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# EFFECT OF SLOW EXTERNAL FLOW ON FLAME SPREADING OVER SOLID MATERIAL

## -OPPOSED SPREADING OVER POLYETHYLENE WIRE INSULATION-


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## INTRODUCTION

The effect of slow external flow on solid combustion is very important from the view of fire safety in space because the solid material in spacecraft is generally exposed to the low air flow for ventilation. Further, the effect of low external flow on fuel combustion is generally fundamental information for industrial combustion system, such as gas turbine, boiler, incinerator and so on. However, it is difficult to study the effect of low external flow on solid combustion in normal gravity, because the buoyancy-induced flow strongly disturbs the flow field, especially for low flow velocity. In this research, therefore, the effect of slow external flow on opposed flame spreading over polyethylene (PE) wire insulation have been investigated in micrograivty. The microgravity environment was provided by Japan Microgravity Center (JAMIC) in Japan and KC-135 at NASA GRC. The tested flow velocity range is 0-30cm/s with different oxygen concentration and inert gas component.

## EXPERIMENTAL

Figure 1 shows the test section of the wire combustion. The sample wire is horizontally fixed at the center of the duct and is ignited at the left end of the wire with Kanthal wire coil. At the left end of the duct a

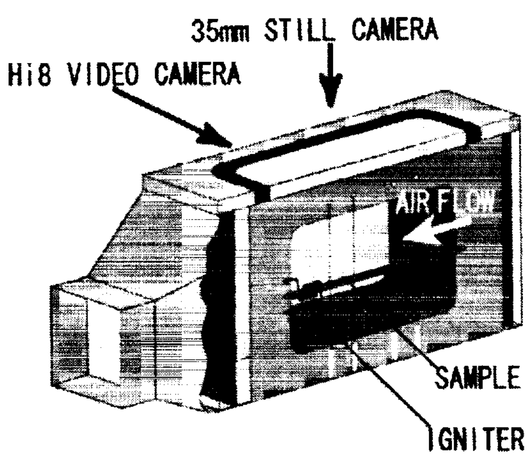


Fig.1 Cross section of combustion chamber

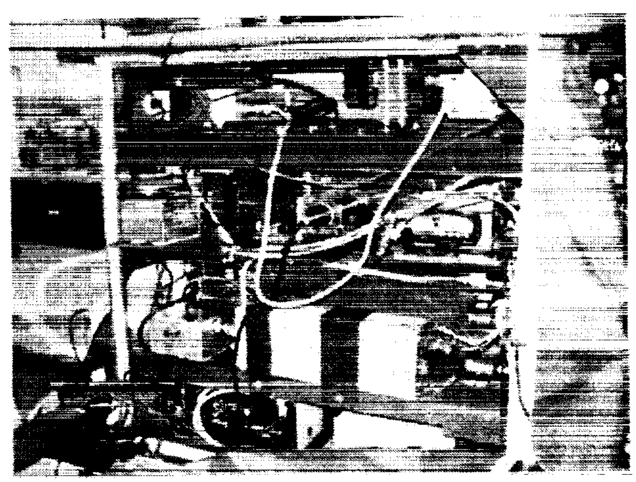

Fig.2 Rig for KC-135 experiments

suction fan is installed and uniform external flow along the wire is given from right to left. Therefore, opposed flow flame spreading over wire insulation is achieved. Flame spread phenomenon is observed from the top and rear window with 35mm still camera and Hi-8 video camera, respectively. Flame spread rate is measured from the motion picture taken by Hi-8 video camera. Figure 2 shows the experimental rig used for KC-135 parabolic flight experiments. The test section described above is located on the second shelf of the rig. The rig is originally designed for TIGER-3D project and is modified for the wire insulation combustion test within a low external flow.

Microgravity tests were performed with KC-135 parabolic flight for high flow velocity case (mainly larger than 10 cm/s) and with JAMIC for low flow velocity case (mainly less than 10cm/s) and high O2 concentration case. The experimental sample used in the test is polyethylene insulated nicrom wire as was used with WIF experiments[1], whose the core diameter is 0.5mm and insulation thickness 0.15mm.

## RESULTS AND DISCUSSION

Figures 3 and 4 show a flame in normal gravity and microgravity, respectively. In normal gravity, flame plume appears naturally because of buoyancy induced flow. In microgravity the plume does not appear and flame locates along the wire. The flame in microgravity is darker, which implies the lower flame temperature even with external flow. In the discussion below flame spread rate over horizontal wire as shown here is compared between normal gravity and microgravity.

