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

Exploring the survival of premixed hydrogen flames below the lean flammability limit

E. Fernández-Tarrazo[1], R. Gómez-Miguel[2], M. Sánchez-Sanz[1]*
*Lead presenter: mssanz@ing.uc3m.es
[1] Universidad Carlos III de Madrid, Av. de la Universidad 30, 28911, Leganes (Madrid), Spain
[2] INTA, Ctra. de Ajalvir Km 4, 28850, Torrejon de Ardoz (Madrid), Spain

Ultra-lean hydrogen flames, which can ignite unintentionally due to leaks near a heat or power source, pose significant safety risks. This study investigates why flames propagate at equivalence ratios below the theoretical flammability limit ($\phi_l = 0.255$), where the equilibrium temperature equals the crossover temperature. To find the answer, we use detailed chemistry to numerically study the conditions that explain recent experimental observations of flame propagation in confined channels at equivalence ratios $\phi < 0.2$.
Our simulations consider a two-dimensional geometry of two parallel plates separated by a small distance to form a straight channel. Adiabatic and isothermal boundary conditions are considered at the walls to evaluate the effect of heat losses on the survival of the flame. The flame curvature, caused by the confinement within the narrow channel, leads to the formation of a high-temperature region near the center of the channel. This region is surrounded by unburned gas flowing close to the channel walls. The reaction is then sustained by the hydrogen that diffuses from the low-temperature region to the reactive front. This behavior is unique to fuels or fuel blends with sufficiently high mass diffusivity and does not occur when the Lewis number is near or above unity. A new scaling, that accounts for the flame curvature to define the characteristic velocity and lengths scales, is proposed to describe the flame dynamics at equivalence ratios near the flammability limit. According to our calculations, self-sustained 2D hydrogen flames may exist at equivalence ratios as low as $\phi = 0.15$, a threshold determined by the existence of a stationary flat flame that is unaffected by heat losses.