Simultaneous PIV/SO_2-PLIF imaging in multi-regime combustion processes

D. Butz[1], S. Walther[2], A. Breicher[2], S. Hartl[2,3], C. Hasse[3], A. Dreizler[1], D. Geyer[2]
[1] FG Reactive Flows and Diagnostics, TU Darmstadt, Darmstadt, Germany
[2] Optical Diagnostics and Renewable Energies, Hochschule Darmstadt University of Applied Sciences, Darmstadt, Germany
[3] FG Simulation of reactive Thermo-Fluid Systems, TU Darmstadt, Darmstadt, Germany
`butz@rsm.tu-darmstadt.de`

Keywords: combined PIV/PLIF imaging, multi-regime combustion, partially premixed combustion, conditional flow field statistics

Introduction

While combustion processes are often classified as purely premixed or purely non-premixed, partial premixing and recirculation may give rise to complex multi-regime combustion scenarios in practical applications. Therefore, a representation of local flame characteristics by pure premixed or non-premixed processes may not be sufficient [1]. In contrast to the conditions in practical applications, the majority of laboratory flames, investigation turbulent combustion, are operated with homogeneous mixtures. Due to the lack of compositional inhomogeneities, these flames do not exhibit multi-regime behavior. A number of experiments have been conducted to overcome these limitations, e.g. by Meares et al. [2,4], Barlow et al. [3] and Mansour et al. [5]. However, a comprehensive database of experimental results for multi-regime combustion processes based on canonical flame configurations with well-defined boundary conditions is required for both the understanding of the underlying processes as well as the validation and development of more generalized numerical models. In order to provide this data, a novel burner configuration to quantitatively investigate multi-regime combustion processes, the multi-regime burner (MRB), was designed.

Burner design

The novel multi-regime burner configuration consists of three inlet streams, which can be operated with different equivalence ratios (see Figure 1). A central stainless steel jet tube with an inner diameter of 3 mm and an outer diameter of 3.3 mm is surrounded by an annular slot (slot 1) with an outer diameter of 7 mm. Slot 2 has an inner diameter of 40 mm and an outer diameter of 60 mm. A recirculation zone between slot 1 and slot 2 is stabilized by a bluff body which is kept at a temperature of 80°C by circulation of heated water to avoid condensation on the burner surface. The burner slots are staged with an angle of 26° to allow for optical access at the exit plane. An additional air coflow (1 m/s) around the outer body of the burner (outer diameter of 80 mm) shields the flame and provides well-defined boundary conditions.

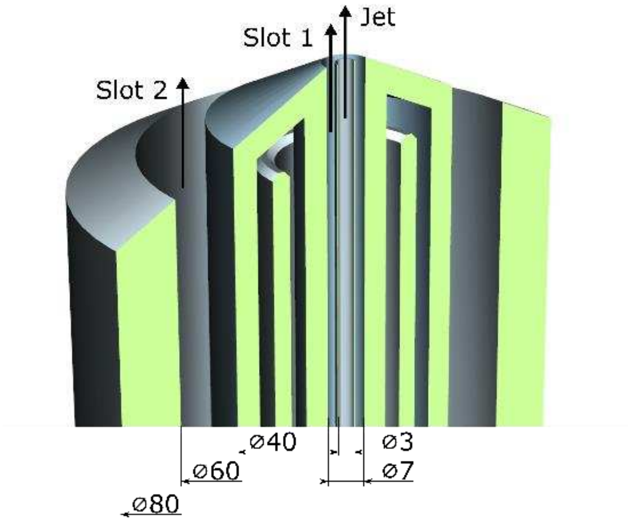

Fig. 1. Illustration of the MRB burner geometry

Operating conditions

Operating conditions including different ranges of methane/air-mixtures extending beyond the rich flammability limit have been studied. The flow from slot 2 was kept at an equivalence ratio of $\varphi = 0.8$ with an exit velocity of 20 m/s while the jet flow was varied from $\varphi = 1.4$ up to $\varphi = 2.6$ with a velocity of 105 m/s, yielding a Reynolds number of about 20000. Flames are named according to the equivalence ratio in the jet flow, where case 14 corresponds to $\varphi = 1.4$ and so forth. Jet and slot 2 are separated by a flow of pure air emanating from slot 1 with velocities of 7.5 m/s (“a”-cases) and 15 m/s (“b”-cases). Figure 2 show flame photographs of selected operating points.

