Burning Liquid Fuel Films from Flat Plates

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Introduction

Miniature combustors have the potential to provide high levels of power in compact devices, and consequently, the development of miniature combustors (on the order of centimeters in primary dimension) has been of research interest during recent years. One particular strategy for miniature combustion using liquid fuels is to evaporate the fuel off of the chamber walls. For this purpose, beaded surfaces, or catalyzed porous slabs or screens have been used to distribute the fuel throughout the inner combustor surfaces. The challenge to miniature fuel-film combustion is that the fuel must evaporate, mix, and burn in close proximity to the wall so that the flame can effectively sustain its fuel source. In order to understand this process better, we examine the flame/evaporating fuel-film interaction using flat plates in a laminar flow wind tunnel. Understanding the role of the surface will help in the design of improved combustors.

Fuel film evaporation and burning has been studied classically by Emmons [1] and fairly popularly in the context of flame spread [2] and flame stability [3,4], as well as in microgravity conditions [5]. These works are relevant to our study, but none of them examines a flame stably supported by an evaporating liquid fuel film. We have constructed a flat plate liquid film combustion experiment that approximates the classical laminar diffusion flame problem described by Emmons. Three different plate surfaces are examined: (a) sintered porous surface, where the fuel is held in the pores, (b) a beaded or roughened surface where the fuel spreads through the bead channels, and (c) a fine mesh screen surface. The paper describes flame location and shape, as well as fuel consumption rate, for different air flow rates over the different plates. Comparison with predictions is also included.

Experimental Setup

As shown schematically in Figure 1, the experiments are performed using a rectangular combustion chamber of 10 cm x 10 cm cross section in a subsonic horizontal wind tunnel. Air is supplied from a blower, through a calibrated venturimeter, diverging nozzle, and settling chamber to the combustion chamber. The settling chamber contains honeycomb tube and five layers of damping screens to reduce the intensity of turbulence. A sintered bronze screened plate, a beaded plate, or a porous plate of 7.6 cm x 7 cm surface area and 1.3 cm thick is mounted on the optical rail in the combustion chamber. Heptane is injected through the plate by a high pressure digital liquid pump. Provision is made to flood the chamber with nitrogen supplied from a cylinder bottle in order to extinguish the flame. Sapphire windows on opposing walls of the chamber provide the optical access for photographs and laser measurements in the flame zone. We will use this access to measure the temperature profile from near the surface to the flame using coherent anti-Stokes Raman spectroscopy (CARS) and the flame location using self-light photography and schlieren imaging.

Preliminary Results

A photograph of a heptane flame burning in the tunnel above a screened surface is shown in Figure 2. We have found that the flame can be sustained only above a minimum liquid fuel flow rate (approximately 0.5 cc/min). With less fuel delivered than this minimum, the flame extinguishes. In addition, and as expected, different air flow rates change the flame anchor location, but the flame continues to burn steadily (without flame spread) over a wide range of air flows (50- 183.4 L/min). Actually, the flame anchor location moves back as the airflow increases as seen in Figure 3. The flame anchor point moves back in order to initiate the reaction in a zone of approximately constant shear near the surface. That is, at higher velocity, the boundary layer thins, increasing the shear at a given downstream position. The flame moves downstream to reduce the strain rate until the combustion process can occur. In the extended paper we will compare the flame anchor position to the strain rate at this position assuming a Blasius boundary layer flow over the plate.

Our preliminary CARS measurements show good signals in calibration runs, but we have not yet complete experiments under burning conditions.

