



Numerical Prediction of Turbulent Premixed Hydrogen-Air Bunsen Flames Using a Laminar Flamelet Combustion Model

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Hydrocarbon fuelled combustion offers an effective pathway to reducing harmful green-house gas emissions associated with carbon dioxide. Nevertheless, differential diffusion and thermal-diffusive effects are known to be important in turbulent premixed flames involving hydrogen as a fuel, and the ability to predict these effects accurately will be fundamental to arriving at effective numerical combustion models needed for hydrogen flames. For perfectly premixed flames under atmospheric-pressure conditions, the further away from the preferential diffusion neutral condition which corresponds to an equivalence ratio, ϕ , of $\phi \approx 1.8$, the stronger the effects. In addition, diffusive-thermal effects also contribute to the combustion processes, for which the neutrally stable condition has been observed to be for equivalence ratios of approximately $\phi \approx 0.8$. In this study, large-eddy simulation (LES) of turbulent premixed hydrogen-air flames is considered using the so-called presumed conditional moment - flame prolongation of intrinsic low-dimensional manifold (PCM-FPI) combustion model, a laminar flamelet-based combustion model, for a number of atmospheric-pressure flames including both neutral stability regions for both diffusive-thermal and preferential diffusion processes from the lean to rich limits. In particular, premixed Bunsen-type flames with equivalence ratios in the range $0.3 \leq \phi \leq 3.57$ and for Reynolds numbers of $Re = 7,000, 20,000$, and $40,000$ are all examined and the LES predictions are compared to available experimental data from the previous experimental studies. Comparisons are also made to similar Reynolds-averaged Navier-Stokes (RANS) simulations of the Bunsen flames also using the PCM-FPI model. The comparisons illustrate the mutual influence of turbulence and differential diffusion and thermal-diffusive phenomena on the turbulent flame structure, burning rate, and flame height and highlight the limitations and directly assess the errors of the PCM-FPI combustion model, which does not account for these effects. In the lean limit with unstable diffusion conditions, over-prediction of flame heights and under-prediction of turbulent burning rates are observed. Furthermore, the relative contributions of the preferential diffusion and thermal diffusive effects on flame wrinkling decrease with turbulence intensity leading to reductions in the predicted errors. The opposite is observed in the corresponding rich limit and, for the Bunsen flames having equivalence ratios in the intermediate range $1 \leq \phi \leq 1.8$, the LES approach proves to be effective in reproducing the observed experimental behaviour.