Mechanism of flashback in laminar lean premixed H2-air jet flames

Mechanism of flashback in laminar lean premixed H_2-air jet flames

R.A.J. Julien, S.M. Ali, R.J.M. Bastiaans

Power and Flow Group, Dept. of Mechanical Engineering, Eindhoven University of Technology,

Den Dolech 2, 5612 AZ, Eindhoven, Netherlands

Abstract

- Current research aims to computationally explore the flashback mechanism in laminar premixed H_2-air jet flames in a lean regime. The goal is to get a clear view of flashback development for different burner tube sizes. Difference in flame profiles during flashback between the different tube sizes showed that hydrogen distribution within the tube might be of influence for the flashback mechanism.

Background and challenge

- H_2 is a carbon free alternative for fossil fuels.
- If the velocity gradient of the gas inflow at the tube wall is lower then the laminar flame speed (S_L) divided by the penetration distance (δ_p), flashback occurs
- H_2 Flashback is likely to happen due to its high reactivity, and thus a high flame speed.

Goal

- Understanding the mechanism of flashback for a laminar flame in lean regimes using CFD

Methodology

Computational domain

- 2D axisymmetric computations for fully developed flows (Poiseuille flow) in Ansys Fluent.
- Reactant inlet tube (diameter *D)*, containing a premixed lean hydrogen-air mixture (φ = 0.42)
- Air inlet tube with diameter 10*D*.
- Reactive Navier-Stokes equations with detailed chemistry
- Mesh size of 25 µm at locations of interest
- Conjugate heat transfer at the solid-fluid interference at the tube wall.

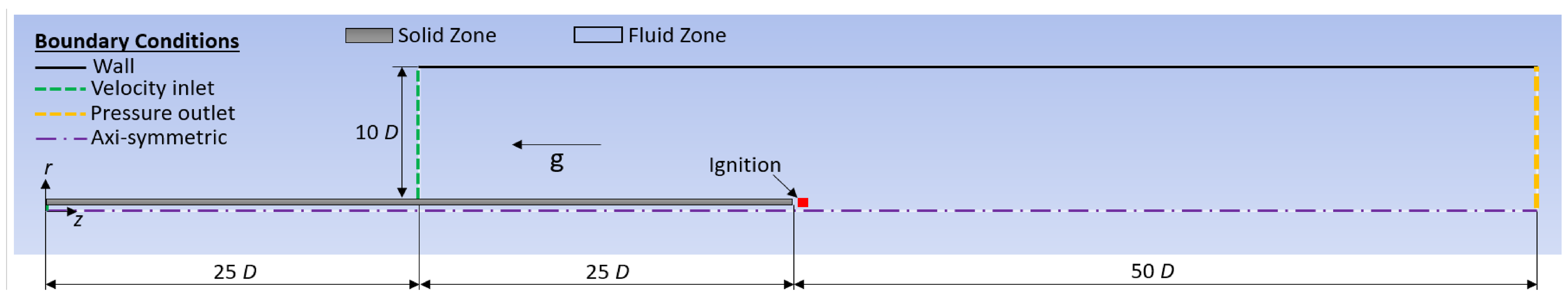

Fig. 1 Schematic of the computational domain

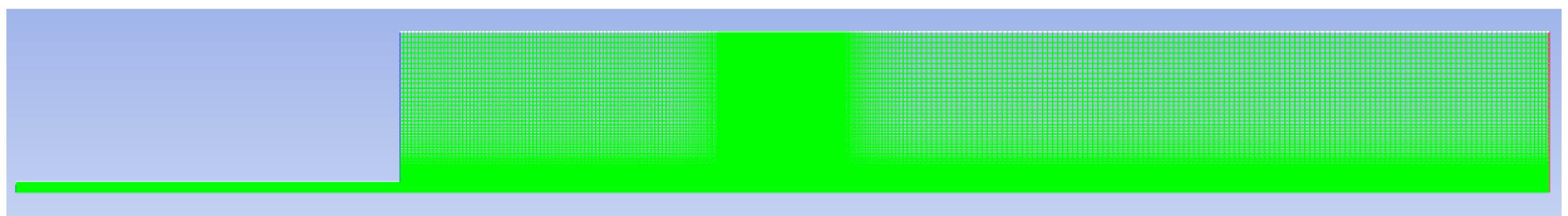

Fig. 2 Mesh of the computational domain, where the areas of interest have a smaller mesh size compared to the other regions

