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Two-Dimensional Ignition Prediction of Pressurized Hydrogen Jets Using a Reduced-Order Homogeneous Mixing Ignition Model

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The accidental release of high-pressure hydrogen into air can result in spontaneous ignition without an external ignition source, presenting a significant safety concern for hydrogen storage and handling systems. Previous studies have shown that ignition originates within the thin hydrogen–air mixing layer formed during release, where shock-induced heating competes with cooling caused by rapid expansion. The one-dimensional Lagrangian diffusion–reaction framework developed by Maxwell and Radulescu (2011) provided a predictive description of this mechanism and established ignition limits; however, the model was limited to predicting ignition at the jet head and did not account for multidimensional flow structures that influence mixing and ignition in practical releases. In this work, a coupled modelling framework is developed by integrating a reduced-order zero-dimensional reactive model within a high-resolution two-dimensional inert compressible flow solver. The two-dimensional solver resolves the global jet dynamics, including shock propagation, expansion, and vortex-ring formation, while Lagrangian trackers extract local thermodynamic histories used to advance chemical reactions through a homogeneous mixing ignition formulation. Simulations are conducted for storage pressures ranging from 50 to 225 atm and release hole radii of 0.5 mm and 5 mm. This approach enables spatial prediction of ignition within the mixing layer throughout the flow field, including regions associated with vortex-ring entrainment, thereby extending predictive capability beyond previous one-dimensional models. Validation against past results and an in-house reactive solver demonstrates consistent ignition behaviour in the large-radius regime, while predicting a systematically lower critical ignition pressure in the small-radius regime relative to earlier one-dimensional models. The results further identify the lower ignition boundary for high-pressure hydrogen releases and provide a computationally efficient framework for predicting ignitability, contributing to improved physical understanding and safer design considerations for hydrogen storage systems.

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