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Demonstration of swirl-controlled 3D-printed mesoscale burner array using gaseous HCs

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mimc

Introduction

- Small length scale flames, microscale (~mm) and mesoscale (~cm), have potential for applications to power small scale devices
- Potential replacement for batteries in certain applications to ***increase efficiency***
- Small scale flames are driven by different fluid physics and flame chemistry than flames on the macroscale
- Extinction modes and flame instabilities become much more prevalent on the small scale and are currently poorly understood
- Swirl flow enhances flame stability via creation of an internal recirculation zone

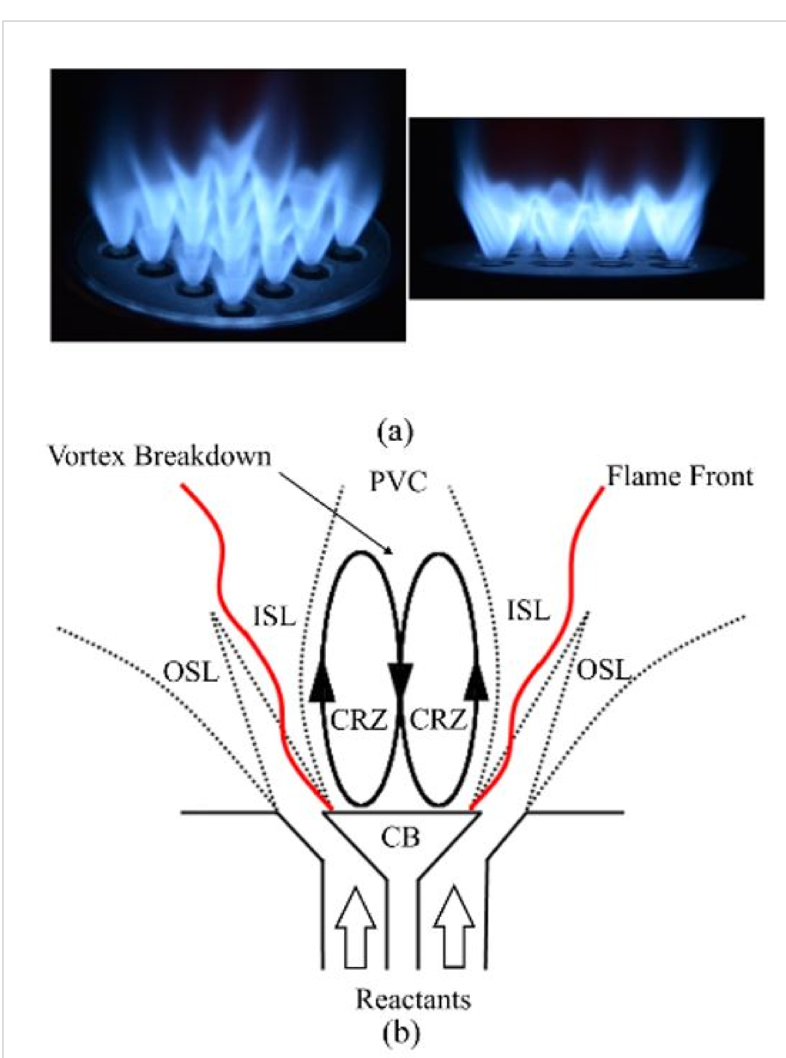

Figure 1: (a) Pictures of flame stabilized 4x4 mesoscale burner array operating with methane air mixture in partially premixed configuration (b) Flow field for a swirl stabilized flame; CB – center body, OSL – Outer shear layer, ISL – Inner shear layer, CRZ – Center Recirculation Zone, ORZ – Outer Recirculation Zone, PVC – Precessing Vortex Core

Experimental Methods

- 4x4 mesoscale burner array was designed through several iterative variations and 3D printed to study mesoscale flames
- The effectiveness of swirl flow was evaluated for both partially and fully premixed methane-air flames via a measure of flame temperature

Test Conditions

- 10 - 20k scc/min total flow (MFCs)
- 0.5 ≤ Equivalence Ratio (φ) ≤ 2
- 0 - 80% of total flow from swirl

