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Combustion dynamics in trapped vortex combustor: effect of hydrogen blending

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To advance the transition towards decarbonization and reduced emissions in power generation and propulsion, among many innovative and novel techniques, the trapped vortex combustor (TVC) has emerged as a promising concept. TVC can operate in different configurations (lean premixed, non-premixed, rich-burn quick-quench lean-burn (RQL), or a hybrid approach), which makes it fuel flexible and allows for a compact design. Early studies focused on optimization of cavity geometry and flow dynamics, followed by flame stabilization and injector optimization [1]. A recent investigation examined the effects of swirl with hydrogen as a fuel [2]. Though many experimental and numerical works have studied the global characteristics of TVCs, high-fidelity simulations which reveal flow-chemistry interactions are unavailable. In this study, large-eddy simulations (LES, with a dynamic k equation closure and the partially stirred reactor (PaSR) model) were performed to characterize methane oxidation in RQL configuration. Furthermore, the effect of hydrogen blending on the flame stabilization and structure is investigated. The simulations employ a chemical kinetics mechanism with 21 species and 84 elementary reaction steps. The simulation setup was validated with non-reacting cavity flow results [3] and OH-PLIF data from an experimental TVC rig. Pure methane-fueled simulations were conducted where lean and rich premixed reactants were introduced from the main channel and cavity, respectively. Upon assessing the efficacy of RQL operation, it was observed that stoichiometric oxidation was avoided, with the bulk of the combustion occurring in either lean or rich mode. Additionally, it was observed that a distributed OH radical in the cavity assisted the flame stabilization in the shear layer. The flame is subjected to stretching while traversing the aft wall of the cavity, which results in local flame extinction, and consequently fuel leakage. Upon hydrogen blending, the RQL combustion mode was more pronounced and the flame stabilized close to the aft wall of the cavity. Flame extinction due to straining was mitigated, resulting in much lesser fuel leakage. Other notable differences include a higher mixture temperature downstream of the cavity and an enlargement of the secondary vortex. Overall, H_2 blending was found to minimize flame extinction, reduce unburnt fuel and increase flame penetration in the main flow.

References

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