Experimental and numerical investigation of hydrogen injection, spontaneous ignition and flashback in a lab-scale sequential combustor at high pressure

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Sequential combustion staging strategy has emerged as a particularly well-suited approach for burning hydrogen in gas turbines, while maintaining low emissions and high cycle efficiency. A characteristic feature of sequential combustion systems is the high inlet temperature and, therefore, the complex balance of flame propagation versus spontaneous ignition controlling flame stabilization in the second combustor stage. In the present context of costly, and urgently needed, industrial development of gas turbine combustion systems able to operate on carbon-free fuels, it is crucially important that experimental data at the relevant conditions is available and that turbulent combustion models are able to accurately predict flame stabilization in a highly turbulent reacting flow at sequential combustor conditions. Accordingly, due to the complexity of the propagation-to-autoignition balance in controlling flame stabilization, experimental validation of numerical models plays a key role in combustion systems development.

The work presented is part of the Clean Hydrogen Partnership project FLEX4H2. Experiments at typical sequential operating conditions are performed in an optically accessible high-pressure combustor rig. For a wide range of inlet parameters (temperatures, pressure, velocities) and equivalence ratios, the heat release zone is measured with OH*-Chemiluminescence, and high-speed imaging with a recording rate of 5 kHz is used to study the transient phenomena of spontaneous ignition and flashback. The experimental results obtained serve as a basis for validation of Large-Eddy Simulation (LES) performed in massively-parallel calculations. In these, a turbulent combustion model with detailed chemical kinetics and a fully compressible representation of the reactive flow is used. Several reheat flame-stabilization configurations are considered, featuring different fuel flows and global equivalence ratios and leading to significant differences in the steady-state flame stabilization characteristics.

Depending on air flow velocity, inlet temperature and hydrogen flow rate, the flame changes its morphology and stabilization mechanism. The numerical model is able to capture the main flame-stabilization location observed in the experiments, although, for the case with lower hydrogen fraction, it fails to predict the intermittent occurrence of small ignition kernels in the mixing section.

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