Near-infrared Visualization of Flame Spread in a Narrow Space

Koji Ikebe[1], Takashi Tsuruda[2], Tadafumi Daitoku[2]
[1]Graduate School of Akita Prefectural University, [2] Akita Prefectural University
84-4 Aza Ebinokuchi Tsuchiya, Yurihonjo City, Akita 015-0055 JAPAN

1 Introduction

In January 2011, a fire broke out during routine inspections at Hamaoka Nuclear Power Plant [1]. The fire was caused by the metal shavings that fell on the sheet during fusing operation. If there is a narrow space on a sheet, floor, or wall, a high-temperature heat source such as chips generated during welding and melting can fall, and cause fire. To implement fire prevention measures, it is necessary to clarify the mechanism of flame spread in a narrow space.

Olson et. al. [2] reported finger-like smoldering patterns over a thin cellulose-based fuel with external airflow in microgravity. Zik et al. [3] reported fingering propagation along a thermally thin solid in a narrow space with external airflow under normal gravity.

Takahashi et al. [4] [5] studied the flame spread of thermally thin combustible solids in a narrow space under natural convection. Three types of flame spread were observed. The first is a uniform flame spread. The second type is flame quenching. The third type of spread is a non-uniform flame spread, which is the phenomenon of a flame spreading like fingers. Tanaka et al. [6] discussed the flow field in the upper gap.

In this study, simultaneous investigations for flame spread were performed under both visible and near-infrared light.

2 Experimental Apparatus

Figure 1 shows a schematic diagram of the experimental apparatus. The experimental apparatus consists of a test section, an ignition system, digital video cameras, and an enclosure. A hole is drilled at the top of the windbreak for optical access.

Figure 2 shows the detailed top and side views of the test section. The test section consists of a glass window, combustible solid, and stage. The combustible solid was fixed to a 1.0 mm thick mica holder. Combustible solid was a homogeneous filter paper (ADVANTEC, No.1) with a thickness of 0.20 mm. The gap between the stage and combustible solid is defined as the lower gap d_L (mm), and the gap between the glass window and combustible solid is defined as the upper gap d_U (mm). For d_L = 9.5 mm

Correspondence to: M24M002@akita-pu.ac.jp

and d_U = 19.0 mm, fingering occurred, and for d_L = 9.5 mm and d_U = 60.0 mm uniform flame spread occurred. A fine electrically heated chromel wire was used as an ignitor.

Cameras recorded the test sections vertically from the top. In visible light, the camera was set to 60 fps with a shutter speed of 1/60 s. For near-infrared light, a near-infrared transmission filter was attached to the camera. The image could not be recorded because of the low light intensity. Therefore, the shutter speed was set to 1/2 s.