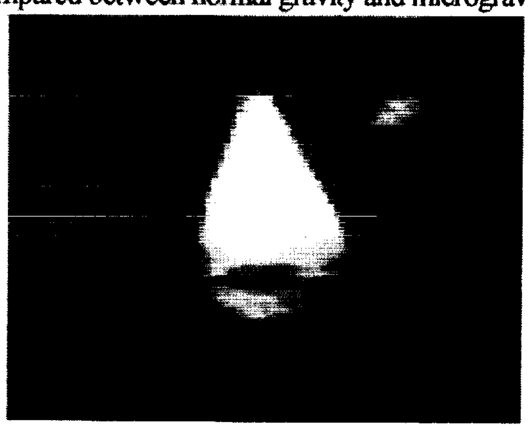

Fig.3 Flame in normal gravity(O2=35%,V=1.3cm/s)

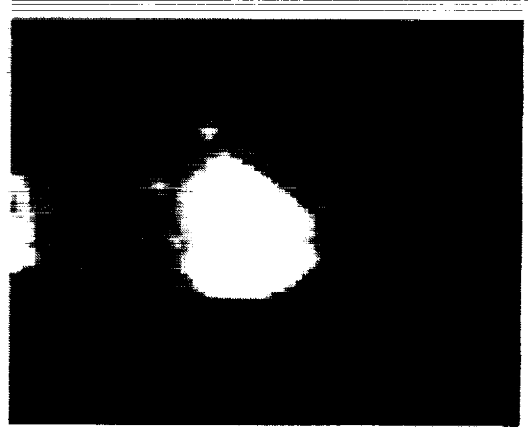

Fig.4 Flame in microgravity(O2=35%,V=1.3cm/s)

Figure 5 shows the flame spread rate in normal gravity. As seen in the figure, spread rate decreases monotonously with increase in flow velocity for each O2 concentration, while the effect of O2 concentration to increase the spread rate is significant. In microgravity, as shown in Fig.6, trend is different from that in normal gravity. Flame spread rate increases with increase in flow velocity in low velocity range and it shows a maximum value at a certain flow velocity. This trend is more obvious at higher O2 concentration. Figures 7 and 8 show the change in the spread rate versus external flow velocity with different balance gas taken in normal gravity and microgravity, respectively. The effect of balance gas on the spread rate is also strong as well as O2 contestation. According the comparison of the two figures, it is understood the trends in normal and microgravity is different each other as was seen in the comparison between Figs. 5 and 6. Flame spread rate tends to show a peak value at a certain flow velocity in normal gravity, while it monotonously decreases in normal gravity.

