fixed to the sample holder with igniter, is installed in the center of the flow duct parallel to the external flow. Flame spreads opposed to the external flow (from left to right in Fig.1). ETFE (ethylene- tetrafluoroethylene copolymer) insulated copper wire was used as a test sample. The sample use in the experiments is 0.32mm inner core and 0.15mm insulation thickness (AWG28). Experiments were performed with different O_2 concentrations, external flow velocities and dilution gas, N_2 and CO_2.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 OBSERVATION OF FLAME

Figure 2 shows photographs of spreading flame at different flow velocity in 35% O_2 with CO_2 dilution. It shows that the flame is luminous with blue flame region at the front of the flame in all external flow velocity. At 0cm/s, the trailing edge of flame becomes wide in comparison with the leading edge. When external flow is given, flame shape as seen in Fig.2 (b), (c) and (d), is cylindrical with almost same diameter along the wire.



(a) 0cm/s (b) 2cm/s (c) 5cm/s (d) 10cm/s

Fig.2 Photographs of spreading flames over ETFE insulated wire under different external air flow with CO_2 dilution (O_2=35%)

Another interesting phenomenon is unsteady flame spreading with CO_2 dilution at low flow velocity, 0 and 2cm/s. Figure 3 shows the typical sequential photos of spreading flame at 2cm/s with CO_2 dilution. The time interval of each photo is approximately 0.2s. A most ordinal flame shape is the one as shown in Fig. 3 (a). Then, at the flame front blue flame propagates fast as shown in Fig.3(b), (c). After that, another luminous flame grows at the front of spreading blue flame front as see in Fig.3 (d). This secondary luminous flame is small at first but increases in size with time as shown in Fig. 3(e), (f). Then, the primary luminous flame quenches and secondary flame spreads. This unsteady phenomenon is unique phenomena observed in low external flow condition with CO_2 dilution. One of the possibility reasons of the unsteady phenomenon is reabsorption effect of CO_2 gas. In low flow velocity, preheat length is strongly affected by reabsorption [8]. The preheat length becomes longer with time by CO_2 reabsorption when flow velocity is low. Then, heat transfer to unburned fuel at the preheat zone increases. When total heat supply to the unburned region reaches critical amount, suddenly flame spreads fast and the preheat length decrease again.

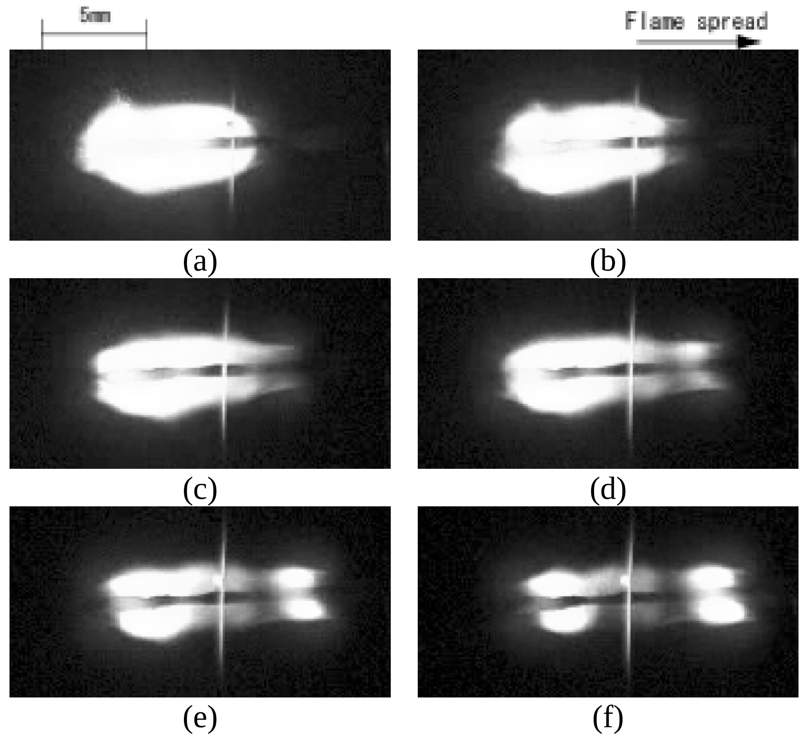


Fig.3 Sequential photographs of spreading flames in low velocity flow with CO_2 dilution (V_e=2.1cm/s)