Simulation

- Stationary simulations for a small (*D*=2.16 mm) and large (*D*= 4.52 mm) burner tube.
- Use of Konnov (2019) mechanism. Approximately 20,000 iterations for convergence.
- Steps to detect flashback
  1. Cold flow simulated for 1000-2000 iterations,
  2. Ignition added and reactant inlet velocity adjusted till a stable flame was found.
  3. Reactant inlet velocity reduced in step sizes of 0.1 or 0.2 m/s.
  4. Close to the flashback the velocity was reduced in smaller step sizes
- Figure 3 shows the effects of the reactant inlet velocity reduction.
- The critical velocity for flashback was compared to experiments done by Von Elbe (1945), for model validation.

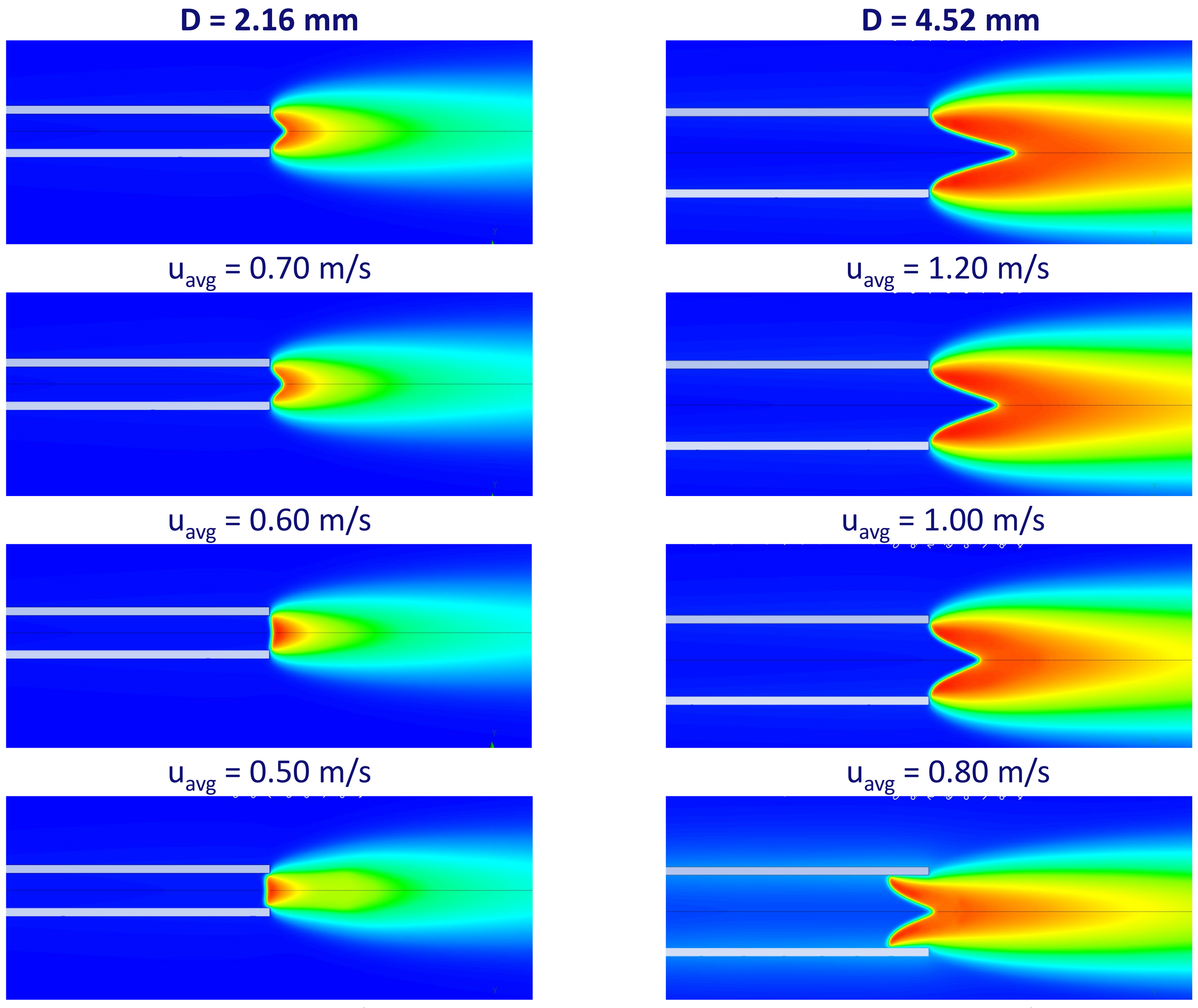

Fig. 3 Temperature contours showing the location of the flame for varying velocities

