PIV Measurement of Transient 3-D (Liquid and Gas Phases) Flow Structures Created by a Spreading Flame over 1-Propanol

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ABSTRACT

In the past, we measured three-D flow structure in the liquid and gas phases that were created by a spreading flame over liquid fuels [1]. In that effort, we employed several different techniques including our original laser sheet particle tracking (LSPT) technique, which is capable of measuring transient 2-D flow structures. Recently we obtained a state-of-the-art integrated particle image velocimetry (IPIV), whose function is similar to LSPT, but it has an integrated data recording and processing system. To evaluate the accuracy of our IPIV system, we conducted a series of flame spread tests using the same experimental apparatus that we used in our previous flame spread studies [1] and obtained a series of 2-D flow profiles corresponding to our previous LSPT measurements.

We confirmed that both LSPT and IPIV techniques produced similar data, but IPIV data contains more detailed flow structures than LSPT data. Here we present some of newly obtained IPIV flow structure data, and discuss the role of gravity in the flame–induced flow structures. Note that the application of IPIV to our flame spread problems is not straightforward, and it required several preliminary tests for its accuracy including this IPIV comparison to LSPT.

FLAME-SPREAD EXPERIMENT

We employed a fuel tray whose side-wall is Pyrex (300mm long x 10 mm high x 2mm thick) and bottom is PMMA. To test the effect of tray width on the flow structure, two different tray widths (5 and 20 mm) were used without changing the tray length and height. 1-propanol was placed in the tray just before the experiment and its initial temperature was measured by a 50μm-diameter type-K thermocouple that was placed just below the fuel surface. The initial temperature of propanol was changed between 10°C and 20°C in which temperature range, the flame-spread behavior is either uniform or pulsating. To achieve repeatable experimental data, we enclosed the fuel tray with an opaque box of 250 mm wide x 250 mm high x 400 mm long with two transparent PMMA windows for observation and recording.

IPIV FLOW MEASUREMENT

IPIV technique requires seeding for both air and liquid; hollow glass particles (8-12 μm diameter) for liquid and smoke particles (1-2 μm) for air were used. Two laser pulses were sequenced to track trajectories of the seeding particles that were distributed in a 2-D laser illuminated plane. Figure 1 shows a schematic of our flame-spread apparatus and IPIV system that were applied to the flow measurement. Using two independent laser sheets, one for the top (x-z) view and the other for the side (x-y) view, a 3-D flow field can be obtained. In this study, however, we only report 2-D flow data in order to compare it with LSPT data.

SOME EXPERIMENTAL RESULTS

Here we report some of our IPIV data. IPIV detected a liquid circulation, which is consistent with our previous LSPT [1] and HI [2] results. We also found that the flame-induced liquid flow structures are quite different between the 5mm wide tray and the 20mm wide tray, supporting previous study's results by NASA [3,4] and our group [1,2].

Figure 2 shows 2-D velocity profiles measured by IPIV for (a) gas and (b) liquid propanol. The initial propanol temperature was 14°C (flame is in pulsating spread region) and the fuel tray width was 20mm. There was an approximately 2mm-diameter re-circulation cell in the gas phase, while in the liquid phase there was a large circulation whose center is located just ahead of the flame leading edge and approximately in 3mm deep. Schiller et al. [4] predicted the existence of the existence of a small gas-phase re-circulation cell. They explain that this re-circulation cell is driven by a combination of buoyancy-driven flow opposed to the flame propagation direction and the flow in the same direction as flame spread induced by thermocapillary-driven motion at the liquid surface. Our IPIV experiment confirmed that this gas-phase cell exists as long as the flame spreads in pulsating mode in the 20-mm fuel tray, but not in the uniform region.

Figure 3 shows 2-D velocity profiles for (a) gas and (b) liquid propanol at its initial propanol temperature 19 °C (flame is in uniform spread region). Again there was no re-circulation cell in the gas phase, but there was a liquid circulation whose diameter was somewhat smaller than the pulsating spread case and center is located behind of the flame leading edge. For the pulsating spread, the relative location of the liquid circulation center to the flame leading edge changes, so the figure 2 (b) is not representative in nature. However, in both cases the liquid circulation always ahead the flame leading edge indicating the flame spread to be driven by the liquid circulation.