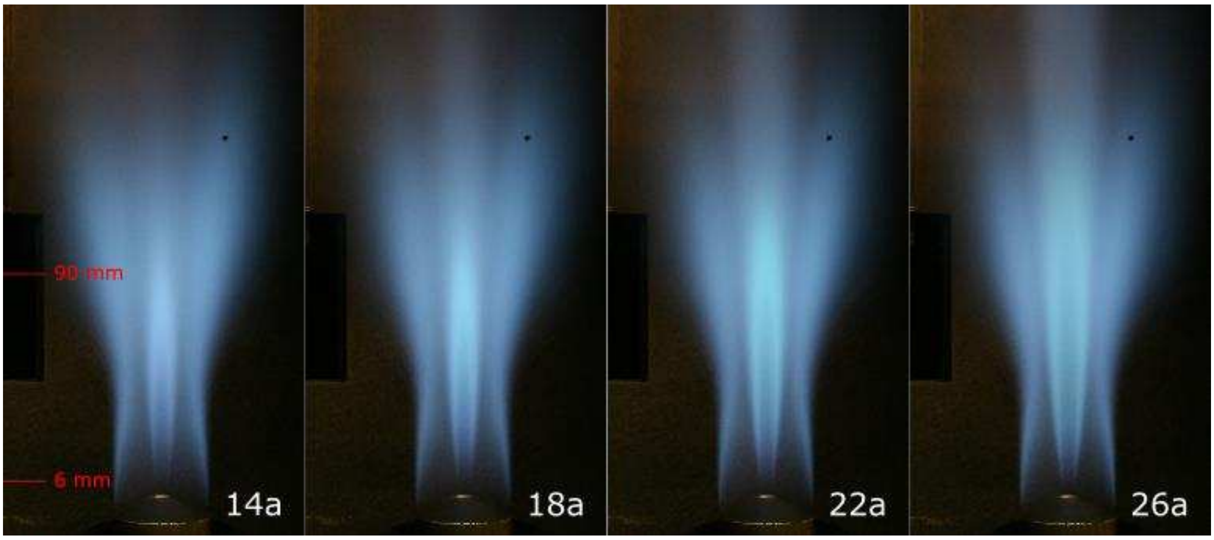

Fig. 2. Flame photographs

Multi-regime combustion

In order to decide if pure premixed or non-premixed flame structures can describe the local flame structure of the multi-regime burner setup, canonical flame characterizations were investigated as a preliminary step. Following, the suitability of the manifolds, based on freely propagating flames (premixed) and 1D counterflow flames (non-premixed) flames and the effect of multi-regime combustion is discussed.

Simultaneous PIV/PLIF

Three dimensional velocity data was acquired using stereo particle image velocimetry (PIV). Experimental results characterize the flow field of both reacting and non-reacting cases and provide valuable data for the validation of numerical simulations. Further, the intensity of planar laser induced fluorescence (PLIF) of Sulphur dioxide is strongly temperature dependent and has been demonstrated as a useful tool for flame front tracking [6]. Therefore, a detailed examination of the interaction of fluid dynamical quantities and the turbulence-chemistry-interaction is enabled by the simultaneous acquisition of the velocity field (PIV) and information on the position and orientation of the flame front (PLIF). Figure 3 shows profiles of axial and radial velocities (mean and standard deviation) at selected axial positions above the burner exit as well as a processed PLIF image with detected flame fronts above the jet and slot 2.

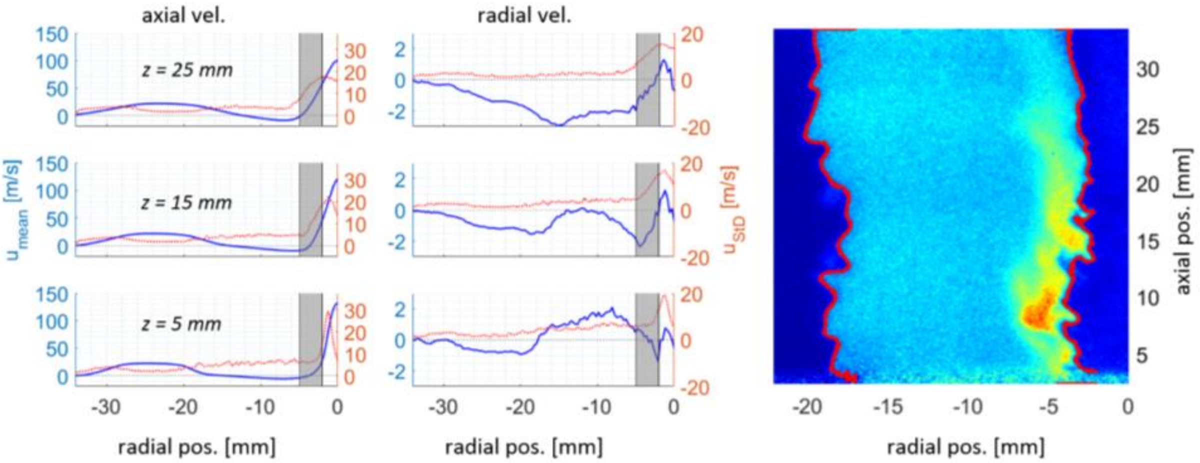

Fig. 3. Mean and standard deviation of velocities at three axial positions z above the burner (mean flame position indicated by grey boxes) and instantaneous PLIF image with detected flame fronts (red)

References

1. E. Knudsen, H. Pitsch, Combust. Flame, 159 (2012) 242-264.
2. S. Meares, A.R. Masri, Combust. Flame, 161 (2014) 484-495.
3. R.S. Barlow, S. Meares, G. Magnotti, H. Cutcher, A.R. Masri, Combust. Flame, 162 (2015) 3516-3540.

4. S. Meares, V.N. Prasad, G. Magnotti, R.S. Barlow, A.R. Masri, Proc. Combust. Inst., 35 (2015) 1477-1484.
5. M.S. Mansour, H. Pitsch, S. Kruse, M.F. Zayed, M.S. Senosy, M. Juddoo, J. Beeckmann, A.R. Masri, Experimental Thermal and Fluid Science, 91 (2018) 214-229.
6. Honza, R., Ding, CP., Dreizler, A. et al. Appl. Phys. B (2017) 123: 246.