Burner Array Design

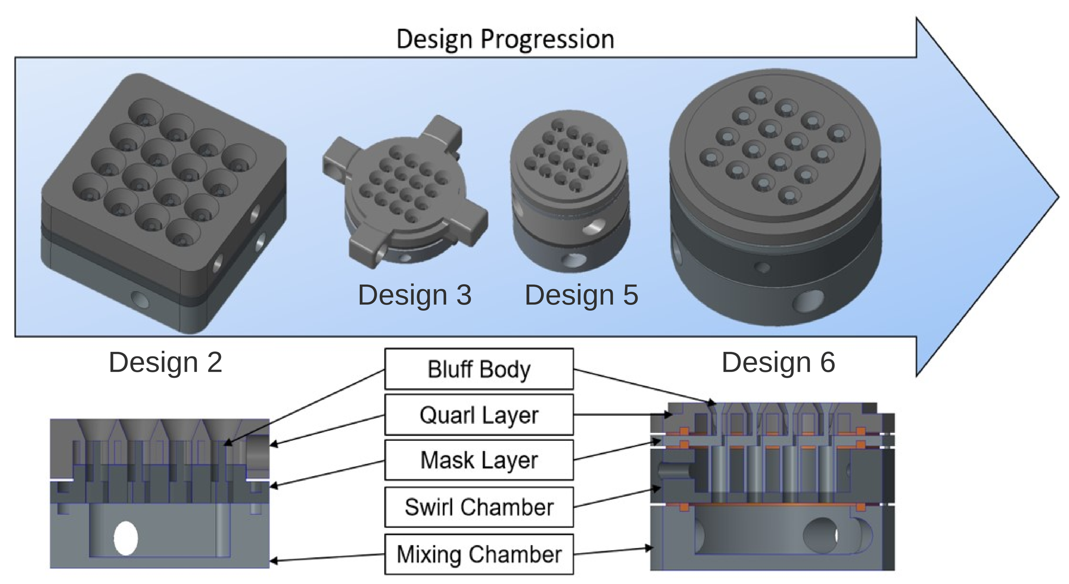

Figure 2: Design iterations highlighting layered structure and internal geometries of Design 2 and Design 6

- The design sought to improve:
  1. Independent swirl flow control
  2. Uniform flame structure
  3. Range of test conditions (flow rates, φ)
- The final prototype employed the best of these optimized features for the design goals
- Additive manufacturing techniques were employed to rapidly iterate through designs

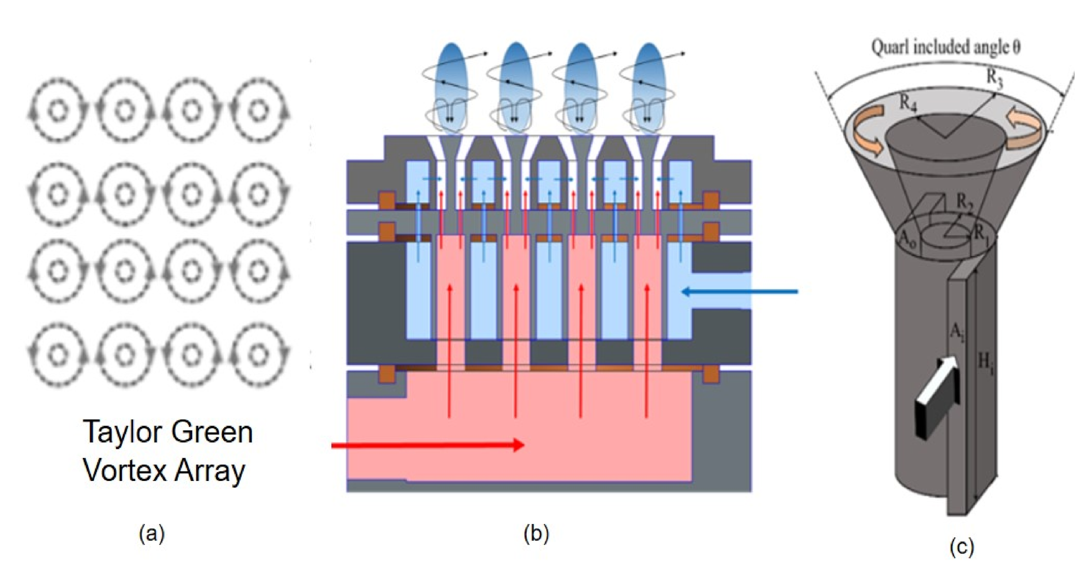

Figure 3: (a) 4x4 Taylor Green vortex arrangement. (b) Cross sectional view of the burner array design (c) Individual burner array element schematic.