In the upstream gas phase near the fuel surface in Fig. 2 (a), airflow is parallel to the fuel surface and is concurrent to the flame spreading direction. The concurrent airflow is likely induced by the liquid circulation (but not by the flame), because the velocity of the concurrent airflow decreased with an increase of the initial propanol temperature. In the uniform spread region, a millimeter-order gas-phase circulation, which was formed just ahead of the flame leading edge was found only for the 5-mm wide tray, but not for the 20-mm wide tray. For the 5mm wide tray, viscose effect may be more dominant than the 20mm wide tray and flow structure is rather 2-D, while for the 20mm wide tray the viscose effect is rather weak and the flow structure is 3-D. The 3-D flow structure in the 20mm wide tray helps to distribute the fluid momentum across the space in front of the flame leading edge.

Both the length (L) and velocity (V) of liquid surface flow were measured from IPIV diagrams and plotted as a function of the initial propanol temperature (Fig. 4). It is interesting to see the subsurface liquid flow to always ahead in the very similar way the flame leading edge for both tray width cases, despite the fact that there is a big difference in gas phase flow structure between both tray width cases. This suggests the flame spread to be controlled by the liquid flow, but not by gas phase heat transfer.

Acknowledgements

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References

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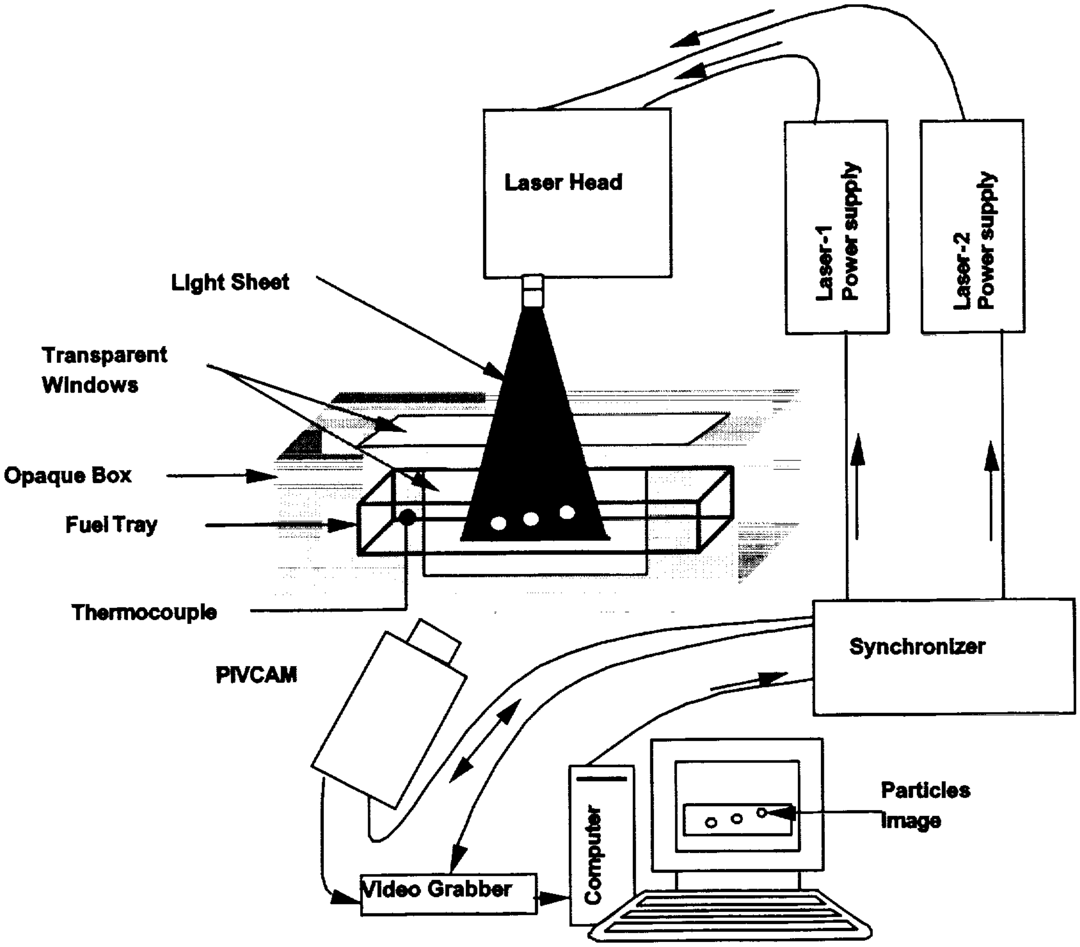

