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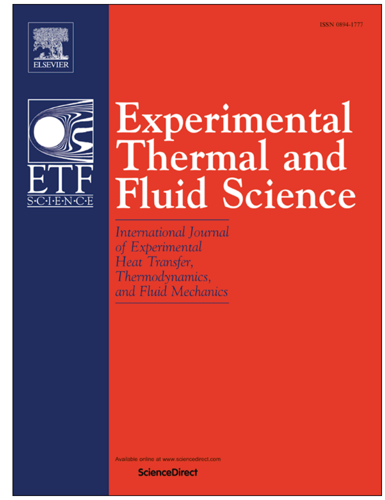

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Observation of large-scale structure in flickering diffusion flame by time-resolved particle image velocimetry and shadowgraph imaging

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Abstract
In order to understand the flow structure of a flickering flame, time-resolved observations are carried out of the velocity and density fields in a diffusion flame in co-flow using particle image velocimetry (PIV) and shadowgraph imaging, respectively. The PIV measurement combined with invalid velocity vector analysis using proper orthogonal decomposition (POD) allows for the high spatial resolution measurement of the velocity field in the flame, while the shadowgraph images show the high-temperature contour and soot formation of the flame. These experimental results indicate a periodic variation in the flow field and soot structure of the flickering flame. The observation of the velocity field shows that the periodic inflow and outflow are generated in the outer layer of the flame near the burner, which promotes the flow acceleration in the vertical direction leading to clip-off behavior. It is found that the vorticity contour evaluated from the velocity field matches well with the high-temperature contour observed in the shadowgraph images. Further examination of the flow structure is carried out using the first two POD modes, which demonstrate the presence of counter-rotating vortices in the outer flame contributing to stretching of the flame due to the clip-off motion in the flame.

Key words: Diffusion flame; Buoyancy; Flickering; Large-scale structure; Flow visualization

1. Introduction

It is well known that a combusting flame oscillates periodically under certain experimental conditions owing to the instability arising from the high-temperature region of the flame. Flickering flames have been a fundamental topic of interest in combustion science and the related field of thermal engineering. Therefore, the periodic motion of the flame and the large-scale structure generated outside the flame have been studied in the literature [1, 2].

The flickering frequency is one of the most important characteristics of a flickering flame. This is often observed to be around 10 to 20 Hz under normal experimental conditions, and it is slightly dependent on the Froude number and the experimental factors, such as the fuel type, flow rate, and burner size [1-3]. Although there are several experimental and numerical studies on the flow structure of flickering flames [4-10], the phenomenon has not been fully understood yet, owing to the complexity of the flame structure and the limitation of the quantitative flow visualization technique.

The first flow visualization study on a flickering flame was carried out using the reactive Mie scattering technique [2], which allows for the qualitative characterization of the periodic behavior of a flickering flame. The result suggested that flame flickering was caused by the formation of a large-scale structure in the outer flame, which is often called toroidal vortices; however, the detailed structure of the vortices was not clearly understood. Later, the presence