Flame spread along a combustible slope

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1 Introduction

Wild fire consumes combustible above the ground. Its surface may be along a slope. Wild fire seems to spread faster upwards than downwards due to buoyancy-induced flow. Unexpected wild fire spreads have caused causalities of responding personnel. There are various conditions, which cause this unexpected flame spread, i.e., wind disturbances or non-uniformity of combustible distributions. Terada carried out a study on flame spread along a slope [1]. He constructed a scaled model with two gauze sheets along an asbestos board. He observed flame spread along the gauze surface from an ignition source. He found that flame spreads only downward direction and flame does not spread upward around the inclined angle of 35 degree. He pointed out that the flow induced by the flame suppresses convective mass transfer of oxygen to the reaction zone of upward spread flame front. Hori carried out experiments on flame-spread along combustible slope [2]. Flame spreads only downward direction in lower layer. The separation between combustible bottom and base was 3.8 mm. Hirano shows a series of Schlieren photographs along paper sheets at various inclined angles in free space [3]. The upward spreading flame approaches closer to the combustible surface as inclined angle increases. Experiments on flame spread along thermally thin combustible show that flame spreads faster in upward direction than downward in free space [3]. As the material near pyrolysis zone is heated by convection of the bottom side, the presence of base surface below the combustible sheet may affect the behavior of flame along surface. A change of mechanisms of flame spread for thick fuels occurs at 15-20 degrees [4]. To reproduce the experimental condition, the separation between combustible and base should be constant during flame spread. Large temperature gradient at flame zone causes deformation on the combustible surface and spacers. To maintain the minimum separation between the surfaces of combustible and base, fire-resistant spacers with low thermal conductivity need to support the combustible. In this study, flame spread along slope was examined with a video camera to determine the flame spread with the inclined angle.

2 Experimental Setup

Figure 1 shows experimental set up. A round granitite disk of 380 mm in diameter is the base. Perlite particles of 3 mm support a paper disk of 300 mm in diameter D on the base. Separation between paper

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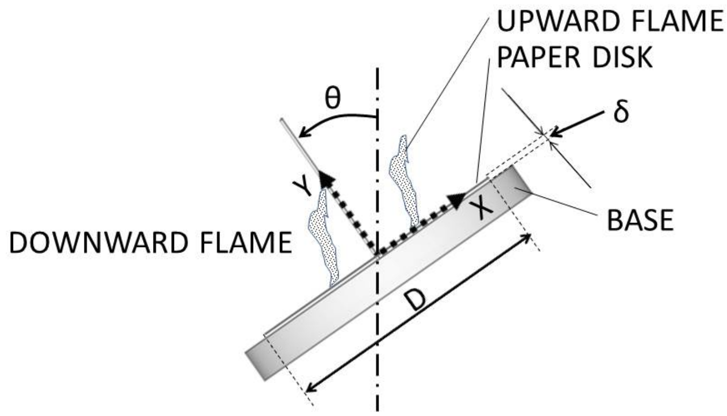

Figure 1: Experimental Setup

disk and base is δ. The base surface was inclined to an angle θ from horizontal plain and gas flame ignited the paper disk at the center. After ignition, upward and downward flames spread along paper disk.

3 Experimental Results

Figure 2 shows the flame fronts at 20, 35, and 60 degrees with a separation of δ =3 mm after 40 seconds of ignition. x-t diagrams at the central vertical line show flame front trace on figure 3.
For 20, 35, and 60 degrees, the flame front shapes are different between upward and downward sides.
At 20 degree, x-t diagram shows V-shape two lines of upward and downward spread traces.
At 35 degree, the upward flame disappeared after ignition. The downward flame is seen in this figure. A fan shape burnt area appears lower part of the paper disk. After the downward flame reached lower rim of the paper disk, flame spread along the paper edge and consumed whole paper disk. x-t diagram shows the disappearance of upward flame as a horizontal line until flame reaches lower rim of paper disk. Width of upward flame trace is larger than that of downward flame trace. This width indicates the thermal boundary of upward flame is larger than that of downward flame.
At 60 degree, x-t diagram shows that upward flame is faster than downward flame. The flame reached upper rim of paper disk after 40 seconds of ignition. Upward spread rate is nearly two times of downward rate. These rates are between 1.16 mm/s to 1.56 mm/s for these inclined angles.
Figure 4 shows the flame front and x-t diagram at 35 degree. The pyrolysis zone width of the upward flame at t_1 is larger than that of the lower flame. Comparing the upper and lower traces near t_1, the spread rate of the upper flame is larger than that of the lower flame. The heat from the lower flame heats the upper pyrolysis zone and enhances the gasification of combustible gas. This enhanced gasification results in the large pyrolysis zone width. The inter actions of upper and lower flames might induce extinction. The upward

