Flame Spread along a Slope

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1 Introduction

Flame spread along slopes has been investigated in the context of wild fire studies and to better understand flame spread [1]. Generally, Flames spread along a horizontal surface such as a ground or floor. However, in the case of wild fire [2], [3] the spread along slopes. Excluding the convection effect [4], flames spread in three directions: upward, downward, and horizontal directions affecting in the convective heat transfer. Under normal conditions, heat transfer in the upward direction is larger than that in the downward direction. Under low flow velocity, flames spread faster in a head wind than a tailwind [4]. A higher heat transfer rate increases the flame spread rate and heat flux in the combustible material. This increase of heat flux changes the thermal thickness of the combustible. When flames propagate over a thermally thin surface, thermal decomposition tends to occur uniformly owing to the small temperature gradient in the combustible. Terada [1] studied flame spread using thin paper and found that at a slope angle of 35°, flames spread only in the downward direction. Hiyama [5] experimentally investigated the downward spread limit for the slope angle and the separation between combustible and slope surface. He observed the presence of traveling flames between the combustible and slope surface. This observation indicates the non-uniform thermal decomposition of the combustible. The ”Terada phenomenon” in which flames spread only downward along the slope was examined with thermally thick combustibles.

2 Experimental Procedure

Various studies have explore flame spread using thermally thick combustibles [6]. A simple approach involves laminating sheets using adhesives. Several adhesives were tested, and the shape and density of the combustible were observed. Laminating sheets were pinned up using pins 11 mm in length and 1 mm in diameter on a 10 mm mesh. The sheets were fastened with pin holes. As the combustible sheet a 100 mm filter paper(JIS P 3801:Class 1) with a thickness of 0.2 mm and a basic mass of 90 g/m^2, was used as the combustible sheet. A single sheet, two sheets, and four sheets were used as samples in this experiment. Figure 1 illustrates sample and slope. A ceramics board was used as slope, and 3 mm spacers were used to hold the sample. The slope angle was set to 35° [5]. The sample was attached to the spacer with adhesive tape. An electric heater was used to ignite the center of the sample. The heating was terminated after the flame started to spread. A movie camera was used to record the flame from the normal angle to the sample surface. Two lights were used to illuminate the sample. Each experimental condition was tested in triplicate to ensure reproducibility.

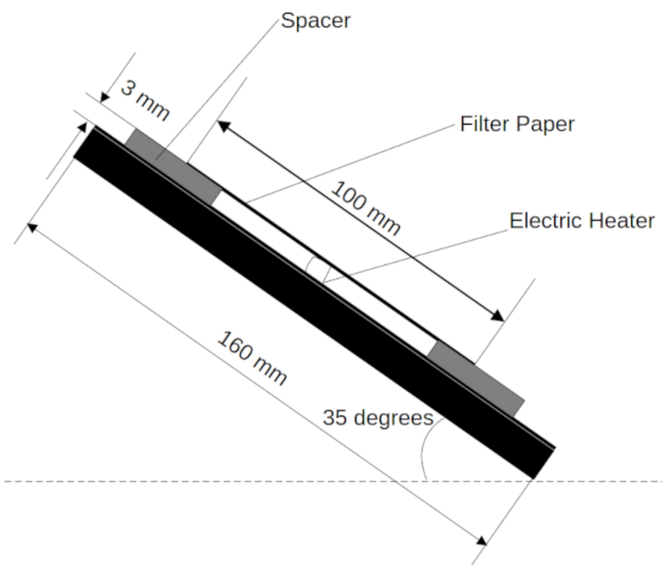

Figure 1: Sample and slope.