Fig. 1 Flame spread apparatus and an integrated particle image velocimetry.

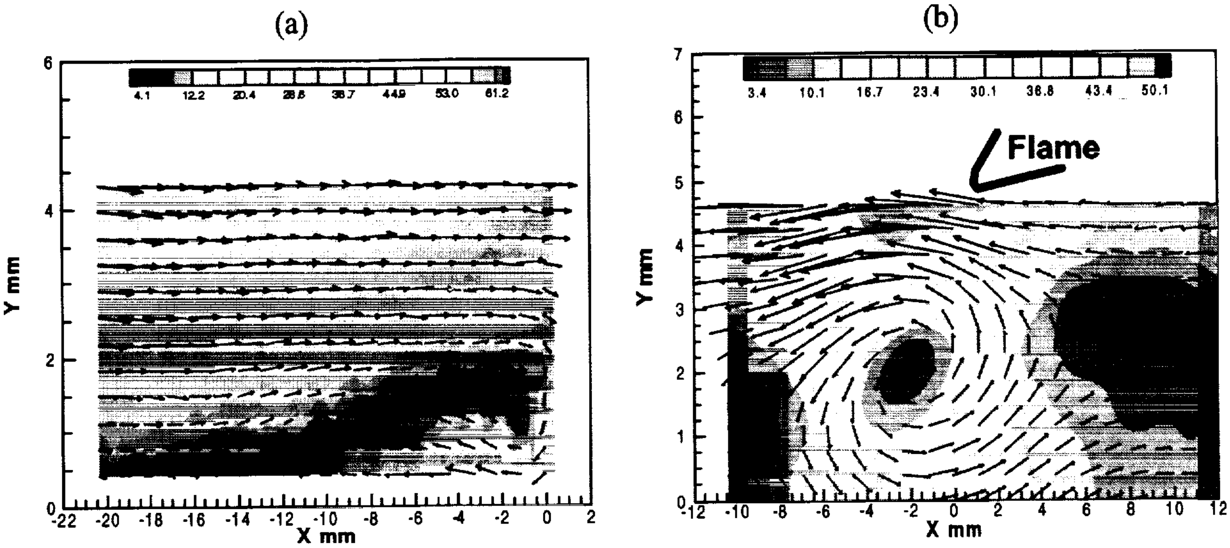

Fig. 2 Two-D velocity profiles for (a) gas and (b) propanol using a 20-mm wide tray. The initial propanol temperature was 14°C.

