Numerical and experimental studies of laminar counter-flow diffusion flames using low enthalpy fuels

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Introduction

Further advance in the utilization of biomass-based gas fuels in internal combustion engines requires a deeper understanding of the complex combustion chemistry behind, as well as of the coupling of the chemistry with physical phenomena such as turbulence. The former is investigated in the present study combining both experiments with numerical simulations on different types of laminar diffusion flames (sooting and non-sooting).

Laser-based spectroscopy techniques, in particular laser-induced Rayleigh scattering and laser-induced fluorescence, are applied as diagnostic tools, which can provide accurate understanding of temperature distributions, as well as monitoring the flame front through the tracking of intermediate species, such as CH_2O, respectively.

Methods

The focus here is put on non-premixed product gas mixtures with CH_4 or CH_4 diluted by CO_2, N_2, O_2, and/or H_2 as fuel and air as oxidizer at a wide range of air-fuel ratios. The flow velocities are increased until aerodynamic quenching of the flame occurs. The combustion behaviour at these different flame conditions is studied in a flat-flame counter-flow burner representing an essential element to advance the understanding of the so-called flamelet model of turbulent combustion processes. In correspondence to these experiments, the mentioned flames were numerically simulated by an implicit Fortran code capable of simulating this type of reactive flows [1].

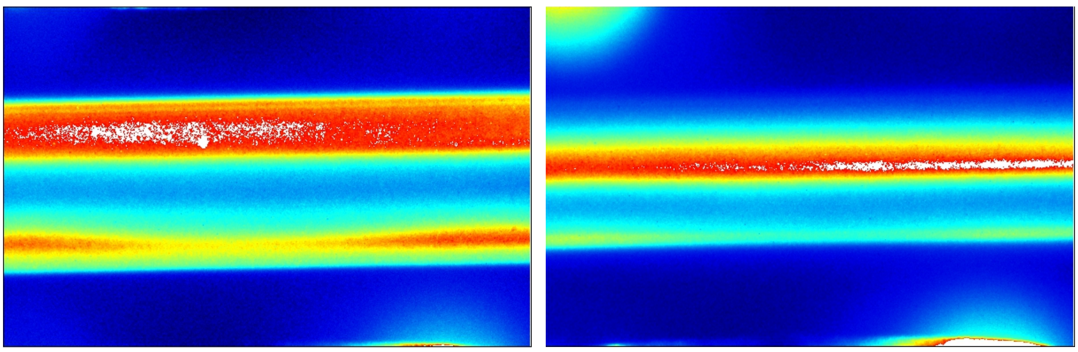

Figure 1. Rayleigh signal (corresponding to temperature fields for diluted non-premixed CH_4-CO_2-air flames (top: air side; bottom: fuel side); left figure: low strain rate case; right figure: high strain rate case

By solving the governing equations for momentum, mass fractions, energy and total mass, temperature and species fraction profiles can be calculated for various strain rates, i.e., flow velocities, finally resulting in a flamelet library to be applied in future work for the numerical simulation of turbulent flames.

Furthermore, based on the simulated species profiles and the incorporation of the Rayleigh cross sections of the major species, together with the imaging system's possible point spread function to minimize crosstalk background phenomena, a good fit between model and experiment can be established.

This study supports the study of Connelly et al. [2] that models should simulate experiments rather than experiment data being used to estimate quantities such as temperature indirectly.

Results

An increase of flow velocities and the thereby finally induced extinction, or straining out, of the diluted flames, are discussed with respect to the changes of the temperature profiles and decreasing peak temperatures. Furthermore, with increasing strain rates a reduction of the flame width and a rise of the CH_2O concentration as well radicals in the pre-flame region like, e.g., CH_3O, are analysed. A major role plays the choice of the diluent, especially when trying make the flames more resistant to extinction by strain. Especially an addition of O_2 to the fuel expanded the flammability of the system markedly with respect to strain.

On the corresponding experimental side and the interpretation of the experimental data, a preliminary analysis regarding the point spread function of the CCD camera indicates a Moffat function in shape. With the convolution of the laser instrument's Gaussian function, line-broadening effects lead to a total function which is Voigt like in profile. All contributions to background arising from scattering and the point spread function of the CCD need therefore to be included when analysing the experimental measurements and comparing them with the numerical results of the corresponding flames.

[1] Deutschmann, O., Behrendt, F., Warnatz, J., Modelling and Simulation of Heterogenous Oxidation of Methane on a Platinum Foil, Catalysis Today **21(2-3)**, 461-470 (1994)

[2] Connelly, B.C., Bennett, B.A.V., Smooke, M.D., Long, M.B., A paradigm shift in the interactions of experiments and computations in combustion research. Proc. Comb. Inst. 32, 879-886 (2009).