3 Results and Discussion

Figure 2 illustrates a series of images depicting the flame along a single sheet sample. These photographs were captured at 10 s intervals. This sample did not include a pine hole. The heater can be observed at the center of the picture. The lower side of the heater hole is circled with a clear black line, while the upper side is with a wide gray line. As the lower front spread at a constant velocity, the upper front did not spread, whereas the horizontal front did. Once the front reached the lower edge of the sample, the upper front spread.
Figure 3 shows a series of images depicting the flame along the two-sheet sample. A 10 mm grid of pin holes can be observed in these images. The shape of the burnt area is similar to that of the single sheet sample. However, the flame spread rate was approximately half that of the single-sheet sample.
Figure 4 shows a series of images depicting the flame spread along the four-sheet sample. A 10 mm grid of pin holes can be seen in the corresponding images. A line of smoke from the pin hole to the upward edge is shown in the first picture. The shape of the burnt area is slightly different from the two-sheet sample. Based on the study [6], four sheets of 0.2 mm thick filter paper is thermally thicker that the limiting 0.5 mm for paper. The shape of the burnt area was flatter than that with the two-sheet sample. The flame spread rate was almost one fourth of that with the single-sheet sample. Additionally, the upper front also spreads along the center line of the sample as the lower front spreads.
Figure 5 illustrates flame fronts of figure 2 along the single-sheet sample. The edge of the decomposition area was found from flame images using a graphic software. The flame front spread only downward at a constant velocity.
Figure 6 illustrates flame fronts of figure 3 along the two-sheet sample. The flame front spread only downward at a lower constant velocity than that of figure 5.
Figure 7 illustrates flame fronts of figure 4 along the four-sheet sample. Excluding the flame front at the center, the flame front spreads downward to lower corners of the sample at a lower fluctuating velocity than that of figure 6. A longer heating duration was required for ignition; during this time, the central area was subjected to prolonged heating, and natural convection appeared to distort the shape of the flame front.
Figure 8 shows x - t diagram of four-sheet sample with a 3 mm separation between sample and slope along center line downward. Approximately 80 seconds of heating were required before flame propagation began. Yellow bands are observed near the propagating edge as shown by markers. The ejected material removes part of heat from flame and the low heating results lower flame spread rate.

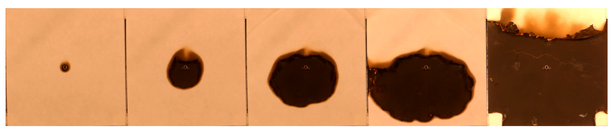

Figure 2: Single sheet sample-3 mm separation between sample and slope (10 s intervals).

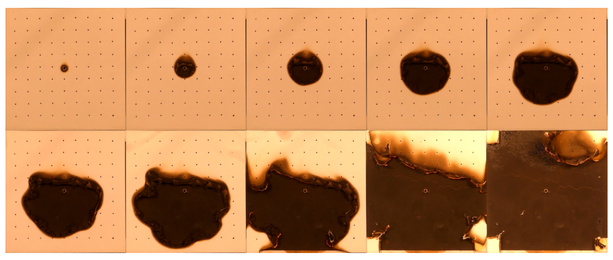

Figure 3: Two-sheet sample-3 mm separation between sample and slope (10 s intervals).

4 Conclusions

In the ”Terada phenomenon,” flame spread occures only in the downward direction along a slope. This behavior was examined with thermally thick combustibles that were prepared by pinned up sheets in a 10 mm pitch grid. Three different samples were used and downward flame spreads were observed. Once flame reached the low edge, the upward flame started spreading. The presence of flame in the lower part suppressed the flame from spreading upward. As the sample thickness increased, the horizontal spread rate became larger than those of upward or downward direction. In the four-sheet sample, the flame front propagated at a lower and more fluctuating velocity compared to the two-sheet or single-sheet.

References

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[6] Hirano T, Tazawa K. (1976). Effect of Thickness on Downward Flame Spread over Paper. Bull. Jpn. Asso. Fire Sci. Eng. 26-1:7-13.

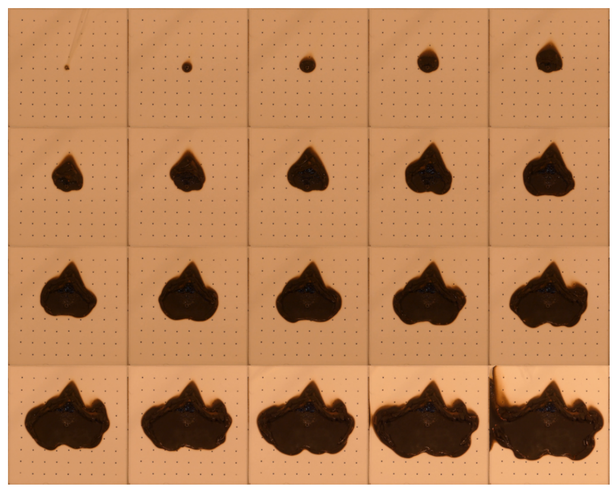

Figure 4: Four-sheet sample-3 mm separation between sample and slope (10 s intervals).

