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High-fidelity simulation of a spatially developing ammonia-diesel interaction jet flame: Efficient combustion and flame stabilization mechanism of ammonia

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Dual-fuel combustion of ammonia with high-reactive fuels offers a promising route for power technologies to achieve clean and low-carbon combustion. However, the narrow flammability range and low reactivity of ammonia render the formation of a self-stabilized flame and complete combustion challenging. Therefore, in this study, a high-fidelity simulation of the ammonia-diesel interaction jet flame is conducted to provide more detailed and fundamental insights on flame behavior, structure and combustion mode. This is crucial for understanding the underlying mechanism of flame stabilization and enabling efficient ammonia combustion. The configuration comprises two separate injectors for ammonia and diesel, respectively. Ammonia is expected to be ignited by the high-temperature diesel flame, ensuring stable combustion with favorable local mixing and thermal conditions for ammonia combustion. To make the simulation computationally feasible, the injection parameters and domain geometry are downscaled based on prior experimental and large-eddy simulation (LES) studies in a constant-volume chamber (CVC). The flame thickness and Kolmogorov scale are resolved sufficiently through local mesh refinement. In order to obtain the flame stabilization mechanism of ammonia, the spatiotemporal evolution characteristics are extracted for the heat release rate and temperature, resolving the development process of the flame surface and combustion modes in detail. Moreover, the interaction effects of turbulence and chemistry are also analyzed using the Q-criteria to visualize the small-scale eddy structures and justify their contribution to flame stabilization. In general, a high-fidelity numerical database and detailed analysis for ammonia-diesel dual-fuel combustion are presented in this research, which also facilitates the future development and validation of flamelet-based combustion models.