Dynamics of the Auto-Ignition of Biogas in Turbulent Flows

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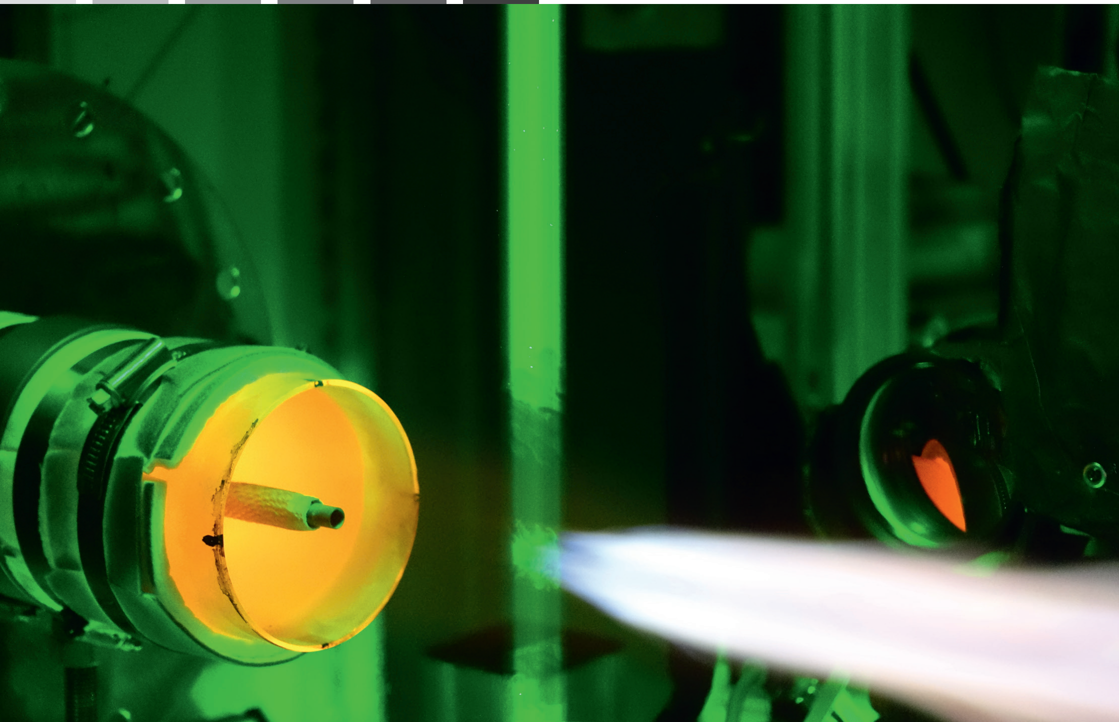

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For the development of future energy conversion concepts, sustainable, efficient combustion processes will continue to play a major role. A promising option is the use of renewable sources, such as biomass-derived gasses (biogas). In a variety of present combustion applications, auto-ignition is an essential process. This includes homogeneous charge compression ignition and diesel engines, and burners using flameless combustion. On the other hand, auto-ignition must be prevented in lean premixed pre-vaporized gas turbines or spark-ignition engines. In those practical devices, the fuel and oxidizer flows are highly turbulent. Therefore, understanding the complex, transient and three-dimensional turbulence-chemistry interactions underlying auto-ignition is of high relevance. For that purpose, this work presents an experimental study on auto-ignition of synthetic biogas (CH_4/CO_2 mixture). The experimental configuration consists of a fuel jet issuing into a high-turbulence, hot air co-flow to mimic conditions as those of practical devices. The study is focused on two main research aspects, instantaneous two-dimensional (2D) scalar field measurements during the onset of auto-ignition and time-resolved three-dimensional (3D) detection and tracking of auto-ignition kernels. For this purpose, advanced laser-optical diagnostics are adapted for simultaneous multi-parameter measurements.

Instantaneous 2D scalar fields of temperature, mixture fraction and scalar dissipation rate were derived by means of simultaneous Rayleigh scattering and planar laser-induced fluorescence of nitric oxide (NO-PLIF), which enables detecting auto-ignition events, and quantifying the corresponding local mixture fraction and temperature during the onset of auto-ignition. The analysis of these events experimentally confirmed previous fundamental findings from direct numerical simulations (DNS) and experiments which concluded that auto-ignition occurs preferentially in spots (kernels), on isocontours of the so-called most reactive mixture fraction, at locations with low scalar dissipation. A statistical evaluation of the effect of the boundary conditions on the auto-ignition characteristics of biogas showed that, for the presented configuration, neither the Reynolds number of the jet nor the co-flow temperature have a strong influence on the mixture fraction at which auto-ignition occurred. Additionally, it was found that the high level of local anisotropy prevented the onset of auto-ignition.

Regarding 3D transient phenomena, time-resolved tomographic LIF of the hydroxyl radical OH, which combines volumetric laser illumination with a multi-camera detection, was used to study the 3D size, structure, location, and orientation of synthetic biogas auto-ignition kernels and their temporal evolution. Results showed that auto-ignitions occurred in well-defined radial regions of the 3D flow, with strong fluctuations in the main direction of the flow. The statistical evaluation of the orientation and growth of auto-ignition kernels with respect to the mean flow field revealed that the kernels were oriented tangentially to the main flow direction and temporally evolved towards this preferential direction as the ignition event progressed.

Findings derived from the results of the presented work will contribute to better understand the fundamentals of auto-ignition processes and will provide experimental data for validation of numerical simulations and the development and improvement of models.