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Numerical and Experimental Studies of Laminar Counter-flow Diffusion Flames Using Biomass-based Gaseous Fuels

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Abstract

Biomass thermochemical conversion processes are a promising alternative for decentralized biomass energetic utilization and waste treatment. In particular, processes such as pyrolysis and gasification offer the possibility of producing a fuel gas to be used, among other applications, in internal combustion engines for heat and power generation (CHP). However these fuels present higher complexity than conventional gas fuels regarding their composition and also higher heterogeneity depending on the conversion process. For this reason, a detailed characterization of their behaviour during combustion is still needed in order to, mainly, improve the engine performance, as well as control and reduce emissions. This 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. Additionally CH* chemiluminescence during the combustion is quantified, as this radical has considerable application in the reaction zone marking, providing a possibility to exactly measure the spatial position of the flame. The focus here is put on non-premixed product gas mixtures with CH_4 diluted by CO_2, N_2, CO, O_2, and/or H_2 as fuel and air as oxidizer at a wide range of air-fuel ratios. 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. 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.
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 both in regards to the corresponding Rayleigh signals. Furthermore, with increasing strain rates a reduction of the flame width and flame shifts and additionally a rise of the CH_2O concentration in the pre-flame region are analysed. Investigated are the roles of the diluent, especially when trying make the flames more resistant to extinction by strain, and also an addition of O_2 to the fuel, to expand the flammability of the system markedly, also with respect to strain.