Experimental Investigations of Laminar Triple Flames and Triplet Flames in Strained Flow Fields

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Abstract

The present paper concerns the experimental investigations of laminar methane-air triplet and triple flames established in a flat counterflow burner. For the cases of steady triplet flames the velocity fields were carried out using digital particle image velocimetry (DPIV). This was complemented using planar laser induced fluorescence (PLIF) to map the relative OH concentration fields. The structure and behaviour of highly unsteady triple flames had been investigated by visualization using a highspeed CCD-camera.

Introduction

In the last few years so-called *triple flames* have received increased attention due to their relevance for the modelling of turbulent combustion using laminar flamelet models, see e.g. [1]-[4]. By nature, triple flames are unsteady. They establish themselves as a consequence of inhomogeneities in mixture layers as they occur, for instance, during combustion in internal combustion engines. To perform basic experimental studies of triple flames it is desirable to establish magnified steady triple flames in either coflow or counterflow geometries. Counterflow geometries are particularly useful to study the effects of strain on the flames, which may lead to extinction or ignition phenomena, and to perform parametric studies of the influence on flame structure of varying mixture strengths.

If counterflow burners are operated in a stationary mode, so-called *triplet flames* can be generated which represent all of a triple flame except the triple point. In particular, triplet flames essentially comprise three flames, namely a lean premixed flame on, say, the left, a rich premixed flame on, say, the right, and – in between – a diffusion flame in which the excess fuel from the rich flame and the excess oxidizer from the lean flame burn. In this paper, both triplet flames and – to a lesser extent – triple flames are investigated experimentally. For the steady triplet flames digital Particle Image Velocimetry (DPIV) is used to investigate velocity fields and planar laser-induced flourescence (PLIF) to measure OH distributions. Highly unsteady, propagating triple flames are vizualized using a Phantom high-speed CCD camera.

Experimental Setup

Both triplet flames and triple flames can be stabilized in various burner configurations. Herein a flat counterflow burner consisting of two identical ports mounted on a stable table and directed towards each other is used. The premixed gasflow in each port reaches the burning area located between the ports through a mixing chamber, through meshes, through a flowstraightener and finally through a nozzle with exit area of about $400 \times 29\,\mathrm{mm}^2$. Between the nozzles, the two streams directed towards each other form a free stagnation point flow. The parameters that can be varied in the experimental investigations are the separation distance between the nozzles Δy and, in each stream independently, the flowrate $\dot{V}$ and the mixture ratio ϕ; in this study Δy was fixed at $\Delta y = 50\,\mathrm{mm}$.

The investigations of velocity fields reported here were carried out using digital PIV. The DPIV system is controlled via a PC unit to aquire the images and to calculate and display the velocity field. The laser is a Spectron Nd:YAG-Laser (320 mJ/pulse at 532 nm) and its laser beam is guided to the light-sheet optics through a light-guiding arm system. The CCD-camera is a so-called cross-correlation camera with a pixel resolution of about 1280×1024 pixel. Camera and optics are mounted perpendicular to each other in a modular tripod.

Planar LIF is used to map OH concentration fields. To this end, an electronic image-intensifier is used with the CCD-camera. The laser system consists of a dye-laser (1 mJ/pulse at 281 nm) pulsed by a Nd:YAG-Laser (100 mJ/pulse at 355 nm) at 12.5 Hz.

Some Results

Due to space limitations, here only a short description of selected exemplary results for one case of steady triplet flames and unsteady triple flames can be given. In the conference, a detailed presentation of the work carried out will be provided.

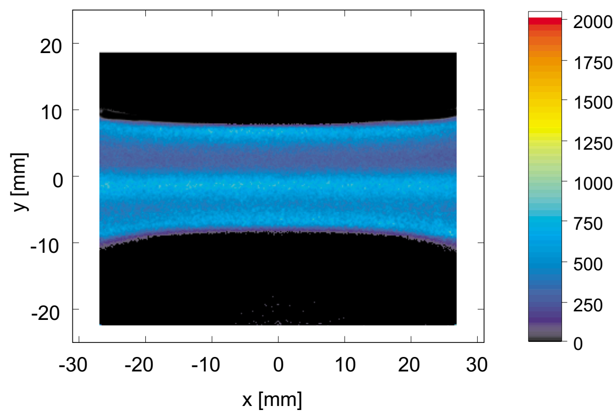

Figure 1: *Distribution of the relative OH concentration*

Shown in Figs. 1 and 2 are the PLIF and DPIV results for a steady triplet flame in a flat counterflow burner. The strainrate calculated from the volumetric flowrates and the nozzle distance is approximately $70\,\mathrm{s}^{-1}$. The two premixed flames are located at the respective upper and lower transition from dark grey to light grey of the PLIF plot. They pertains to an equivalence ratio of 1.3 and 0.8 respectively. The diffusion flame is located between the premixed flames. The lighter grey of the PLIF plot indicates that for this case the relative OH concentration is higher than in the two premixed flames. This finding is consistent with results from numerical simulations and previously obtained PLIF data of triple flames.

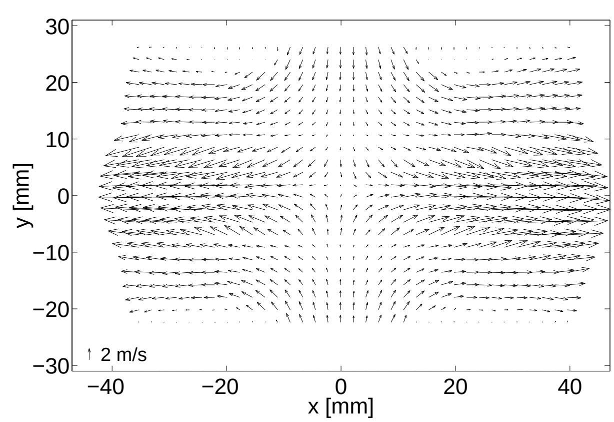

Figure 2: *Velocity field of a triplet flame in counterflow geometry*

As usual, in Fig. 2 the DPIV results for the velocity field are prsented in form of arrows which have the obvious meaning. Whereas the thermal influence of the two premixed flames on the velocity field can be identified in the region of strong fluid accerelations in the DPIV plot, such an influence is not clearly identifiable for the diffusion flame.

