Flame Spread in Opposed Flow along the Ground Soaked with High-Volatile Liquid Fuel

ISHIDA, Hiroki and KENMOTSU, Yusuke

Laboratory of Mechanics, Nagaoka National College of Technology

888 Nishikatakai, Nagaoka, Niigata 940-8532 JAPAN

1. Introduction

On the ground of which the temperature is near the stoichiometric temperature of the spilled liquid fuel, if the ignition occurred by some heat source, one can see the small leading tip of a pale precursor flame traveling along the surface before the steady spread of a large flame. When the ground temperature is much above the stoichiometric temperature, the precursor flame does not vanish at the end of the fuel-spillage area owing to the existence of sufficient fuel-air mixture, and the ground is covered with a large flame in a very short time [1]. Our previous paper reported the behavior of the precursor flame tip in detail under the effects of surrounding airflow and the inclination of the ground surface [2]. The present study aims to clarify experimentally the effect of opposed flow velocity on the flame spread aspect along the high-temperature ground soaked with high-volatile (low flash point) liquid fuel [3].

2. Experimental Setup and Procedure

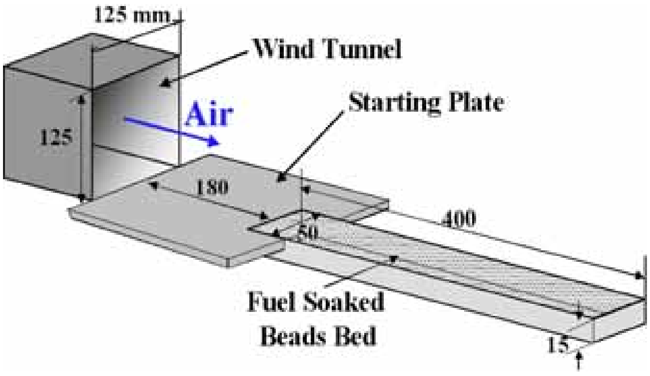

Figure 1: Experimental Setup

Figure 1 shows the experiment setup of this study. A stainless steel tray (50mm in width, 400mm in length, 15mm in depth) filled with fine glass beads (0.1mm in dia.) was used as the model of the ground, and the temperature of the glass bead bed surface was controlled and maintained constant as about 28$\pm$1 ^{o}C with good accuracy by heated tray and natural cooling, which was monitored by thermocouple (K-type) sensor. Pure n-Octane (Flash point; 15^{o}C, Stoichiometric temperature in air; 24^{o}C) was used as the model of spilled liquid fuel. The glass bead bed was set horizontally in the rectified uniform airflow from the rectangular outlet (125 x 125 mm) of the wind tunnel in which the flow velocity is controlled; 0 ~ 350 cm/s. Preceding the glass bead bed, a starting plate (180mm from the exit) was set as shown.

The airflow velocity above the beads bed surface was measured at 15 cm far from the upstream end of the tray by a heat ball type (2mm in dia.) airflow sensor, which is installed on the cathetometer to confirm the distance accurately above the beads bed surface. The data acquisitions of airflow velocity measurement, at every 1 mm above the surface, were by time-averaged; 10~20 s. The glass bead bed surface at the downstream end of the tray was ignited manually by a small pilot flame or by the spark of induction coil.

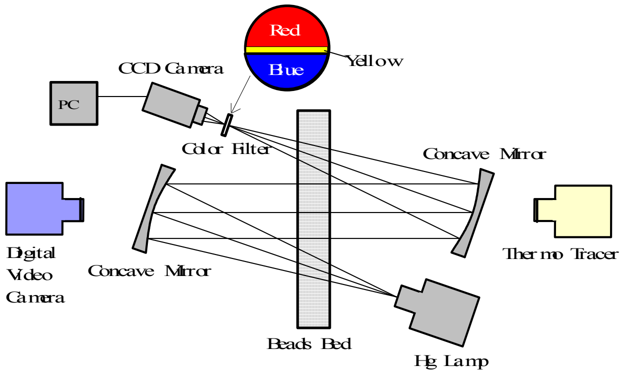

Figure 2: Optical measurement system

The schematic illustration of the optical measurement system is shown in **Figure 2**. The velocity of flame spread was measured by a digital color video movie, and the thickness of fuel-air mixture layer on the fuel-soaked beads bed was measured by the color Schlieren image based on a fixed threshold extracted from the digital color image. The image by color Schlieren movie was obtained using Toshiba CCD Color Video Camera IK-C40; Shutter speed 1/4000 s, Frame rate 30 fps. The preheat zone ahead of the flame leading edge during the spread was acquired by infrared image video camera; Thermo Tracer (NEC-Sanei TH-1101). All the image data in the measurement were sent to personal computers and processed by image processing software to be shown on the monitor.

3. Results and Discussion

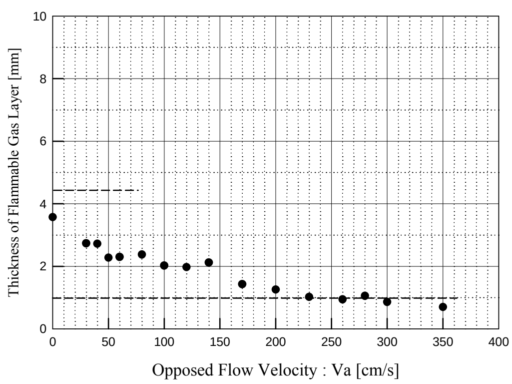

Figure 3: Thickness of Fuel-Air mixture Layer ahead of Flame Tip.