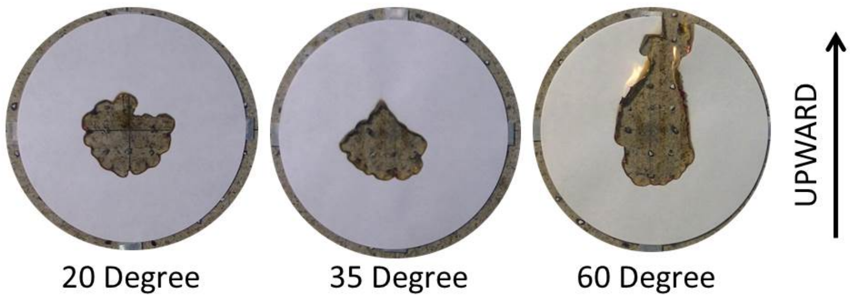

Figure 2: Flame Fronts at 20, 35, and 60 degrees

flame disappears at t_2. The edge of upper pyrolysis zone becomes convex downward. The flame spreads horizontally and the upper filter paper does not burn during this period. The width of pyrolysis zone is wider for upper filter paper edge than for lower edge. The downward flame consumed lower part at t_3 and flame spread upward and horizontal directions.

4 Discussion

The upward spreading flame disappears around 35 degree while the downward flame spreads. The separation between combustible and base surface less than 3 mm suppresses lower flame. The observed flame spreads along a thin combustible without heating from bottom side. The presence of downward spread flame enhances the heat transfer to the pyrolysis zone of upper flame and results in faster gasification than the other mechanisms i.e., oxygen diffusion, decomposition of fuel. The experiment shows large spread rate and wide pyrolysis zone width of upper flame before extinction. For 20 and 60 degree, heat from outer area reignites flame and resumes spread. For 35 degree, heat from outer area fails to reignite.

5 Conclusions

Upward flame spread along an inclined slope disappears around 35 degree and reappears at 60 degrees. This extinction and stabilization are controlled by the heat transfer at the upper surface of the combustible through convective heat transfer from the downward spread flame. The extinction around 35 degree is mainly by the mechanisms that flow induced by the flame suppresses convective mass transfer of oxygen to the reaction zone of upward spread flame front [1] and other processes. The stabilization around 60 degree is by the stable heat transfer. This is not seen in free space due to the heating of combustible form the bottom.

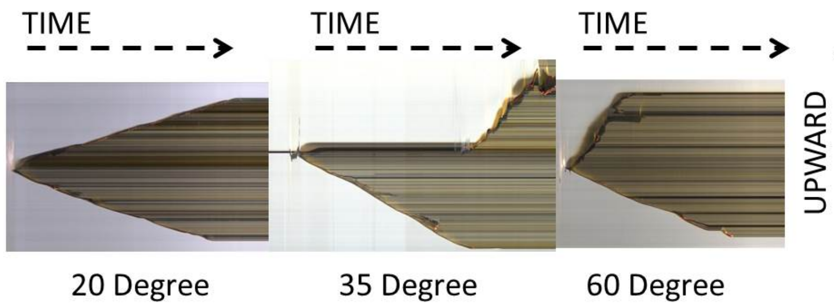

Figure 3: x-t Diagrams at 20, 35, and 60 degrees

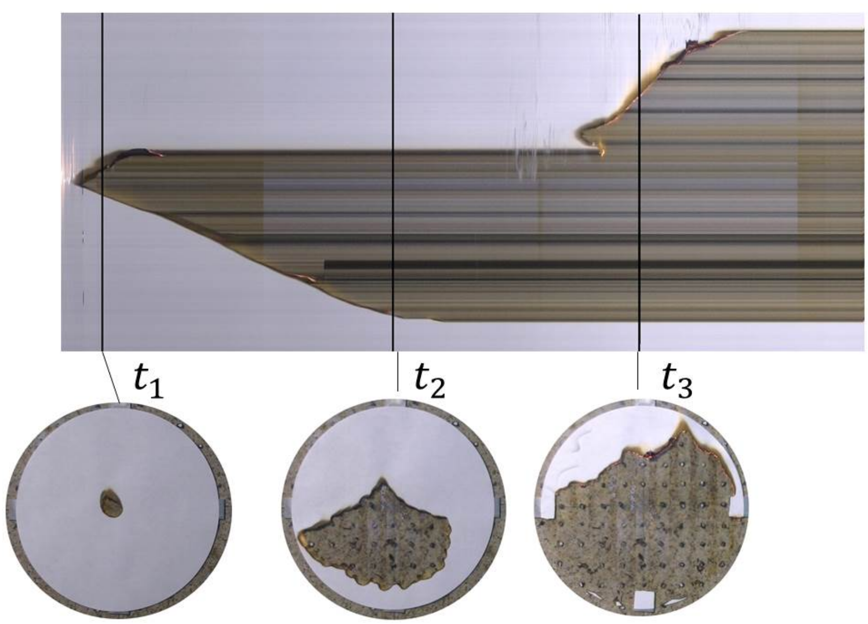

Figure 4: Flame Front and x-t Diagram at 35 degree

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