Keeping the equivalence ratio of the lower premixed flame fixed, e.g. at a value of $\phi_l = 0.6$, a parameter systematicaly varied in the study of triplet flames is the eqivalence ratio ϕ_u of the upper premixed flame. For instance, for $\phi_l = 0.6$ starting at $\phi_u = 0.8$, it is observed that the initial twin flame structure converts itself into a triplet flame structure at approximately $\phi_u = 1.1$.

An exemplary experimental result for a propagating triple flame is presented in Fig. 3. Here a sequence of pictures taken by a high-speed CCD-camera in 20 periods of 1/140 of a second is shown. The triple flame has been ignited at the top of the mixing layer, $\phi_L = 0.8$ and $\phi_R = 1.3$, by using a laser beam focused to the tip of a thin wire mounted near the stagnation plane between the two nozzles. It is seen that after approximately 0.014 s the ignition process is essentially and that then an extended period of quasi-steady flame popagation follows. The propagation speed of the triple flame has been estimated to $u_{\text{triple}} = 1.78\,\text{m/s}$. It has been found that the propagation speed of the triple flame increases with decreasing mixture strength between the lean and rich premixed part of the mixing layer. Further results on propagating triple flames will be included in the oral presentation of the paper.

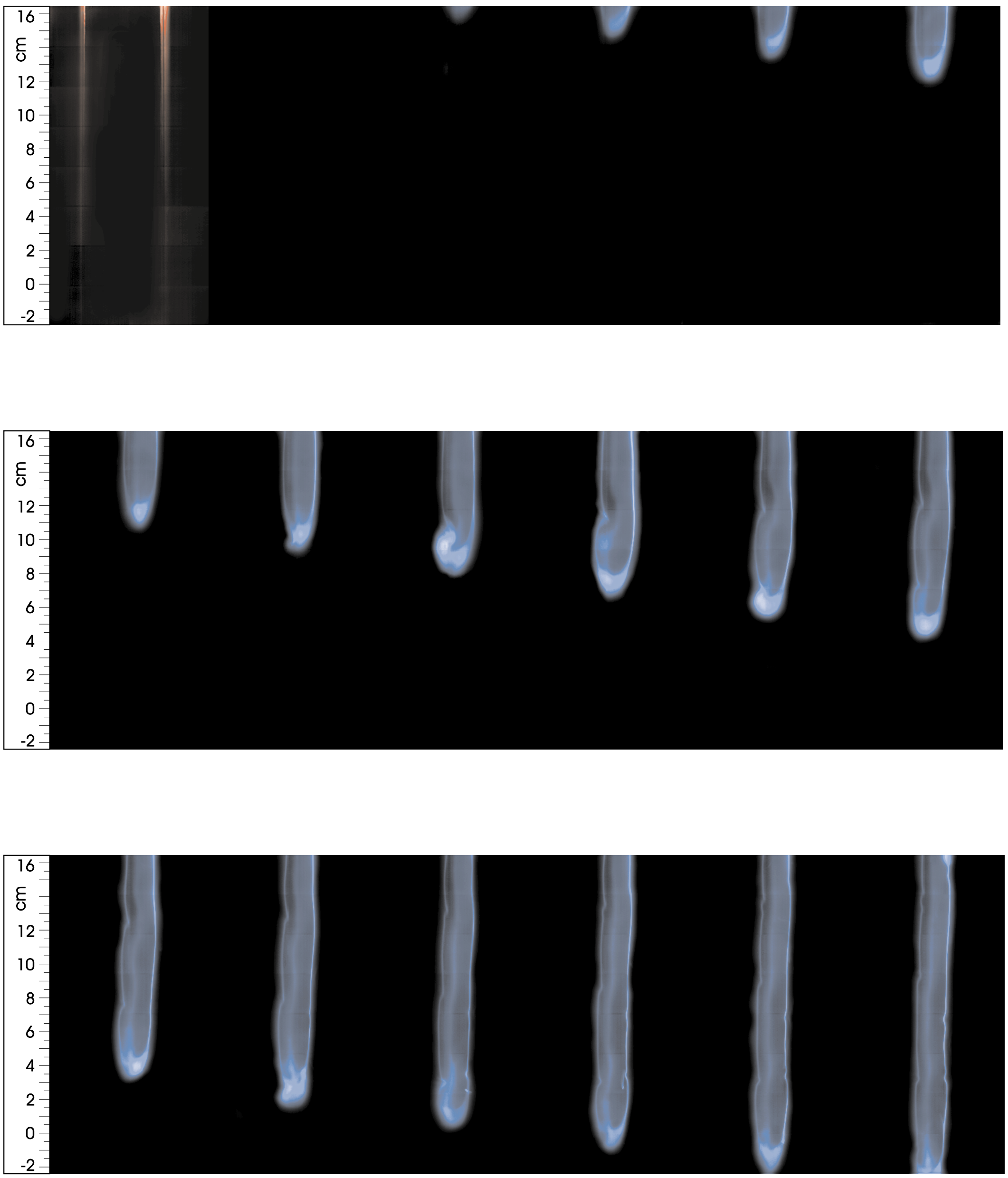

Figure 3: *Sequence of pictures of a propagating triple flame taken by a high-speed CCD-camera.*

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References

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