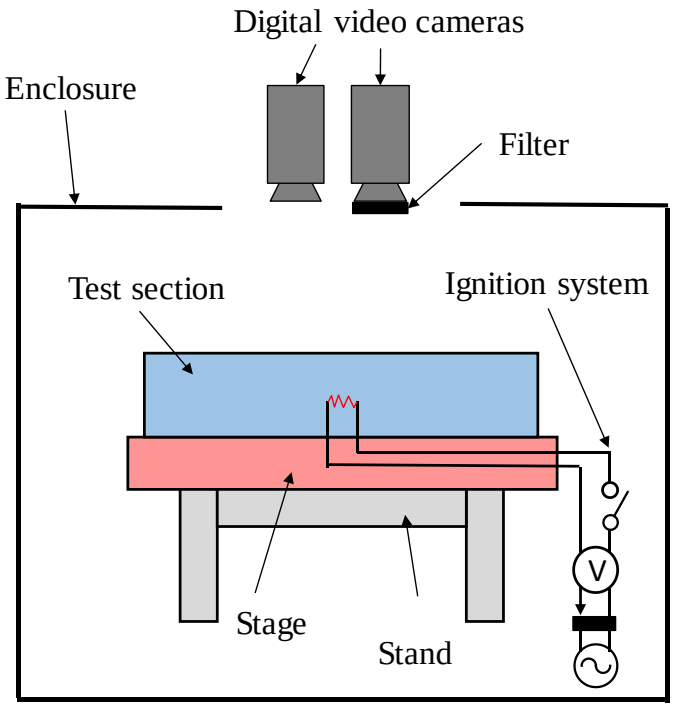


Figure 1: Schematic of experimental apparatus

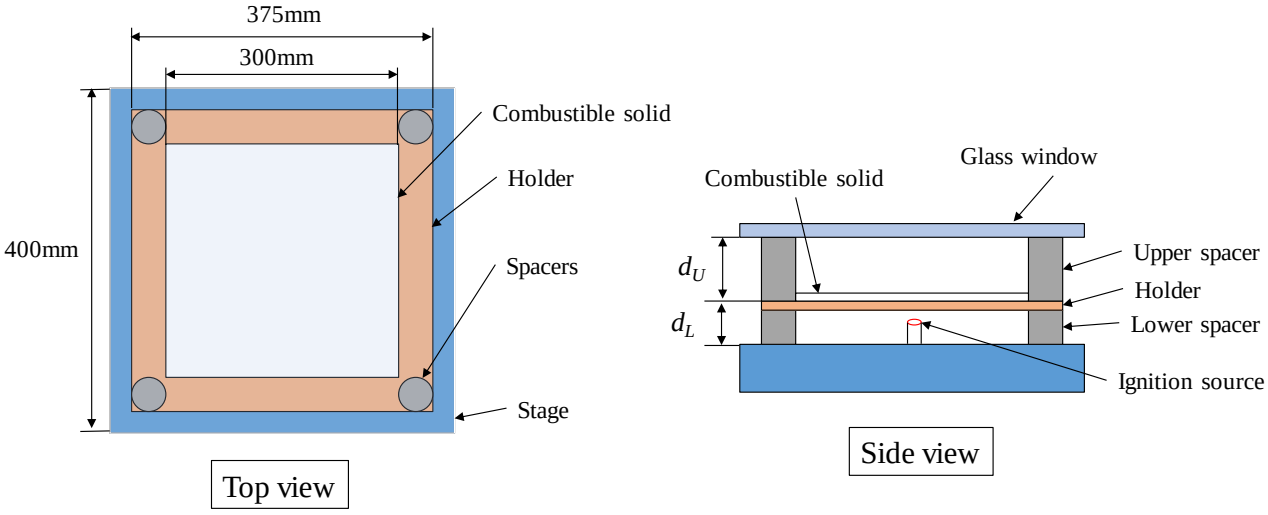
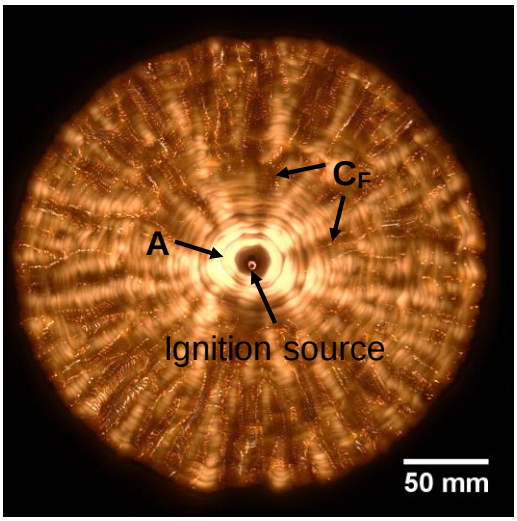


Figure 2: Schematic of test section

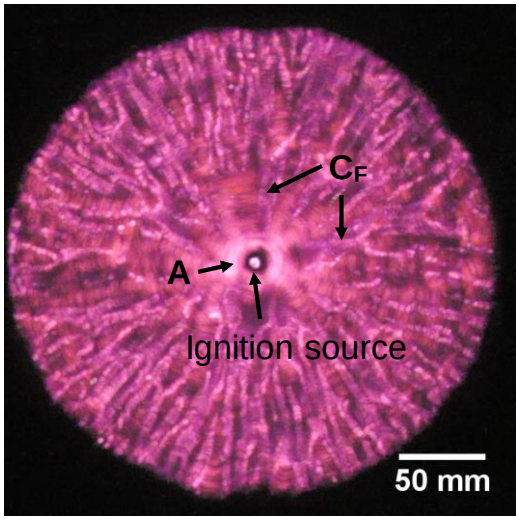
3 Results and Discussion

3.1 Uniform flame spread

The video of the flame spread was split into still images. Figure 3 shows the stack images under visible and near-infrared lights. The orange area can be seen in visible light (Figure 3(a)) and the reddish-purple area in near-infrared light (Figure 3(b)). A flame was observed after ignition at point A, as shown in the Figure 3(a). This flame spread uniformly. The point indicated by arrow C_F in Figure 3(a) represents the glowing orange char fragments. In Figure 3 (b), the flame is observed after ignition at Point A as shown. The point indicated by the arrow C_F in the figure represents the glowing reddish-purple char fragments. The char fragments recorded under near-infrared light were brighter than those recorded under visible light.



