Propagation of Precursor Flame Tip in Surrounding Airflow along the Ground Soaked with High-Volatile Liquid Fuel

ISHIDA, Hiroki
Nagaoka National College of Technology
888 Nishikatakai, Nagaoka, Niigata 940-8532 JAPAN

1. Introduction

On a ground soaked with a high-volatile liquid fuel, if the ignition occurs by some heat source, the flame propagates with a high velocity through the layered flammable gas mixture on the ground. When the ground temperature is near the stoichiometric temperature one can see the small tip of a pale precursor flame traveling along the surface before the steady spread of a large flame. The travelling small flame tip, in general, vanishes at the end of the fuel-spillage area, and thereby the ground surface is not covered with flame. When the ground temperature is much above the stoichiometric temperature, however, the precursor flame does not vanish at the end of the fuel-spillage area, and the ground is covered with a large flame in a very short time [2]. Consequently, the behavior of the precursor flame tip is affected strongly by the conditions of formation of the flammable gas layer; the air stream along the ground, the inclination angle of the ground surface and the temperature of the ground [2,4]. The present study aims to clarify the behavior of the small precursor flame tip in the surrounding airflow on the ground soaked with a high-volatile liquid fuel by using a visualization technique of the reaction zone (OH luminescence zone) along the ground surface [4].

2. Apparatus and Procedure

Figure 1 shows the experiment setup of this study, where the simultaneous measurement system of Color Schlieren photograph and the image of chemiluminescence zone in the flame tip is shown [4]. A stainless steel tray (50mm in width, 400mm in length, 15mm in depth) filled with glass beads (0.1mm in dia.) was used as the model of the ground, and the temperature of the glass bead bed was controlled. n-Octane was used as the spilled liquid fuel.

The glass bead bed was set in the airflow (from 0 to 300 cm/s) from the rectangular outlet (125 x 125 mm) of a wind tunnel. The chemiluminescence image due to OH radical in the flame tip was monitored through the band pass filter (Central-peak wavelength; 307.6 nm, Half-peak width; 10nm), and the image intensified CCD Camera (Shutter speed was fixed as 1/1500 sec by pulse generator).

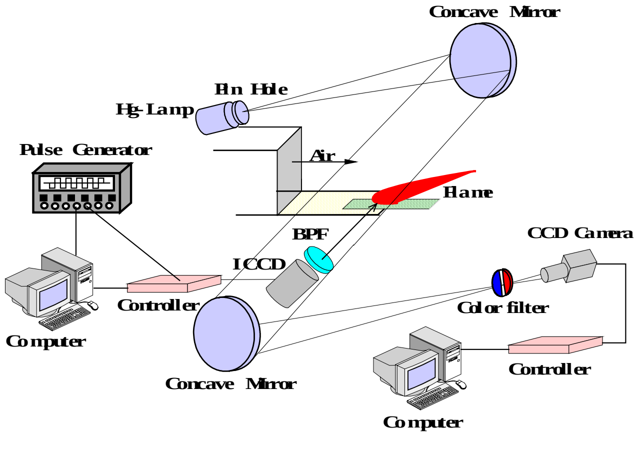


Figure 1: Experimental Setup

Preceding the glass bead bed, a starting plate (180mm from the exit) was set. The inclination angle of the tray with the starting plate was set between 0 and 20 deg. The velocity of airflow was measured by a heat ball type (2mm in dia.) airflow meter. The thickness of flammable gas layer on the surface was measured by the image of Color Schlieren Photography at the center of the tray.

3. Results and Discussion

The typical profiles of the airflow velocity along the beads bed surface shows that they are nearly the same, and not affected dynamically by the main flow velocity, the inclination angle and the position from the exit of the wind tunnel under the present experimental condition. The thickness of the velocity boundary layer is below 15 mm.