Results and discussion

Flame front

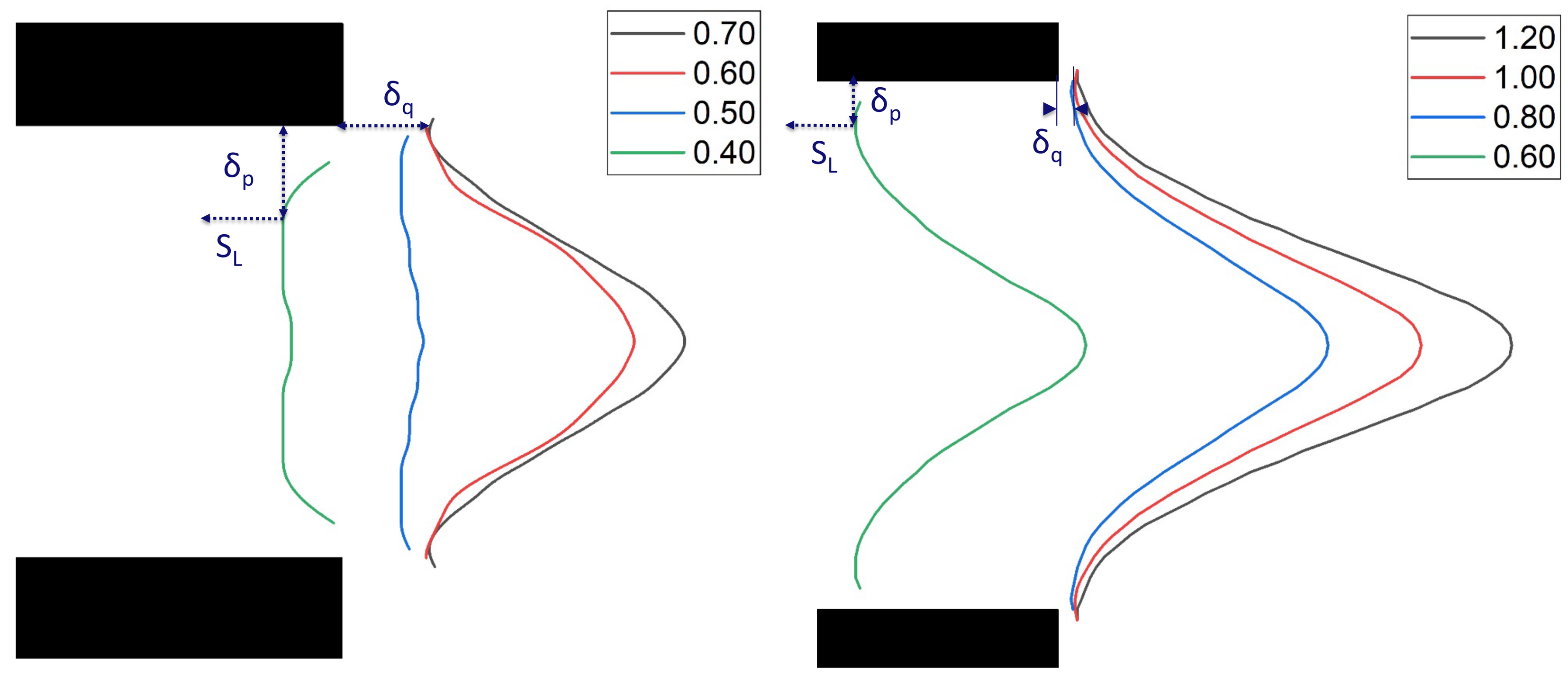

Fig 4. Maximum reaction rate at various *r,z* positions as a function of flow velocity, for the small (left) and large (right) burner tube diameter.

