Chapter 1

Fire Safety on Flame Spreading Over Liquid Fuels

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1.1. Introduction

Flame spreading over liquid fuels is usually accompanied by liquid fuel motions generated by the thermocapillary effect. The heating of the liquid fuel under the flame tip produces surface tension gradients that can lead to motions in the liquid bulk by viscous stresses. Some features of flame spread have been described (see for instance Akita) and computer codes have been developed for these propagation modes. In spite of this, the nature of the involved mechanisms is still now controversial with respect to some points. Furthermore, experimental description of flame spreading has not been completed. The purpose of this work is to contribute to complete this experimental description of flame spreading over liquid fuels.

1.2. Experimental setup

The experimental setup consists of an open channel configuration, filled with a liquid fuel. The initial fuel temperature was kept uniform along the horizontal with a refrigerant circuit. Four aliphatic alcohols (methanol, ethanol, 2-propanol and 1-butanol) and two different channel lengths have been used (40 cm long, 4.0 cm deep, 2.5 cm wide and 100 cm long, 1.5 cm deep, 3.4 cm wide, respectively). Additionally, two different kind of lateral walls were employed (aluminum and Pyrex). Eight thermocouples (Cr-Al), regularly spaced along the fuel surface, record the evolution of the fuel surface temperature; also video-camera records provide the flame front evolution and its spreading velocity, using a composite image technique. Then, the spreading velocity of the flame can be represented as a function of T_∞ as a bifurcation diagram. A typical plot of the flame spreading velocities for ethanol in the 40 cm long channel is shown in figure 1. Qualitatively identical results have been observed for all of the alcohols and channels.

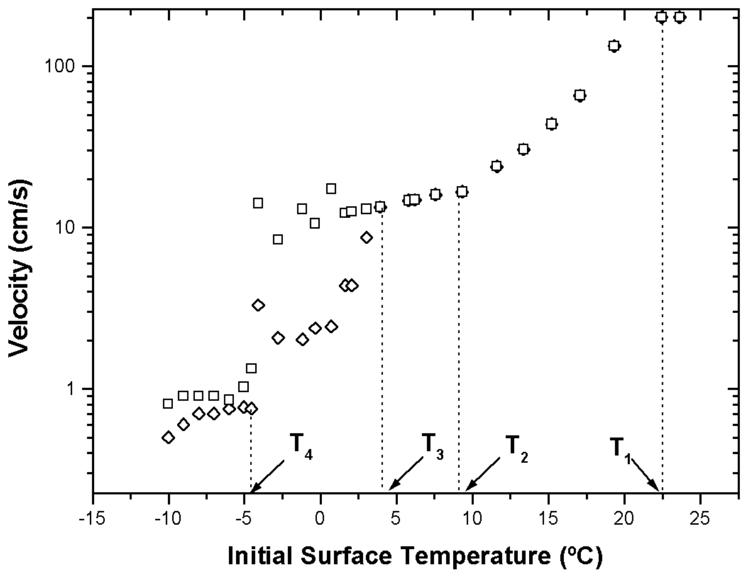

Figure 1: Bifurcation diagram for ethanol in a 40cm long channel. Squares represent the maximum value of flame velocity, while diamonds represent the minimum value.

1.3. Experimental results

As shown by the figure, for large values of the initial surface fuel temperature, $T_\infty \geq T_1$, the fuel vapor pressure is so high that it leads to a flame spreading regime purely controlled by the gas phase, where the presence of the liquid fuel is ignored by the flame. Flame propagation velocities of the order of 100 cm/s are observed in this region. For relatively high temperatures $T_2 \leq T_\infty \leq T_1$, a solid fuel-like regime of uniform flame spreading velocity, v_f, controlled by heat diffusion in the condensed phase appears. Flame velocities vary from the order of 100 cm/s to approximately 10 cm/s, decreasing almost linearly with decreasing temperatures, with a slope of the order of 10 cm/s ºC. For lower temperatures $T_3 \leq T_\infty \leq T_2$, flame spreading is still uniform, but in this case the slope of the $\left(T_\infty - v_f\right)$ diagram is of order 1 \: cm/ sºC, then showing a sharp transition with respect to the preceding regime. The fuel temperature T_2 defines the transition value that should be considered as a *steady state bifurcation point* of the whole system through which flame propagation controlled by heat diffusion in the condensed phase turns to flame propagation assisted by heat convection in the condensed phase. Thermocapillary convection brings hot fuel ahead of the flame tip and a vortex of warm liquid fuel develops there which enhances flame spreading by reducing flame heat losses. For even lower temperatures $T_\infty \leq T_4 \leq T_3$ the flame spreading exhibits oscillatory behavior. A limit cycle appears at $T_\infty = T_3$ as a *Hopf bifurcation* from the thermocapillary assisted spreading regime, known as the pulsating regime. Finally, for temperatures $T_\infty \leq T_4$, flame spreading velocity is almost constant, with values close to 1cm/s. The critical point T_4 corresponds to a *homoclinic orbit*, where a divergence in the period is observed, as we can see in figure 2.

