Turbulent Burning Rate Scaling of Hydrogen-Air Flames at Gas Turbine Conditions: Direct Numerical Simulation and Experimental Data

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Hydrogen has emerged as a promising energy vector for low-carbon power generation and propulsion systems. Ensuring load-flexible power generation in the face of intermittency from renewable sources, hydrogen can seamlessly replace natural gas in this crucial task if burnt in fuel-flexible gas turbines. However, hydrogen's fast molecular diffusion induces thermo-diffusive effects that alter flame front stability and significantly influence the turbulent burning rate of hydrogen-enriched flames at lean stoichiometries. These effects are amplified at elevated pressure, making accurate modeling at realistic gas turbine conditions a challenge. This study evaluates the applicability of a recently proposed scaling parameter [1], based on the ratio of the Zel'dovich (Ze) to Peclet (Pe) number, in collapsing the normalized turbulent burning rate of hydrogen-air premixed flames obtained from experimental measurements and direct numerical simulation (DNS) data, spanning a wide range of conditions. The DNS data includes various premixed hydrogen-air flames in isotropic and sheared turbulence at atmospheric and elevated pressure. Scaling results suggest that the Ze/Pe parameter augmented by parameters describing the turbulence-chemistry interaction is able to collapse experimental and numerical data across a wide range of conditions for varying pressures, turbulence intensities, and equivalence ratios. This result can help ongoing efforts to improve the accuracy of turbulence-chemistry interaction (TCI) models in predicting the turbulent burning rate of thermo-diffusively unstable hydrogen-enriched flames.

References

[1] Rieth, M., Gruber, A. and Chen, J.H., 2023. The effect of pressure on lean premixed hydrogen-air flames. Combustion and Flame, 250, p.112514.