3.2 FLAME SPREAD RATE

Flame spread rate is determined based on the motion picture taken by digital video camera. Fig.4 shows plots of flame spread rate as a function of flow velocity for different oxygen concentrations with N_2 dilution. The flame spread rate generally increases with increase in ambient oxygen concentration, irrespective of flow velocity. Another interesting feature with N_2 dilution is the trend to show a maximum flame spread rate at a certain flow velocity, around

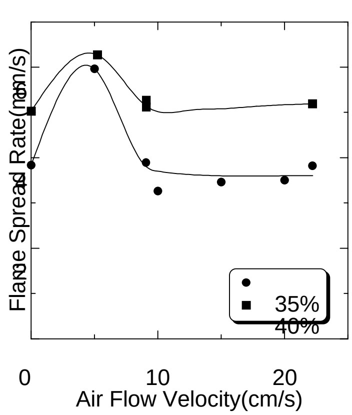


Fig.4 Flame spread rate as a function of external air flow velocity (N_2 dilution)

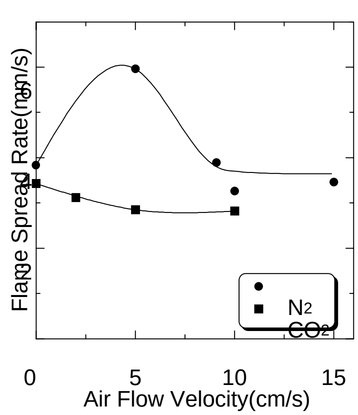


Fig.5 Flame spread rate with different dilution gas (O_2=35%)

5cm/s, in low flow velocity region. This trend qualitatively agrees with the case of polyethylene insulated wire [5]. This is one of the feature of wire insulation combustion, which is explained as an geometrical effect in Ref.[5].

Figure 5 shows the flame spread rate change as a function of external flow velocity with different dilution gas. The flame spread rate with N_2 is faster than that with CO_2 at 35% O_2, irrespective of flow velocity. The trend of flame spread rate is different between N_2 and CO_2. With N_2, flame spread rate tends to have maximum value as mentioned baove. On the other hand, CO_2 dilution case resulted in the highest flame spread rate at V_e=0cm/s and decrease monotonically with increase in flow velocity. Then, it reaches almost constant spread rate over a certain flow velocity. Therefore, the flame spread rate has no maximum value in low flow velocity region with CO_2 case. One of the reasons of the difference is reabsorption effect of CO_2 gas. With CO_2, radiation heat from the flame is reabsorbed in preheat region [8] and flame temperature decrese is not large, while N_2 dilution leads to large temperature decrease causing decrease in flame spread rate. In high flow velocity region the reabsorption effect is not important and the trend becomes similar to N_2 dilution case.

4. SUMMARY

(1) The dependence of flame spread rate on flow velocity was examined with drop tower and aircraft. Specially, flame spread rate with N_2 and CO_2 was compared. Flame spread rate was 2-6mm/s even if oxygen concentration was 35% or higher. Therefore, it is difficult to obtain data with low O_2 concentration or thick sample in ground-based facility. Long term microgravity test such as ISS is expected.

(2) Flame spread rate with N_2 has maximum value in low flow velocity region, while with CO_2 flame spread rate increases monotonically with decrease in flow velocity. One of the explanations of the difference is effects of sample geometry and reabsorption of CO_2 gas.

(3) Unsteady flame spread phenomenon was observed with CO_2 dilution. This phenomenon is explained by CO2 reabsorption effect, which is to be investigated in the next step.

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