The thickness of the velocity boundary layer on the beads bed was below 10 mm regardless of the magnitude of the main flow velocity.

The thickness of fuel-air mixture layer ahead of the flame leading edge was able to be estimated from the Schlieren image as shown in **Figure 3**. Each data-point indicates the time-averaged, about 10 s, thickness shown in the Schlieren image. The thickness decreases with increase in the velocity of opposed flow, but never vanishes approaching gradually constant; 1mm even in the high velocity flow. This is probably due to the high-volatility (high vapor pressure) of the spilled liquid fuel on the beads bed. We should, therefore, focus our attention on the velocity of opposed flow at about 1mm above the ground, which must have a large effect on the behavior of the flame leading edge.

Figure 4 shows the dependence of the velocity of flame spread on the opposed flow velocity. Closed and open points in this figure show fast (instantaneous) flame spread and slow (time-averaged) spread of flame leading edge respectively. The aspect and the velocity of flame spread in the opposed flow in this study are characterized by the velocity ratio as follows;

$$\alpha = Va1/Vf$$

where Va1 is the velocity of opposed flow at about 1 mm above the ground surface, and Vf is the flame spread velocity with no surrounding airflow; about 150 cm/s.

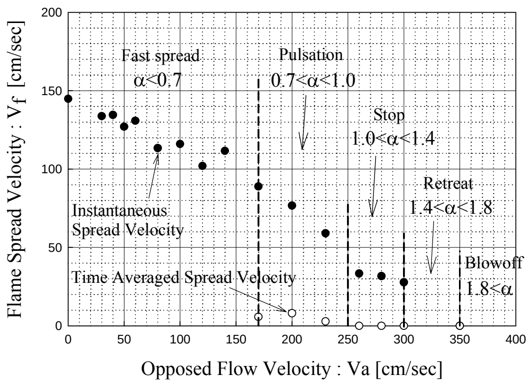

Figure 4: Dependence of Flame Spread Velocity on the Opposed flow Velocity.

We can see the fast flame spread if α is under about 0.7; the main velocity of opposed flow is under about 170 cm/s. When α is 0.7~1.0, the flame leading edge, however, shows the dynamic pulsation with the frequency of 5~7 Hz, and the spread of flame becomes very slow. In this case we can, therefore, measure the time-averaged spread velocity of flame. This pulsation of the flame leading edge is probably due to the instability of the formation of flammable mixture layer and to the aerodynamic instability ahead of the flame. When α increases to about 1.0; the main velocity of opposed flow is about 250 cm/s, the flame spread is stopped but not blown off. This is probably attributed to the blowoff of flammable mixture ahead of flame leading edge by the wind, and the anchoring of the flame is attributable to the sufficient fuel supply through the bed onto the surface beneath the flame. When α increases to about 1.4; the main velocity of opposed flow is about 300 cm/s, the flame leading edge begins to retreat slowly, which leads to subsequent blowoff of the flame.

The characteristic dependence of the maximum preheat distance ahead of flame leading edge on the velocity of opposed flow is shown in **Figure 5**.

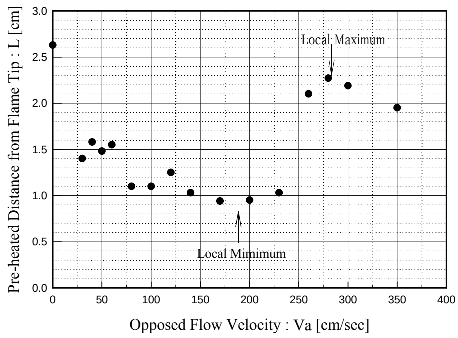

Figure 5: Dependence of the Maximum Preheat Distance ahead of Flame on the Velocity of Opposed flow.

With increase in the velocity of opposed flow, the maximum preheat distance decreases to the local minimum and increases to the local maximum thereafter. This is attributable to the balance between the heat transfer from the inclined flame and the convective cooling by the flow because the flame inclines and becomes close to the ground in downstream.

4. Concluding Remarks

(1) Without surrounding airflow, the thickness of the layer of fuel-air mixture ahead of the flame leading edge is less than 5mm. It decreases with increase in the velocity of opposed flow, and about 1mm in the wind over about 200cm/s.

(2) The flame spread is able to continue even in the opposed flow of which the main velocity is over the flame spread velocity without surrounding airflow; about 150 cm/s. However, when the opposed flow velocity at about 1mm above the ground surface reaches to the same as the flame spread velocity without surrounding airflow, no flame spread occurs.

(3) The aspect and the velocity of flame spread in opposed flow are characterized by the velocity ratio; Va1/Vf, where Va1 is the velocity of opposed flow at about 1 mm above the ground surface and Vf is the flame spread velocity with no surrounding airflow. When the velocity ratio increases to about 1.4, the flame leading edge begins to retreat slowly, which leads to subsequent blowoff of the flame.

(4) The velocity of opposed flow has a large effect on the magnitude of the preheat zone ahead of the flame leading edge on the ground. With increase in the opposed flow velocity, the preheat zone decreases to the local minimum, and increases to the local maximum thereafter. This is attributable to the balance between the convective surface cooling by the opposed flow and the conductive heating through the ground beneath the inclined flame in the downstream.

References

1. H. Ishida, *Fire Safety Journal*, 13: 115-123 (1988)
2. H. Ishida, *Journal of Fire Sciences*, 23: 247-260 (2005) .
3. H. Ishida, *Journal of Fire Sciences*, *in press* (2008)