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Extension of extinction limits through stratification

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Partial premixing and stratification are ubiquitous in practical combustion devices, where fuel and oxidizer have a finite amount of time to mix and differential diffusion exists. Therefore, the impact of stratification on extinction limits is interested in this study. Laminar counterflow flames with different inlet equivalence ratios from the two nozzles are designed and studied computationally and experimentally. Several pairs of inlet equivalence ratios are selected while maintaining an identical global equivalence ratio ϕ_g. The degree of stratification is quantified by the difference between the equivalence ratios of the left and right nozzles, $\Delta\phi = \phi_L - \phi_R$. The extinction strain rate is subsequently compared among different pairs of equivalence ratios that share the same global equivalence ratio. Systematic calculations are conducted for three global equivalence ratios, and four different fuels, including methane, ethylene, n-heptane, and JetA. Methane/air counterflow flames at a global equivalence ratio of 1.3 are highlighted in this presentation. The 38 species and 291 reactions Foundational Fuel Chemistry Model Version 1.0 (FFCM-1) is employed in the simulation. A one-point controlling method is implemented within the framework of the *oppdiff* solver from CHEMKIN II to account for the different inlet compositions and to march through the S-shaped extinction curve. The distance between the nozzles is chosen to be consistent with the experimental procedure, where a counterflow burner with two opposing round nozzles is employed. The computational results show that extinction limit first increases with increasing $\Delta\phi$ reaching a maximum value, and then decreases, approaching that of a counterflow methane/air-to-air flame. The maximum extinction limit can be 2.5 times that of the twin-premixed flame configuration at the same global equivalence ratio. The computational results compare reasonably well with experimental measurements both in terms of absolute values of the extinction strain rates and qualitative trend. In particular, both computational and experiment show that the maximum extinction strain rate occurs around $\Delta\phi = 1.32$. The non-monotonic behavior of extinction strain rate is attributed to the transition of combustion modes with different levels of stratification. Four combustion modes are identified with increasing $\Delta\phi$: (1) twin premixed flame mode for $0 < \Delta\phi < 0.63$ where two premixed flames exist on each side of the stagnation plane, (2) strong back-support mode $0.63 < \Delta\phi < 1.32$, (3) transition mode $1.32 < \Delta\phi < 1.95$, and (4) diffusion-like flame mode $\Delta\phi > 1.95$. In the strong back-support mode, the weaker flame crosses the stagnation plane and is back-supported by heat from the stronger flame, allowing very rich mixtures to burn at strain rates beyond the homogeneous extinction limit. As $\Delta\phi$ increases further, the dominant flame transitions to a diffusion-like flame ($\phi_L \to \Delta\phi, \phi_R \to 0$). Chemical explosive mode analysis (CEMA) is employed to identify key chemical and transport processes that contribute to the enhancement of the extinction limit through stratification. Our findings suggest that deliberate stratification may improve the resistance of combustion systems to extinction, an insight with potential implications for combustion system design.