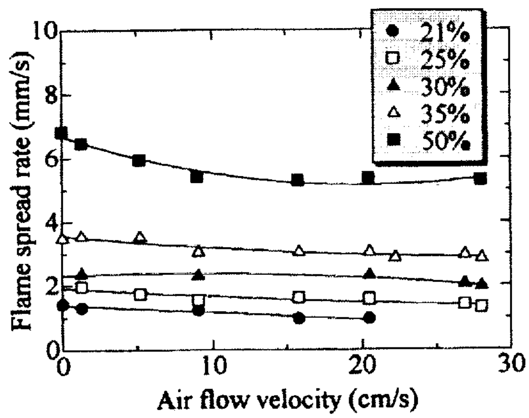


Fig.5 Spread rate vs. external flow velocity in 1G

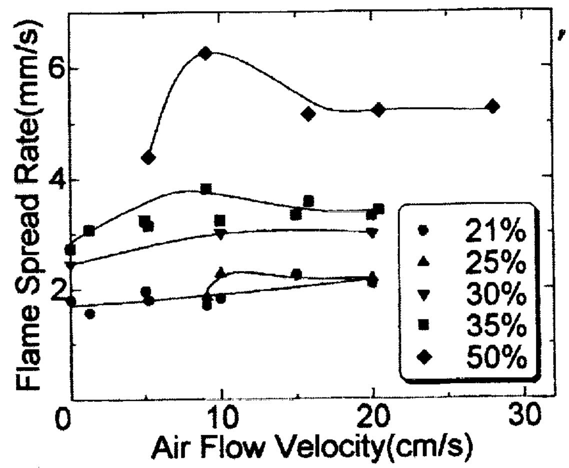


Fig.6 Spread rate vs. external flow velocity in $\mu$ G

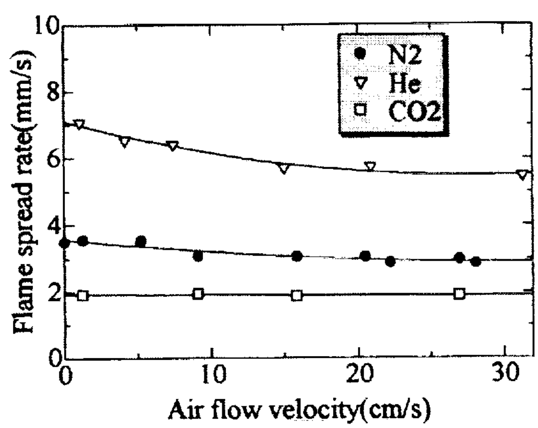


Fig.7 Effect of balance gas on flame spread rate in 1G (O2=35%)

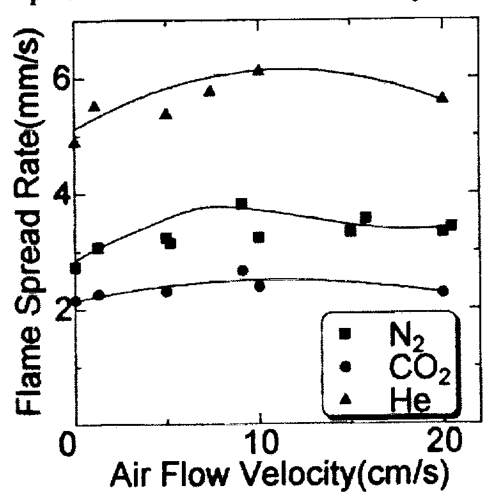


Fig.8 Effect of balance gas on flame spread rate in $\mu$ G (O2=35%)

This trend in micorgravity is very essential because it implies the presence of the most flammable region of wire insulation. The flow velocity to give a maximum spread rate is close to the ventilation flow in spacecraft. In the previous research on paper sheet combustion [2], the trend to appear maximum spread rate was shown even for thermally thin fuel. This trend was explained by the transition from oxygen transport control region to the kinetic control region. In the case, the appearance of a peak value was more obvious in lower oxygen concentration. On the other hand, the trend to show peak value in Fig.6 is more obvious in higher oxygen case and it is assumed that the reason to appear the peak value is different from the transition from the oxygen supply control to the kinetic control.

One of the explanations to appear the maximum value is the increase of preheat zone thickness in low flow velocity under microgravity condition [3,4]. With increase in preheat zone thickness heat flux to the unburned region increases. However, when the external flow velocity is very low close to the quiescent condition flame temperature decreases. Therefore, spread rate decreases again in the low flow velocity region, while the preheat zone is thicker with lower flow velocity. As a result the maximum spread rate appears at a certain flow velocity region. In normal gravity, flame temperature is kept high even in low external flow because of vertical buoyancy induce flow. If the flame temperature is kept high enough, flame spread rate increases with decrease in external flow velocity because of thicker preheat zone as well as larger radiation heat to the unburned fuel.

Another important fact is the comparison of spread rate with CO2 balance in normal gravity and microgravity. The spread rate in microgravity is higher than horizontal flame spread rate in normal gravity, while other balance gas gives the lower spread rate in microgravity than normal gravity. A possible mechanism to explain the effect of CO2 is reabsorption of radiation heat from the flame. The CO2 gas ahead of the flame front is heated with radiation heat and it makes the preaheat zone thickness wider in microgravity. In normal gravity preheated CO2 gas ahead of flame flows away upward because of buoyancy force and the reabsorption effect becomes negligible.

## SUMMARY

Flame spreading over wire insulation within low external flow has been investigated in microgravity by KC-135 at NASA GRC and Japan Microgravity Center (JAMIC). The tested flow velocity range is 0-30cm/s with different oxygen concentration and inert gas component. The results showed that the flame spread rate was almost constant for different flow velocity, when the flow velocity is higher than 10cm/s within the tested range. In the very low flow velocity range, less than 10cm/s, maximum flame spread rate appeared. It means more flammable regime on external flow velocity than the so-called thermal regime. This phenomena is explained by the increase of preheat zone thickness in low flow velocity region as well as flame temperature decrease by radiation heat loss.

## ACKNOWLEDGEMENT

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