International Conference on Numerical Combustion
Rome, Italy, October 14-17, 2025
www.icnc2025.com

The role of curvature in ultra-lean hydrogen-air premixed flames in confined scenarios

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Previous studies have identified the formation of isolated flame kernels in lean hydrogen-air mixtures, propagating through slender channels while experiencing heat conduction through the confining plates [1]. The low Lewis number, which triggers thermodiffusive instabilities, gives rise to corrugated fronts, while the heat losses create quenching areas. These resulting isolated kernels, characterized by a pronounced curvature, sustain significantly higher heat losses compared to the homologous planar flame. Recent numerical studies have focused on ignition cases in Hele-Shaw chambers, using pseudospectral numerical simulations [2], following a quasi-2D formulation under the assumptions of low Mach number and very narrow channel, where the conductive heat loss appears as a sink term in the energy equation.

2D data from the latter study are analyzed in the present work. The composition space projection method [3, 4] is used to decompose the classical terms of the energy equation into their different contributions, serving as an analysis tool to understand the balance between the differential diffusion effects, which promote curvature, and the transversal conductive heat losses to the confining walls. The results show a reaction-diffusion state to the leading order, while the non-negligible losses are primarily balanced by the preferential diffusion term associated with curvature, recovering the main trends of the 2D data.

Finally, a one-dimensional reduced flamelet model is posed, based on the stationary planar case incorporating curvature, differential diffusion, and heat losses. Model predictions are then successfully validated against direct numerical simulations.

References

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