Flame Spread along a paper disk in a narrow channel

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1 Introduction

Flame spread along combustible surface is governing growth and extinction in fire hazards. Understanding of the flame spread is practically important to reduce fire risk. Flame spread is controlled by heat and mass transfer, and chemical reaction. Flame spread has been studied in various conditions, for example, flame spread over liquids[1-7] and solids[8-11].

In nuclear power plant, to prevent contamination, floor and wall are covered with combustible sheet. Narrow gaps between sheet and wall could be present and fire might spread in these gaps. In the narrow channel, the irregular flame spread called fingering might occur[12]. The conditions of the limit of fingering spread are not well understood.

The objective of this study is to determine the flame spread mechanisms in narrow channel. In this research, the flame spread characteristics of solid fuel in a narrow channel is examined, experimentally.

2 Experimental Apparatus and Method

Figure.1 shows a schematic of the experimental system. The experimental apparatus consisted of a test section, an igniter and enclosure. The enclosure removes disturbance of air flow around the test section. The top view of flame spread along a paper disk is recorded through a glass window(the diameter is 400 mm) by a digital video camera. The glass window is ceiling of the test section. A base of the test section is made of granite stone, with the diameter of about 400 mm and thickness of 55 mm. The base is installed horizontally. Figure.2 shows a detailed view of the test section. The test material is a filter paper (ADVANTEC, No.1), and the diameter is 300 mm. The homogeneous filter paper is fixed on a holder made of calcium silicate board held by 16 points using double-stick tape and it was held in the holder by the uniform tension. The holder is a ring of external diameter 360 mm, internal diameter of 280 mm and of thickness 4.5 mm. The holder was installed between the base and the glass window with spacers to maintain a constant gap. d_1 is the gap between the base and filter paper, d_2 is a gap between the glass window and filter paper. An ignition source, a coil-like chromel thin wire was installed on the center of the base. Diameter of the coil was about 3.5 mm. The enclosure made of metal mesh of wire diameter 0.29 mm, mesh pitch 1.00 mm and height 800 mm was used. The top of enclosure is opened in order to observe a flame spread along a filer paper. The paper disk ignited by electric heating of the chromel thin wire, and the electric heating continued until the flame travels 15mm from the center. The obtained image information was analyzed by a computer.

3 Results and Discussion

3.1 Category of the flame spread

Figure 3 show images of the typical aspect of flame spread observed in this study. The aspect of flame spreads were broadly categorized into three; uniformly concentrically (fig.3a), quenched (fig.3b) and irregular (fig.3c-e). The uniformly concentrically is denoted as "Mode a", quenching is denoted as "Mode b" and irregular is denoted as "Mode c". Fig.3e is fingering in "Mode c". In these irregular flame spread such as "Mode c", dense smoke was observed. Fig.3 correspond to the figure of the detail of test section (fig.2). Three spacers is installed every 120 degrees. Flame spreads from the center of the paper disk. The paper disk is held by a white panel ring. A hole is formed on the center of the paper disk after ignition, and the base becomes visible. A line seen on the base is copper foils for power supply to the ignition source. It is confirmed that copper foils of 0.1 mm thick do not affect flame spread in fig.3. As mentioned above, in "Mode b", the flame was quenched and a part of paper disk remained. In "Mode a" and "Mode c", the flame finally reached the holder ring. Furthermore, there was no correlation in a fixed part of filter paper and the location of the finger.

3.2 Relationship between heights of the flow channels

Figure 4 shows relationship between two gaps, d_1 and d_2 of the flow channel. Symbol of circle shows "Mode a" or "Mode c", and symbol of triangle shows "Mode b". Fig.4 indicates that the boundary exists between "Mode a, c" and "Mode b". Near the boundary "Mode c" were observed. In fig.4, the flame spread limit is shown as $d_2 = -0.67d_1 + 21.8$. The effect of d_2 for flame spread is about 1.5 times larger than d_1. Where d_1 is small and d_2 is large (for example, d_1 =5 mm, d_2 =18 mm) fingering appears. As d_2 increases, the natural convection in a gap between the glass window and filter paper grows rapidly, then it seems that the developed natural convection controls the flame spread through the heat and mass transfer in the flow channel.