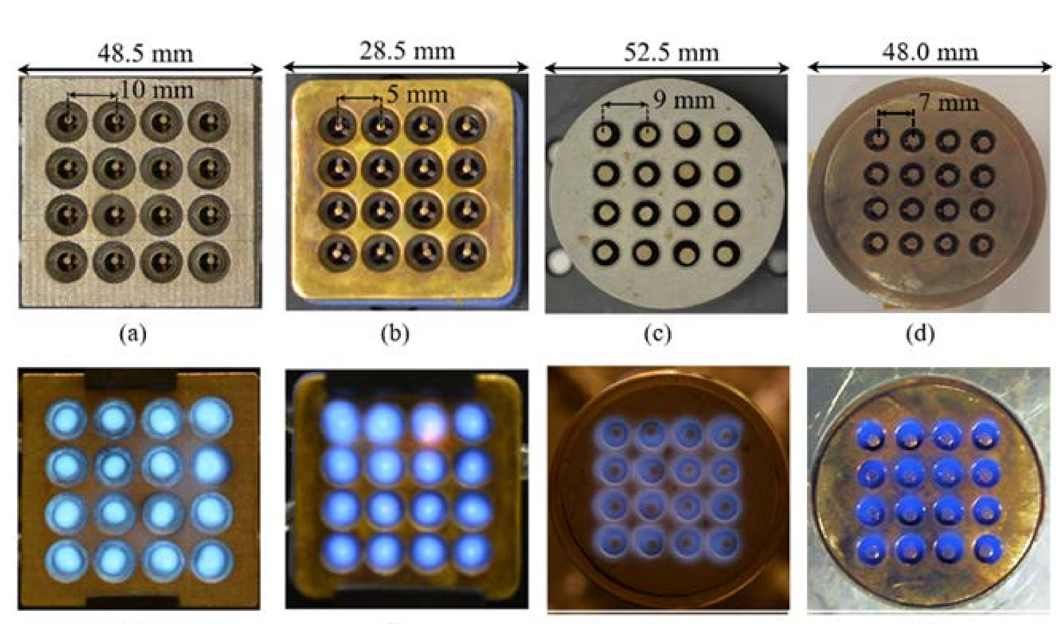

Figure 4: Images of (a through d) various mesoscale burner array designs, D2 through D6. (e through h) Images of same burners operating with methane-air mixture in premixed configuration

