Vortex Structures and Temperature Fluctuations in a Bluff-body Burner

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Abstract: Vortical and thermal structures of non-premixed propane flame in a bluff-body burner are studied experimentally in the transition from laminar to turbulent flow. In particular, we focus attention on the effect of annular air flow on the flame. The small-scale inner vortices inside the flame is stimulated by the annular air flow, and outside the flame, small eddies due to turbulence rather than the large-scale outer vortices due to thermal buoyancy become dominant with increasing air velocity. The interrelation between the vortical and thermal structures is analyzed by looking at the frequency spectrum and probability density function of temperature fluctuations.

Keywords: combustion, non-premixed flame, shadowgraph method vortical structure, thermal structure, bluff-body burner

1. Introduction

Non-premixed flame stabilized by a bluff-body combustor, such as occurs when a central fuel jet issues into a surrounding annular air flow, is often used industrially. Such bluff-body combustors provide good flame stabilization as well as easy control of combustion.

There have been experimental studies on non-premixed flames for several fuels. Roquemore et al. (1986) introduced a two-diemnsional sheet-lighting technique coupled with a fast chemically reacting system to visualize the turbulent mixing and the vortex shedding processes of a bluff-body combustor for C,H,. Lin and Tankin (1987) employed this technique and determined the effect of burner design and flow conditions on fuel jet penetration at low Reynolds numbers. Furthermore, Chin and Tankin (1991) and Nishimura and Takemori (1995) measured vortical shedding frequency using a flow visualization technique in a two-dimensional slot burner and cylindrical-shaped burners, respectively. Huang and Lin (1994) studied the flame behavior and the time-averaged thermal structure for various C,H, and air flows. Schefer et al. (1987) and Namazian et al. (1989) performed velocity and concentration measurements using laser Doppler velocimetry and a combined Raman scattering and laser-induced fluorescence imaging in turbulent flow for CH,. Lee and Onuma (1991) also measured velocity, temperature and chemical species in turbulent flow for H, in order to compare with numerical simulation of a k-ε model.

Although they emphasized the importance of vortical structures in bluff-body burners, the relationship between the vortical and thermal structures under unsteady vortical motion has not been understood fully in the experimental studies. While, more recently, direct numerical simulations have been performed in the transitional flow regime for jet diffusion flames to capture the temporal and spatial development of vortical and thermal structures, i.e., Katta and Roquemore (1993), Yamashita et al. (1996). Such a simulation will be extended to bluff-body burners in the near future. However, there have been few studies providing time-dependent experimental data to test and refine mathematical modeling. These aspects have motivated the present investigation.
and thermal structures in a bluff-body burner are studied experimentally in the transition from laminar to turbulent flow as a necessary initial step in a more realistic situation involving fully turbulent flow. Because we focus attention on the effect of annular air flow on the flame, and it is expected that the fuel jet in the transition regime is responsive to the annular air flow.

2. Experimental Apparatus and Procedure

The bluff-body, vertical, unducted combustor used here consisted of a fuel nozzle located concentric to an annular region where air flowed, as shown in Fig. 1. Commercial-grade propane was employed as the fuel gas. The diameters of the fuel nozzle $D_f$, the inner annulus $D_i$, and the outer annulus $D_o$ were 10 mm, 42 mm, and 56 mm, respectively. One of the objectives of the present study is to examine the effect of the annular air velocity. The test matrix consisted of measurements over a range of annular air velocity under a fixed fuel velocity, listed in Table 1. It should be noted that the jet at this fuel velocity belongs to the transition regime, in the absence of the annular air flow.

<table>
<thead>
<tr>
<th>Case</th>
<th>Central Fuel Jet $u_c (m/s)$</th>
<th>Re</th>
<th>Annular Air Flow $u_A (m/s)$</th>
<th>Re</th>
<th>$u_A/u_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.84</td>
<td>1957</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>B</td>
<td>0.84</td>
<td>1957</td>
<td>0.62</td>
<td>563</td>
<td>0.74</td>
</tr>
<tr>
<td>C</td>
<td>0.84</td>
<td>1957</td>
<td>1.84</td>
<td>1632</td>
<td>2.19</td>
</tr>
</tbody>
</table>

The relationship between vertical and thermal structures was examined by flow visualizations and temperature measurements. A schematic diagram of the experimental set-up is shown in Fig. 2. The vertical structure was visualized by combination of the shadowgraph method and 16 mm high-speed cinematography. A projector lamp was the continuous light source. The motion pictures were analyzed with an image processor.

Fig. 1. Bluff-body burner.

Fig. 2. Experimental apparatus.