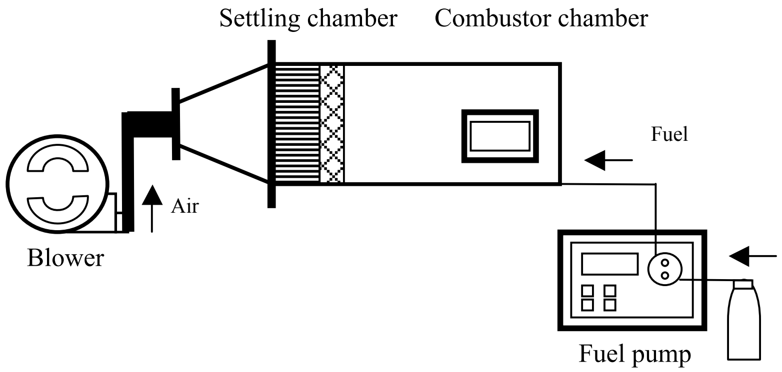


Figure 1 Experiment set-up

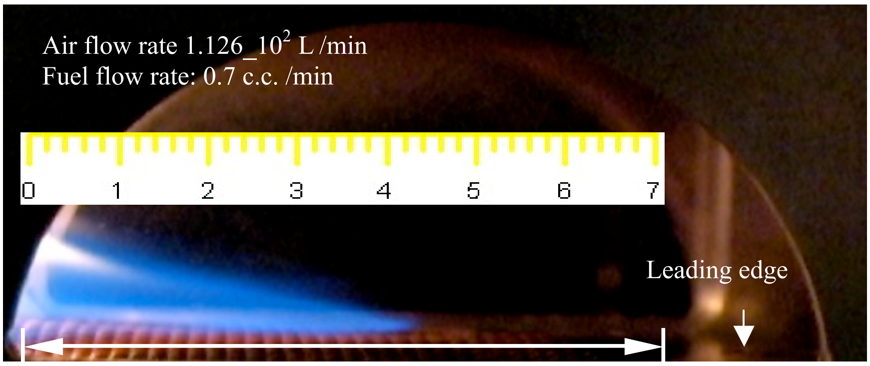
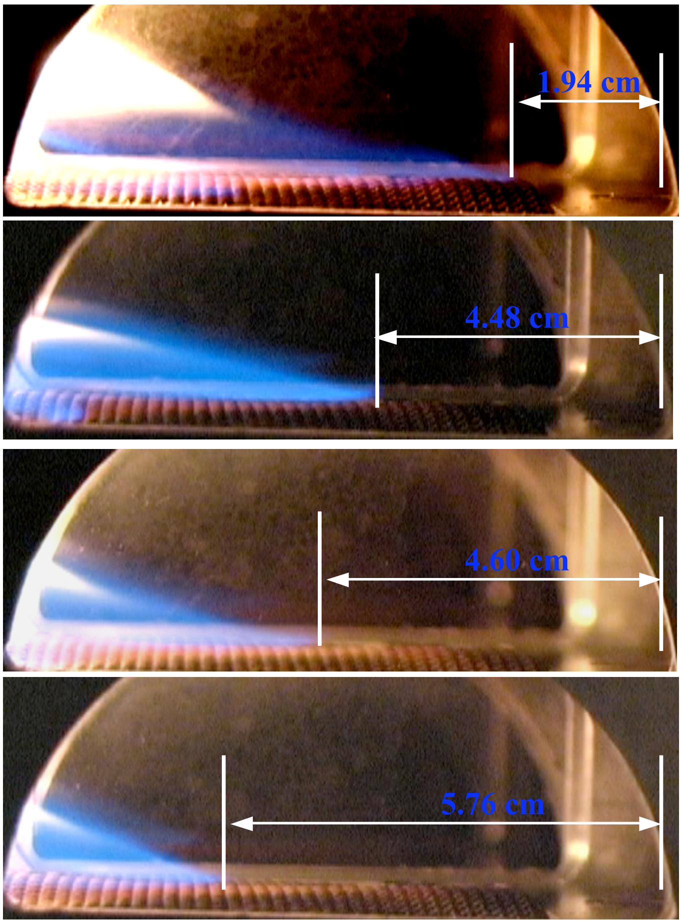


Figure 2 Photo of flame



Air velocity

7.92 cm/sec

18.3 cm/sec

24.7 cm/sec

29.6 cm/sec

Figure 3 flame anchor location in different air flow rates
(fuel rate is 0.7 cc/min)

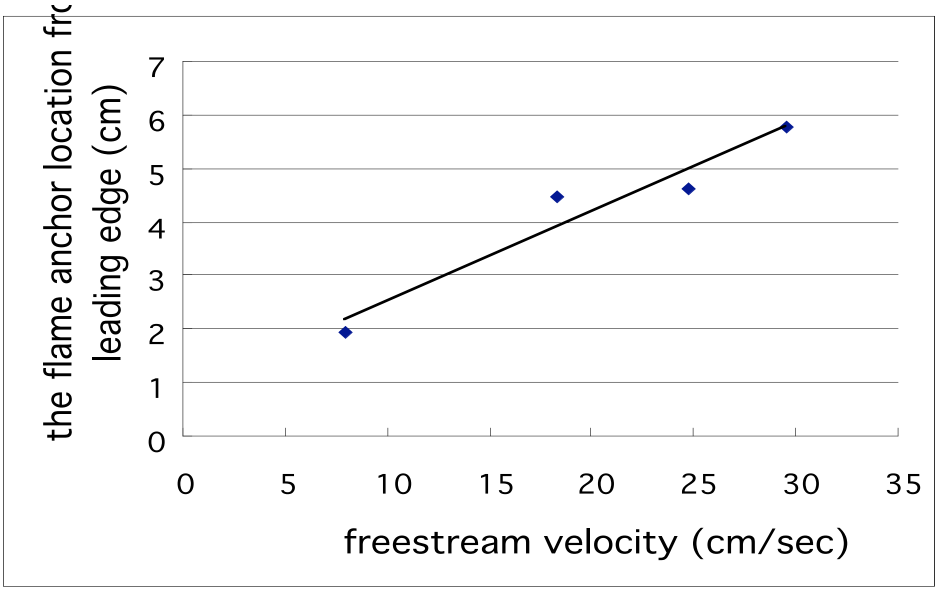


Figure 4

Future Work in Final Paper

The final paper will include further images of flames on different surfaces, as well as schlieren photographs giving the thermal gradients of them. CARS temperature profiles will help assess the heat flux to the fuel surface.

References

[1] Emmons H, “The Film Combustion of Liquid Fuel ,” *Z. Agnew. Math. Mecg.* **36:** 60-71, 1956

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