- Figure 4 shows the flame front development for the two burner tube diameters at decreasing velocities. With δ_p as penetration distance, δ_q as head-on quenching distance and S_L as flame speed.
- Small burner tube (2.16 mm) has a near flat flame front during flashback.
- Large burner tube (4.52 mm) keeps it V-shaped flame front during flashback.

Hydrogen distribution

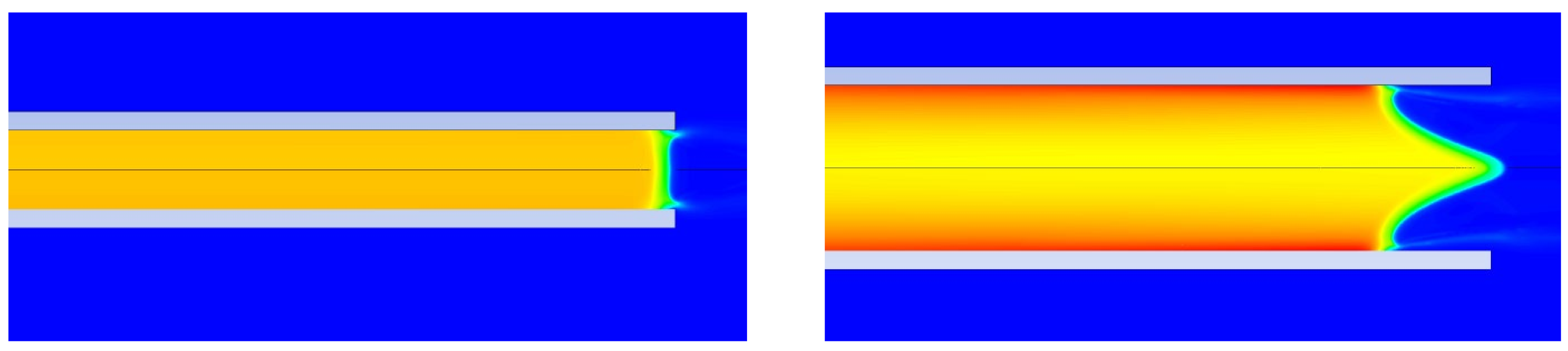

Fig 5. Hydrogen distribution inside the burner tube for the small (left) and large (right) diameter

- Figure 5 shows the hydrogen distribution inside the burner tube for both diameters.
- The difference in hydrogen distribution could be of importance for the different flame fronts.
- Small burner tube has a constant φ=0.42
- Large burner tube varies from φ = 0.35 to φ = 0.71

Conclusion and future work

- Burner diameters are of influence for the mechanism of flashback. The flame fronts of the small burner is near flat while for the larger burner the flame front remains its V-shape.
- At a larger diameter the hydrogen distribution is different from smaller diameters, which might be the cause of these different flame fronts during flashback.
- Future steps in clarification of the flashback mechanism is the use of transient simulations, which will give more insights in both the flame profile development and the hydrogen distribution. Further more, the mechanism of flashback will be explored inside a closed sloth shaped vessel.

Acknowledgements

- The authors thank Rijksdienst voor Ondernemend Nederland for financial support for this study (RVO-High Hydrogen Gas Turbine Combustor High Pressure Test DEI120081).
- The authors would like to acknowledge the Power & Flow, Department of Mechanical Engineering, TU/e for providing the computational resources required for the present work.

References

1. Von Elbe, G. & Morris, M. (1945). Further studies of the structure and stability of burner flames. *The Journal of Chemical Physics, 13(2)*, 89–100
2. Konnov, A. A. (2019). Yet another kinetic mechanism for hydrogen combustion. *Combustion and Flame*, *203*, 14-22.
3. Alireza, K. & McDonell, V. (2017). Boundary layer flashback of non-swirling premixed flames. *Progress in Energy and Combustion Science*, 249-292.
4. Ali, S.M., Julien, R.A.J., Mukundakumar, N. & Bastiaans, R.J.M. (2021, December 5-9). Preliminary results for flashback prediction in laminar H2-air premixed flames. 13th Asia-Pacific Conference on Combustion (ASPACC), Abu Dhabi, United Arab Emirates. (Accepted)
5. Ali, S.M. & R.J.M. Bastiaans (2021, November 10-11). Efficient computational methods for turbulent boundary-layer H_2-air flashback prediction. Combura Symposium 2021, Soesterberg, The Netherlands. (Accepted)