The thickness of the flammable gas layer decreases with an increase in the velocity of airflow, and increases with an increase in the temperature of bead bed. **Figures 2** shows the thickness of a layered flammable gas measured at the center of the tray. The result shows that the thickness of the layered flammable gas is below 10 mm, and decreases with an increase in the airflow velocity. Also the inclination angle of bead bed surface has no major effect on the thickness of the layered flammable gas.

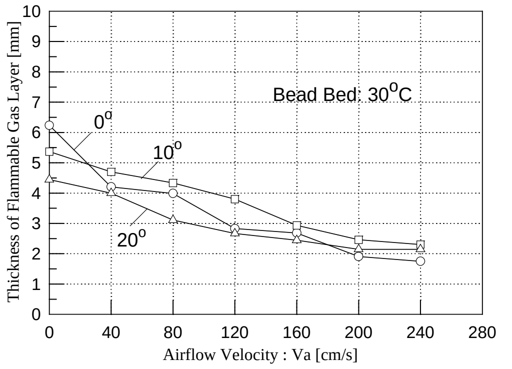


Figure 2: Thickness of Flammable Gas Layer vs. Velocity of Airflow and Surface Inclination Angle

For a discussion of the propagation velocity of the precursor flame tip, we need to know in detail the typical images of the OH luminescence zone in the flame tip and of the Schlieren photograph. In counter flow, both the OH zone and the Schlieren image have nearly the same shape at the flame tip. In assist flow, however, we can not see the clear shape of the OH zone surrounded by the hot burned gas. Also the flammable gas layer is wavy owing to the surrounding assist airflow.

Although the flame propagation in the surrounding airflow along the liquid pool and fuel-soaked solid surface has been a very important (and interesting) subject of study from the point of view of fire hazard prevention, only a few papers on the study have been reported. The pioneering work by Suzuki and Hirano [1] has revealed some important aspects of flame propagation in this study.

Figure 3 shows the propagation velocities of the precursor flame tip in counter and assist airflows. The propagation velocities with no forced surrounding airflow in the downward and upward directions along the inclined ground surface are not the same owing to gravity and buoyancy.

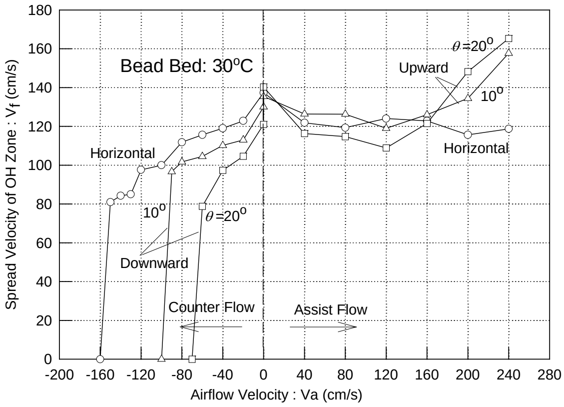


Figure 3: Propagation Velocity of OH zone vs. Velocity of Surrounding Airflow and Surface Inclination

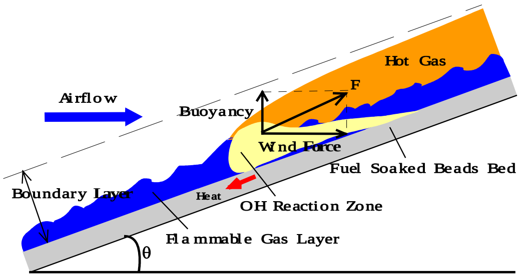
The schematic illustration of the propagation of the OH luminescence zone in the counter and assist airflows along the inclined surface is shown in **Figure 4**. In the downward flame propagation in counter-flow, there exists a large effect of buoyancy and wind force. With the increase in the velocity of the counter airflow, the propagation of the flame tip becomes very unstable. The flame tip will thereby be pushed back with increase in the angle of surface inclination.

It should be noted here that when the ground temperature is considerably higher (30 °C in this study) than the stoichiometric temperature (about 23.5°C for n-Octane), horizontal flame propagation occurs even in the counter flow, the velocity of which is slightly higher than the flame propagation velocity without the airflow; about 130 cm/s. This is attributed to the thickened flammable gas layer and the convective transport of it to the flame tip.