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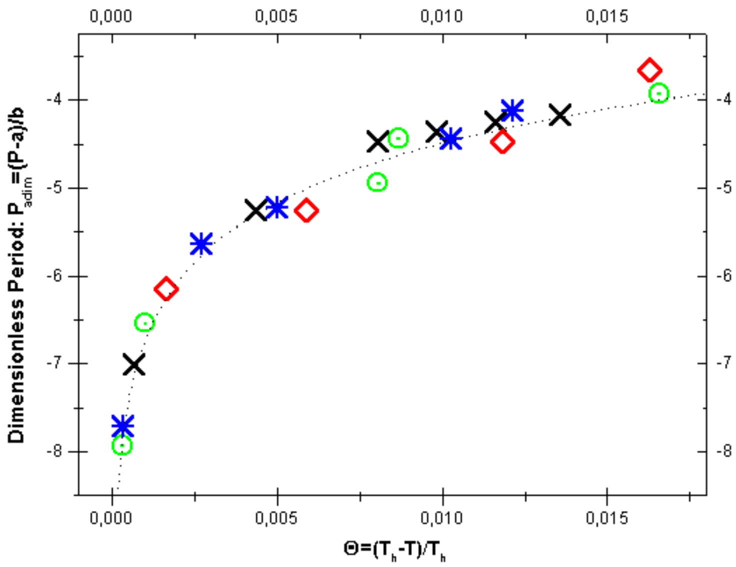

Figure 2: Period of the fuels used in our experiments in the 40cm long channela. Red diamonds, green circles, red diamonds, blue spots and crosses correspond to ethanol, methanol, butanol and propanol, respectively. The periods and the temperature are plotted in a dimensionless way in order to incude them all in the same graphic.

1.3. Preheated region

During the flame spreading experiments in these regimes, the temperature records of each thermocouple experience an abrupt increase with the passage of the flame. Furthermore, in the thermocapillary assisted regime $T_3 \leq T_\infty \leq T_2$ a slight temperature augmentation preceding flame arrival was detected before this abrupt increase in the temperature, indicating the existence of a preheated region of warm liquid fuel ahead of the flame tip. In spite of the limited accuracy of the temperature measurement technique (surface thermocouples), an approximate measure of the horizontal length *L* of this preheat region *versus* the initial fuel temperature is shown in figure 3. The characteristic length *L* vanishes close to T_2 whereas near T_3 it is close to 1 cm. On the other hand, for fuel temperature values $T_\infty \geq T_2$, no detectable increase in the liquid temperature has been observed before flame arrival. These findings agree with the results reported by Ito et al. Ito and Ross et al. where, by using interferometric and rainbow-Schlieren techniques, respectively, they observed a well developed vortex preceding the flame only in the thermocapillary assisted spreading regime.

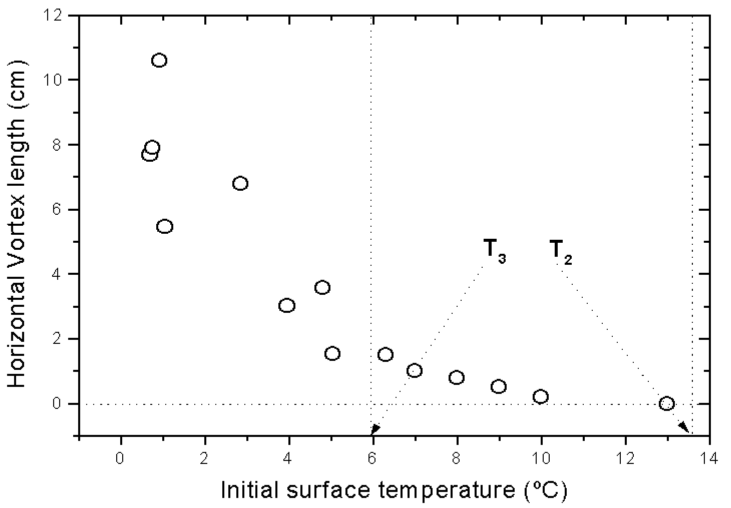

Figure 3: Estimation of the horizontal length of the preheated zone ahead of the flame front., corresponding to a 100 cm long channel filled with ethanol

This is a distinctive characteristic with solid fuels, that modifies dramatically flame spreading conditions.

1.3. Conclusion

The basic characteristics of flame spreading over liquid fuels have been experimentally found. The appearance of a preheated region in front of the flame front seems to play an important role in flame progress, producing then three different regimes. . The initial surface temperature seems to play an important role as a control parameter of flame spreading and can be used to increase fire safety in fuel deposits.
We have reduced our work to a long, almost one dimensional channel. New experiments have to be carried out using different geometries in order to complete our results.

References

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