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A numerical study of flame characteristics at the limits of boundary layer flashback

Hassan Tofaili[1]*, Song Zhao[1], Jean-Louis Consalvi[2], Pierre Boivin[1]
*Lead presenter: hassan.tofaili@univ-amu.fr
[1] Aix Marseille Univ, CNRS, Centrale Marseille, M2P2, Marseille, France
[2] Aix Marseille Univ, CNRS, IUSTI, Marseille, France

The need to reduce emissions is driving the use of hydrogen or natural gas-hydrogen blends as fuel in modern industrial burners [1]. However, hydrogen is characterized by its high flame speed and large diffusivity, making it a capricious gas requiring special attention in terms of safety. One of the main concerns is the high flashback propensity of hydrogen flames and the need for accurate prediction models to improve the safety and proper operation of combustors.

The critical-velocity-gradient concept developed long ago by Lewis and von Elbe [2] has provided a suitable framework for the modeling of boundary layer flashback of unconfined flames. However, key aspects impacting the flashback phenomenon remain unaddressed in the model, such as the complex thermal coupling between the flame and the burner, as well as the effect of flame stretch and preferential diffusion [3]. Both effects can impact the flame speed and quenching distance, and thus significantly modify the flashback limits.

In order to shed some light on the role of these two effects in boundary layer flashback, numerical simulations are carried out using lean methane-hydrogen-air flames, in which two-dimensional laminar flames in a Bunsen burner configuration are stabilized at the flashback limit. Sensitivities of flame speed and quenching distance to variations in wall and preheat temperatures are measured, and the results are compared to predictions from activation-energy-asymptotics theory. The effects of preferential diffusion are also investigated by using different levels of hydrogen fuel percentage (0-100%). For each fuel composition, the flame shape as well as curvature and strain rate distributions at the flashback limit are extracted in the vicinity of the flame's leading point, and the results are compared to a simple geometrical model. Then, the effects of strain rate and curvature on flame speed, flame thickness and quenching distance are analyzed and compared to different models available in the literature. The results are employed to augment the critical gradient model for boundary layer flashback by accounting for preheat and preferential diffusion effects.

References

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