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THIN-FILAMENT PYROMETRY IN FLICKERING LAMINAR DIFFUSION FLAMES

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This paper describes an experimental system for thin-filament pyrometry (TFP) in acoustically phase-locked flickering laminar methane/air diffusion flames. The physical basis of the technique is discussed. The experiment utilizes a 15-μm β-SiC fiber, which is simultaneously imaged at 540 points over a length of 27.5 mm using a cooled CCD camera. This arrangement provides measurements over a 1200–2100-K temperature range having a spatial resolution of $\sim 100\,\mu$m, a temporal resolution of 1.5 ms, and a precision of 1.5 ± 1.0 K for temperatures on the order of 2000 K. The TFP is calibrated assuming that the strongest filament emission at a height 7 mm above the burner for a steady laminar flame corresponds to a temperature of 2000 K. Temperatures at different positions along the filament are then determined by recording relative emission intensities and assuming that the filament acts as a gray-body emitter. Measured filament temperature profiles are found to be in good agreement with earlier radiation-corrected thermocouple results by Richardson and Santoro for the same steady laminar flame. The calibrated TFP is then used to make filament temperature measurements at various heights and phases of a previously studied flickering flame entering a low-velocity air flow. The use of a two-dimensional CCD allows a baseline to be determined, and measurements can be made in the presence of background luminosity, which is observed in sooting regions. In order to demonstrate the effectiveness of the approach, measurements are discussed for various heights above the burner and phases of the flickering flame. The need for an extremely well-characterized flame for calibrating TFP is discussed. Knowledge of flow velocities and molecular composition in both the calibration and flickering flames is required to improve the accuracy of flame temperature measurements using TFP.

Introduction

The experimental characterization and modeling of simple flame systems (such as stationary laminar diffusion flames of simple gaseous fuels) has progressed dramatically. Before these advances can be applied to the design of practical devices, it is necessary to develop similarly detailed experimental and modeling approaches for turbulent combustion. As a step in this direction, a coordinated experimental and modeling effort is being used to investigate acoustically phase-locked flickering laminar diffusion flames in order to better characterize and model flame/flow interactions [1–5].

One of the obstacles to this characterization has been the lack of experimental diagnostics for temperature measurement having high spatial and temporal resolution. Recently, thin-filament pyrometry (TFP) has been shown to have potential for providing such measurements [6]. The current work describes the development of a new TFP approach designed especially to allow measurements in the flickering flames, but which is useful for a wider range of combustion applications. This technique provides highly precise, semiquantitative measurements having excellent temporal and spatial resolution. Representative results are presented to demonstrate the effectiveness of TFP.

Thin-Filament Pyrometry

The use of TFP in flames was pioneered by Vilimpoc et al. [6], and the theory and development of the technique is discussed in detail in several publications [7–9] from this group. Bédat et al. [10] have performed similar measurements.

The physical basis of TFP is simple and elegant. The intensity of thermal electromagnetic radiation from a length of heated silicon carbide (β-SiC) fiber is used to characterize the temperature of the fiber and can be related to the temperature of gas surrounding the fiber. These fibers have very small diameters (nominally 15 μm) while having sufficient strength and temperature resistance to survive hours when inserted in typical atmospheric hydrocarbon diffusion flames. Here the necessary physics and past experimental approaches are summarized. References 6–10 should be consulted for additional details.