(a)Visible light

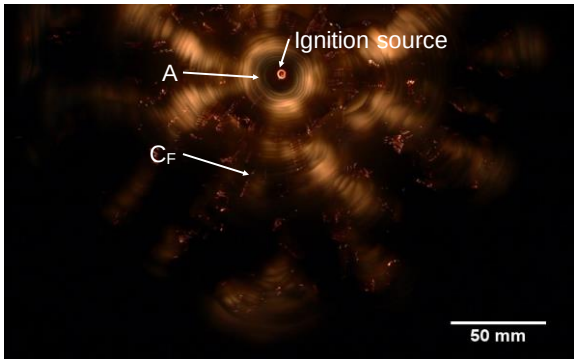


(b) Near-infrared light

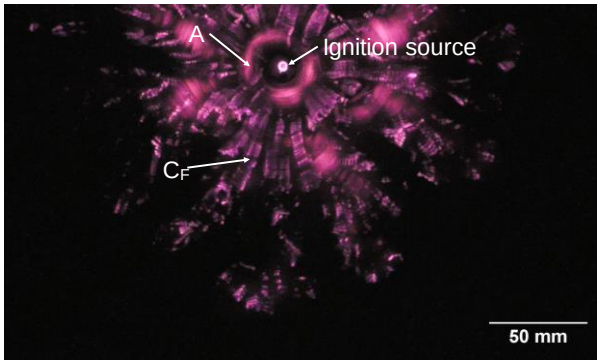
Figure 3: Stack images of uniform flame spread(d_L=9.5 mm, d_U=60.0 mm)

3.2 Non-uniform flame spread

Figure 4 shows stack images under visible and near-infrared light. Figure 4(a) shows the visible-light image where the flame is observed after ignition at Point A. The point indicated by arrow C_F in the figure represents the glowing orange char fragments. Figure 4(b) shows near-infrared light image where a flame is observed after ignition at point A. The point indicated by the arrow C_F in the figure represents the glowing reddish-purple char fragments.



(a) Visible light



(b) Nera-infrared light

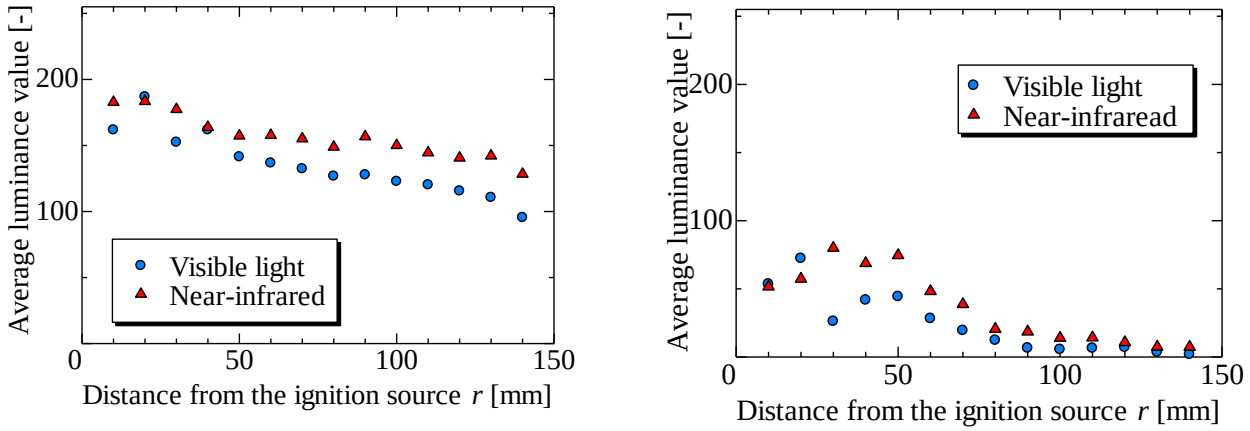
Figure 4: Stack images of fingering (d_L= 9.5 mm, d_U= 19.0 mm)

3.3 Luminance values of flame spread

Figure 5 shows the average luminance values obtained from the stack images. The abscissa of the graph represents the distance from the ignition source *r* and the ordinate represents the average luminance value. Figure 6 shows the variance of the luminance values obtained from the stack images. The abscissa of the graph represents the distance from the ignition source *r* and the ordinate represents the variance of the luminance value.