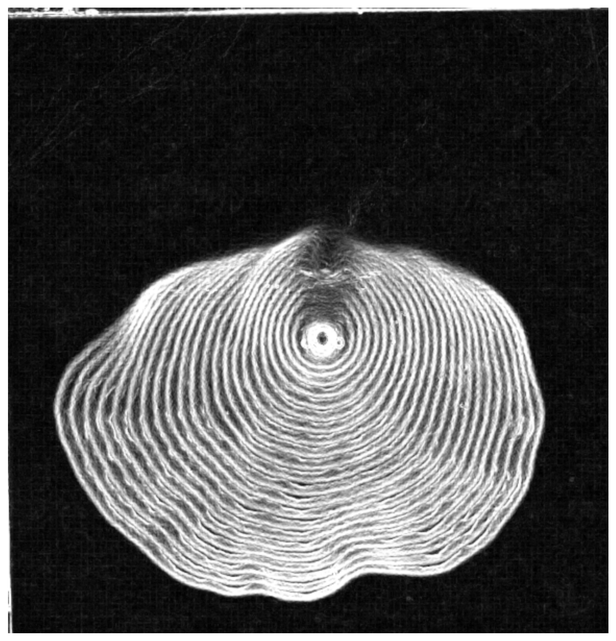

Figure 5: Single sheet sample-3 mm separation between sample and slope (1 s intervals).

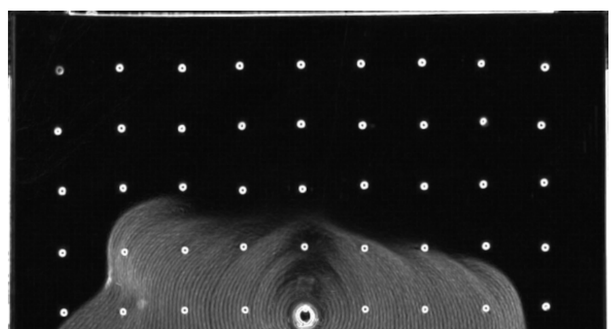

Figure 6: Two-sheet sample-3 mm separation between sample and slope (1 s intervals).

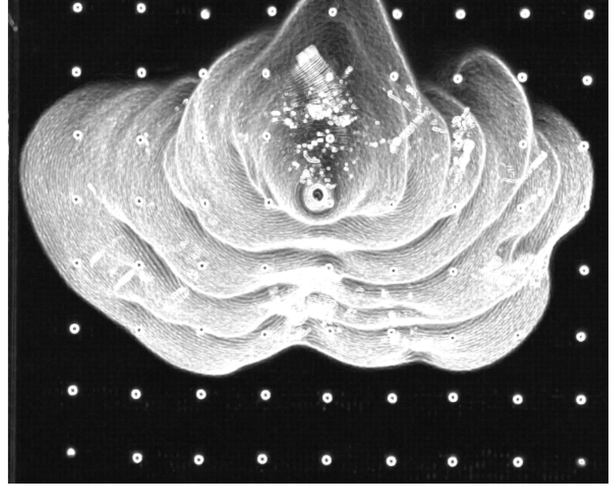

Figure 7: Four-sheet sample-3 mm separation between sample and slope (1 s intervals).

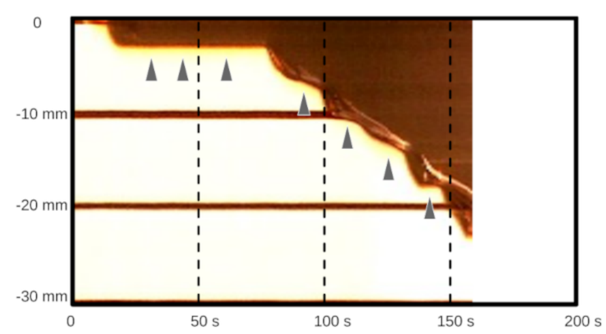

Figure 8: x - t diagram of four-sheet sample-3 mm separation between sample and slope along center line downward.

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