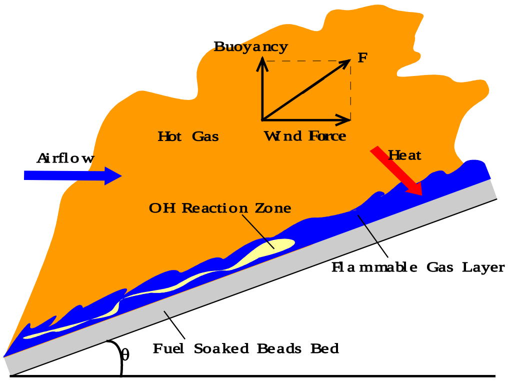
When the ground temperature is not so high; 26 °C in this study (which is over the stoichiometric temperature of spilled liquid fuel), however, no propagation of the flame occurs in the counter airflow, the velocity of which is above the flame propagation velocity without the airflow. This is in contrast to the result shown in the previous study by Suzuki and Hirano [1] on the flame propagation along the methanol pool in an opposing airflow. They showed that the flame is able to propagate along the pool surface without a remarkable decrease in the velocity even in the opposing airflow, the velocity of which is much higher than the flame propagation velocity without the airflow.

The clear difference in the critical velocity of the opposing airflow to prevent the flame propagation is attributed to the thinned layer of flammable gas mixture on the unburned ground surface ahead of the flame. To form the flammable gas layer on the ground, the fuel must be transported onto the surface by capillary rise, vaporization, or both. The thickness of flammable gas layer decreases with increase in the airflow as shown in **Fig. 2.**

In the assist flow, on the other hand, there exists large scale overhanging hot gas ahead of the flame tip, as clearly shown in **Fig.4 (b).** The unburned surface will thus be covered with the hot gas and receive the heat flux from it. It should be noted here that in a weak assist flow (under 40 cm/s in this study) the flame spread velocity decreases as shown in **Fig.3.** This will be due to the thinned layer of the flammable gas on the unburned surface, which is blown by the airflow.



(a) Downward Propagation



(b) Upward Propagation

Figure 4: Schematic Illustration of Propagation of OH Luminescence Zone in the Airflow along the Inclined Surface

With increases in the velocity of the assist flow, however, overhanging hot gas ahead of the flame will develop, which leads to the increase in the heat flux to the unburned surface. The propagation velocity of the flame along the horizontal surface thereby does not so decrease; it nearly becomes constant as shown in this study. On the inclined surface, however, the velocity of flame propagation increases with increase in the velocity of assist flow; over 120 cm/s as shown. This is attributed to the increase in the heat flux from the overhanging hot gas to the unburned surface, which becomes conspicuous with increase in the inclination angle.

4. Concluding Remarks

(1) When the ground temperature is slightly higher than the stoichiometric temperature, no propagation of the precursor flame occurs in the counter flow of which the velocity is over the flame propagation velocity with no surrounding airflow.

(2) When the ground temperature is considerably higher than the stoichiometric temperature, however, horizontal propagation of the precursor flame is able to occur even in the counter flow, the velocity of which is slightly higher than the flame propagation velocity with no surrounding airflow.

(3) In a weak assist flow, the flame propagation velocity is lower than that without surrounding airflow. On the inclined surface, however, the velocity of upward flame propagation increases with an increase in the velocity of the assist flow.

(4) In a high velocity assist flow, the tip of precursor flame becomes very unstable and is not able to propagate when the ground temperature is lower than the stoichiometric temperature.

References

1. T. Suzuki and T. Hirano, *Proc. Combust. Inst.* 19: 877-884 (1982)
2. H. Ishida, *Fire Safety Journal*, 13: 115-123 (1988)
3. F.J.Miller et al., *Proc. Combust. Inst.* 29: 2561-2567 (2002)
4. H. Ishida, *Journal of Fire Sciences, in press* (2004)