3.3 Relationship between ~~a~~ mean radius of flame and time after heating ~~ignition~~

Figure 5 shows mean radius of flame with time after heating. The vertical axis is mean radius of flame obtained by dividing area by perimeter. The abscissa axis is time from heating of the chromel thin wire. There was no difference of flame spread after ignition. In "Mode a", the mean radius of flame spread increased proportionally with time. In "Mode c", the gradient of the graph after 20 seconds decrease. Beginning of irregular flame spread such as “Mode c” was seen about 30 mm from ignition point. In "Mode b", the change of the mean radius of flame was constant after 20 second. In "Mode b", the flame extinction occurred. The observed spread rate in "Mode c" is smaller than that observed in "Mode a". There are some studies on flame spread along filter paper under forced convection [e.g. 12-14]. Those observed spread rates are also lower than that observed under normal condition.

4 Conclusion

(1) Flame spread in narrow channel is categorized into three.
(2) It seems the boundary exists among "Mode a, c" and "Mode b".
(3) In "Mode a", the mean radius of flame spread increased proportionally with time. And flame spread rate of "Mode c" is clearly slow in comparison with "Mode a".
(4) It seems that the developed natural convection controls the flame spread through the heat and mass transfer in the flow channel.

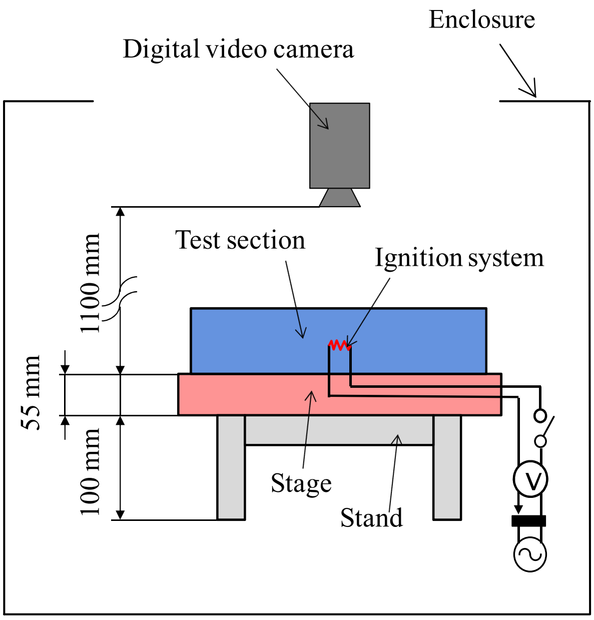

Figure 1. Schematic of experimental set-up

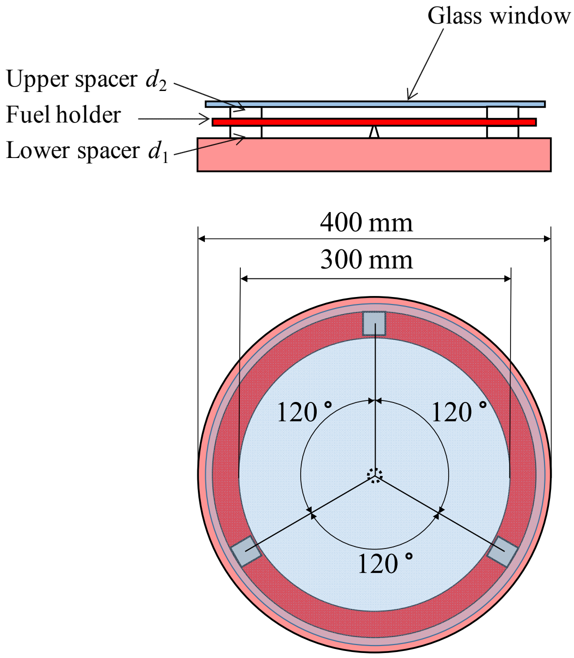

Figure 2. Detail of test section

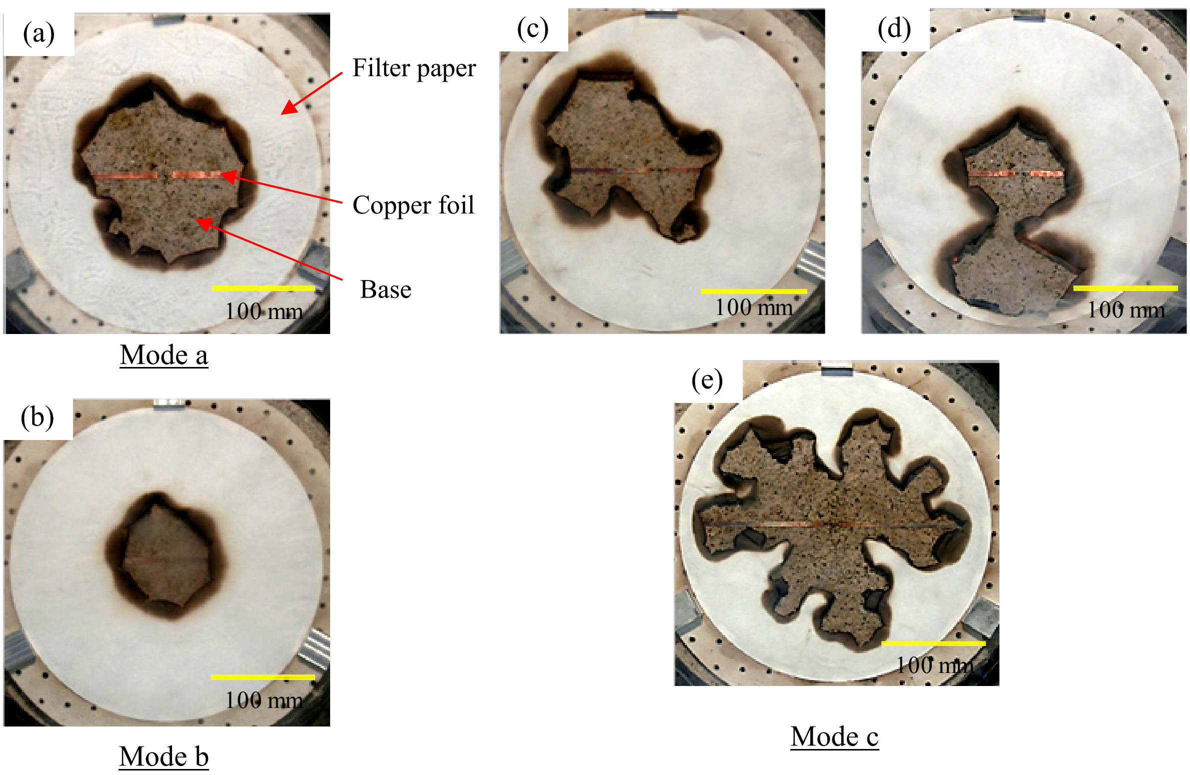

Figure 3. Typical image of flame spread

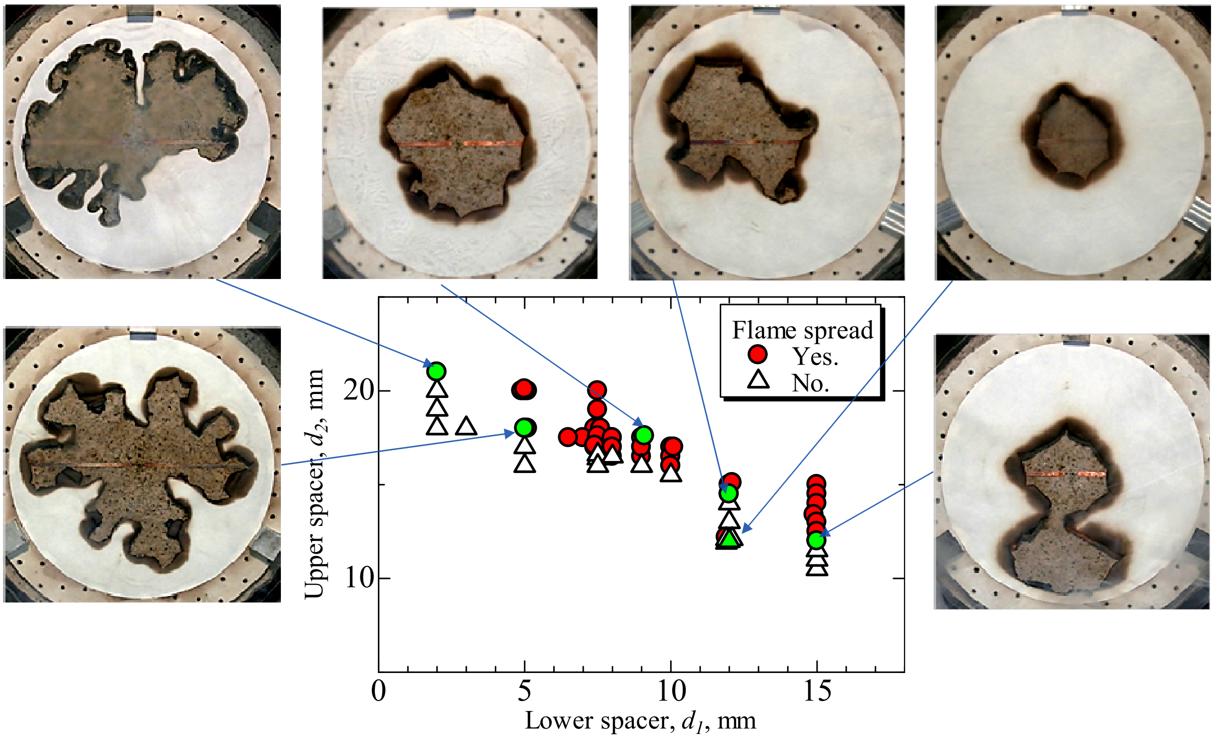

Figure 4. Relationship between gaps of the flow channels ~~and flame spread~~

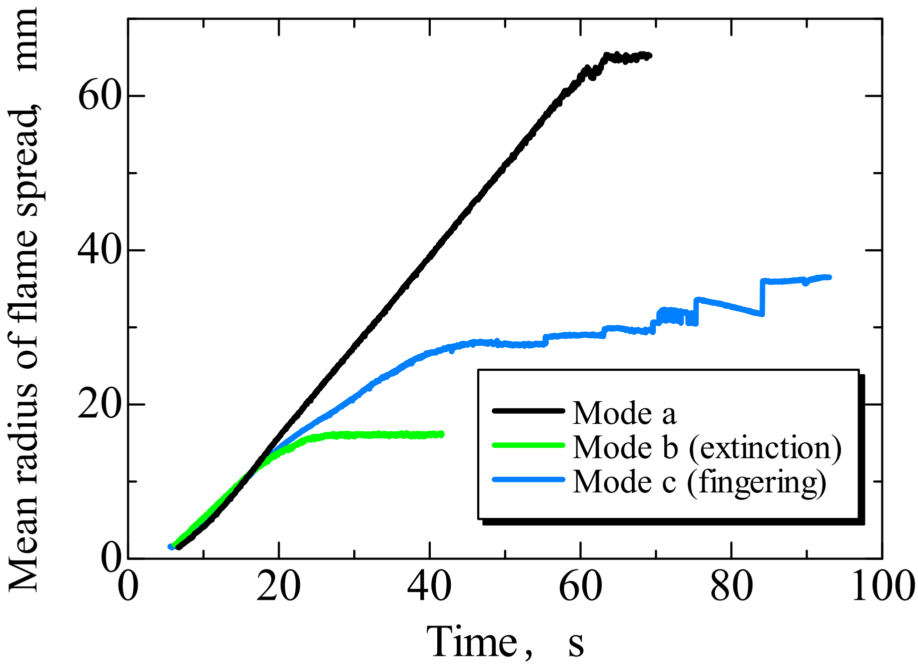

Figure 5. Mean radius of flame and time after heating ~~Relationship between flame spread conformation and flame spread rate~~

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