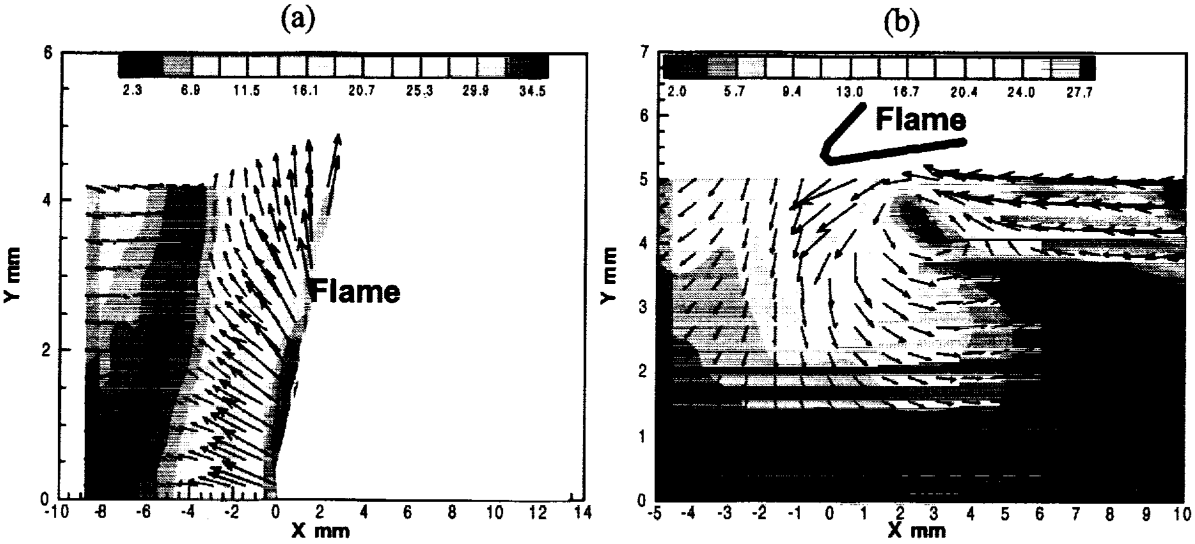

Fig. 3 Two-D velocity profiles for (a) gas and (b) propanol using a 20-mm wide tray. The initial propanol temperature was 19°C.

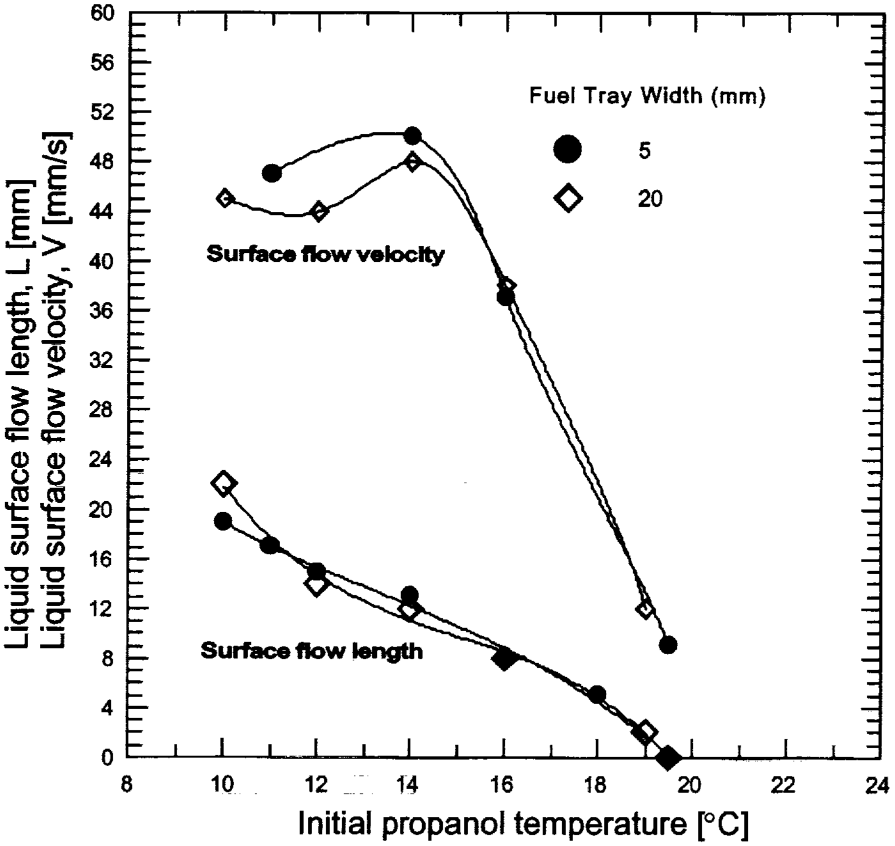

Fig. 4 Liquid surface flow velocity and horizontal distance of liquid surface-flow from a flame leading edge.