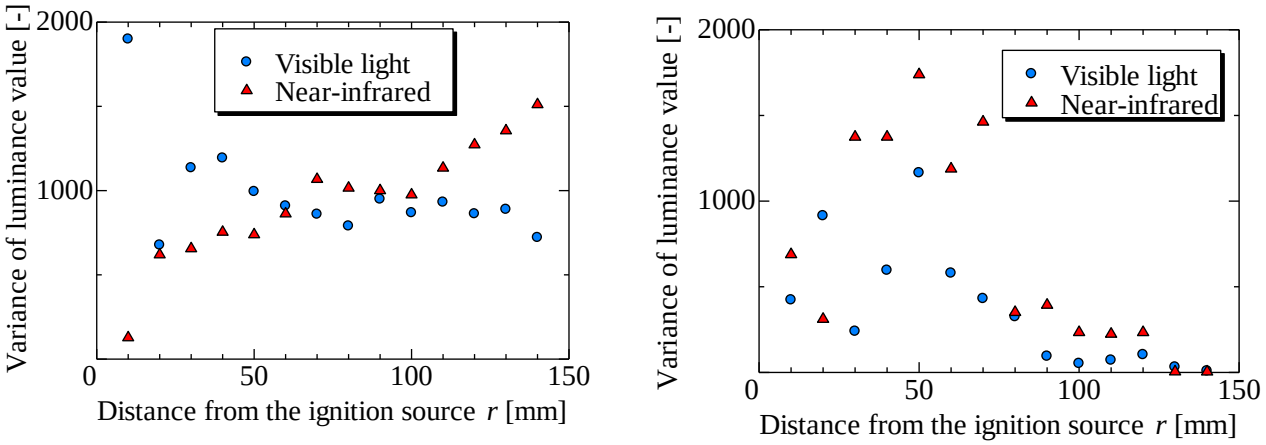
As shown in Figure 5, the luminance values of the uniform and non-uniform flame spreads decreased near the holder(*r* =150 mm). The uniform flame spread showed a gradual decrease in value from the center, whereas the fingerings showed the highest value at approximately *r* = 50 mm.

Figure 6(a) represents the uniform flame spread case. The variance increases in the near-infrared light and decreases in the visible light with distance *r*. Figure 6(b) shows the fingering case. The variance is greater for near-infrared light than for visible light.



(a) Uniform flame spread (b) Fingering

Figure 5: Average luminance value



(a) Uniform flame spread (b) Fingering

Figure 6: Variance of luminance value

4 Conclusions

In this study, flame spread in near-infrared light was visualized. The following conclusions were drawn from this study:

(1) Char fragments could be recorded more clearly in near-infrared light than in visible light.

(2) For both uniform and fingering type of flame spreads, luminance value decreased near the holder.

References

[1] Cause and Countermeasures for Fire in Reactor Building at Hamaoka Nuclear Power Plant, https://www.chuden.co.jp/publicity/press/__icsFiles/afieldfile/2020/02/07/02031.pdf

[2] S. L. Olson, H.R. Baum, T. Kashiwagi (1998). Finger-like smoldering over thin cellulosic sheets in microgravity. Proc. Combust. Inst. 27 :2525.

[3] O. Zik, E. Moses (1998). Fingering instability in solid fuel combustion: The characteristic scales of the developed state. Proc. Combust. Inst. 27 :2815.

[4] T. Daitoku, T. Takahashi, T. Tsuruda (2015). Flame Spread along a paper disk in a narrow channel. Proc. ICDERS. 25:PI-39.

[5] T. Takahashi, T. Daitoku, T. Tsuruda (2017). Behavior of the flame spread along a thin paper-disk in a narrow space. Proc. Combust. Inst. 36:3011.

[6] H. Tanaka, T. Daitoku, T. Tsuruda (2019). Visualization of flow field in narrow space on flame spread along a thin paper disk with fingering combustion. Proc. ICDERS. 27: