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Optimizing Mixture Properties for Accurate Laminar Flame Speed Measurement from Spherically Expanding Flame: Application to $H_2/O_2/N_2$/He mixture

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Abstract

The uncertainty of laminar flame speed due to the extrapolation method can be diminished by using large radii data for spherically expanding flames. However, the wrinkling and subsequent development of cells at the spherically expanding flame surface caused by the hydrodynamic and thermo-diffusive instabilities might limit the range of usable large radii data. In the present study, the method of adding helium to reactive mixture was used to optimize the mixture property and mitigate the development of cellular instabilities. The flame stability theory developed by Matalon was utilized to obtain the optimized mixture composition for which onset of cellularity occurs at a predefined large radius. The laminar flame speed of optimized $H_2/O_2/N_2$/He mixtures with equivalence ratios ranging from 0.6 to 2.0, pressures of 50/80/100 kPa and initial temperature of 300 K was measured. For all the experimental cases performed, the extrapolation-induced uncertainty was below 2% in the error diagram which depends on Markstein length (L_b), the lower ($R_{f,L}$) and upper ($R_{f,U}$) flame radius bounds of the extrapolation range. Unstretched laminar flame speed and Markstein length were used to evaluate the performance of four chemical mechanisms. For unstretched laminar flame speed, it was shown that the deviation between the predictions of four chemical mechanisms and experimental data is less than 10% except for one model for a lean mixture at 50 kPa. Overall, the dynamical response of the flame to stretch rate could not be well reproduced by the mechanisms. The present work indicates that an appropriate framework based on Matalon's flame stability theory to improve laminar flame speed by optimizing the mixture properties was feasible. Nevertheless, the uncertainty of some required parameters like activation energy (E_a) and Zeldovich number (β) that lead to over-estimated critical radius should be explored and minimized.

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