Results

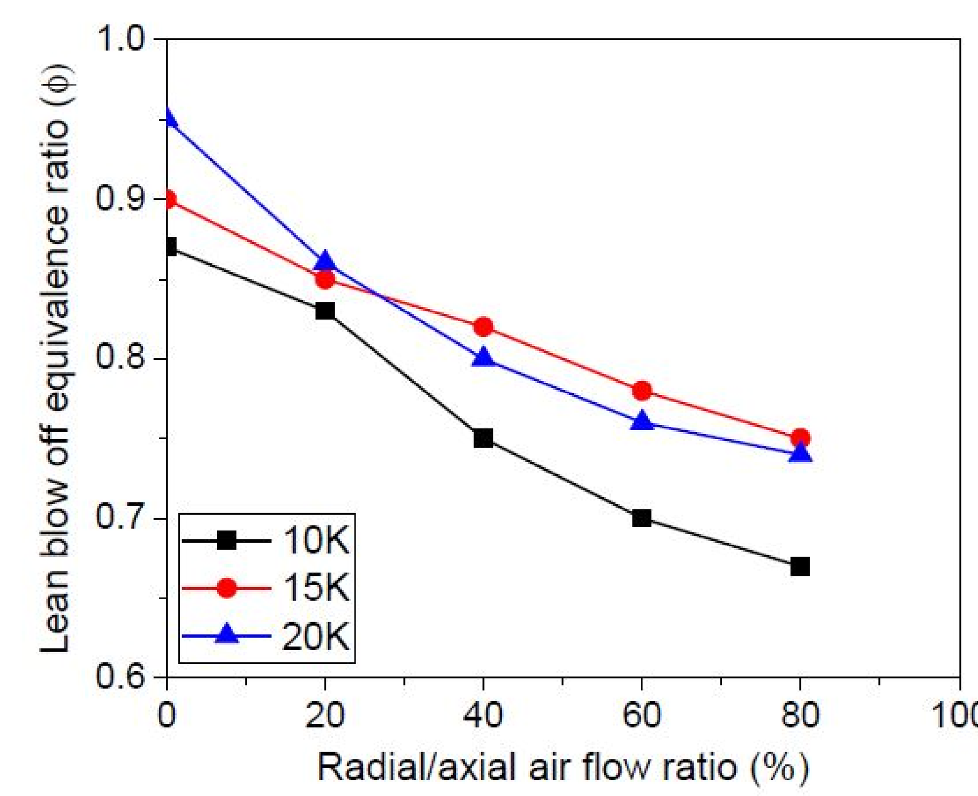

Figure 5: Flame stability limits as a function of the radial/axial flow rate for mesoscale burner array operating in swirl stabilized mode

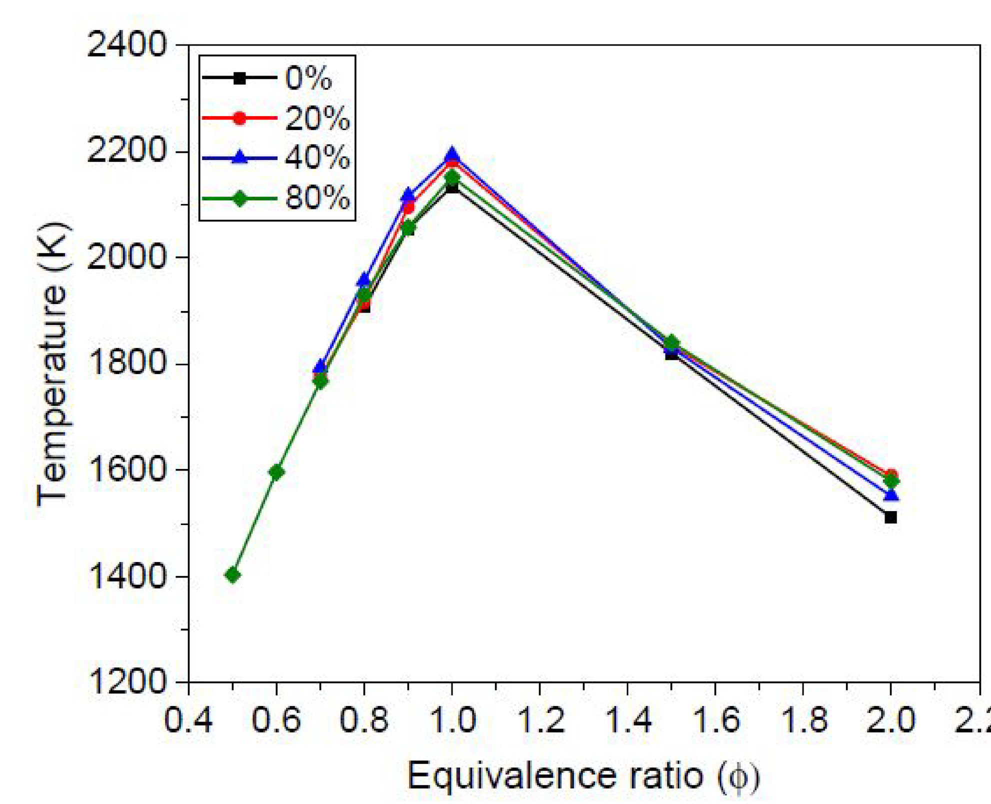

Figure 6: Flame temperature measurements as a function of equivalence ratio for various levels of radial/axial flow ratios

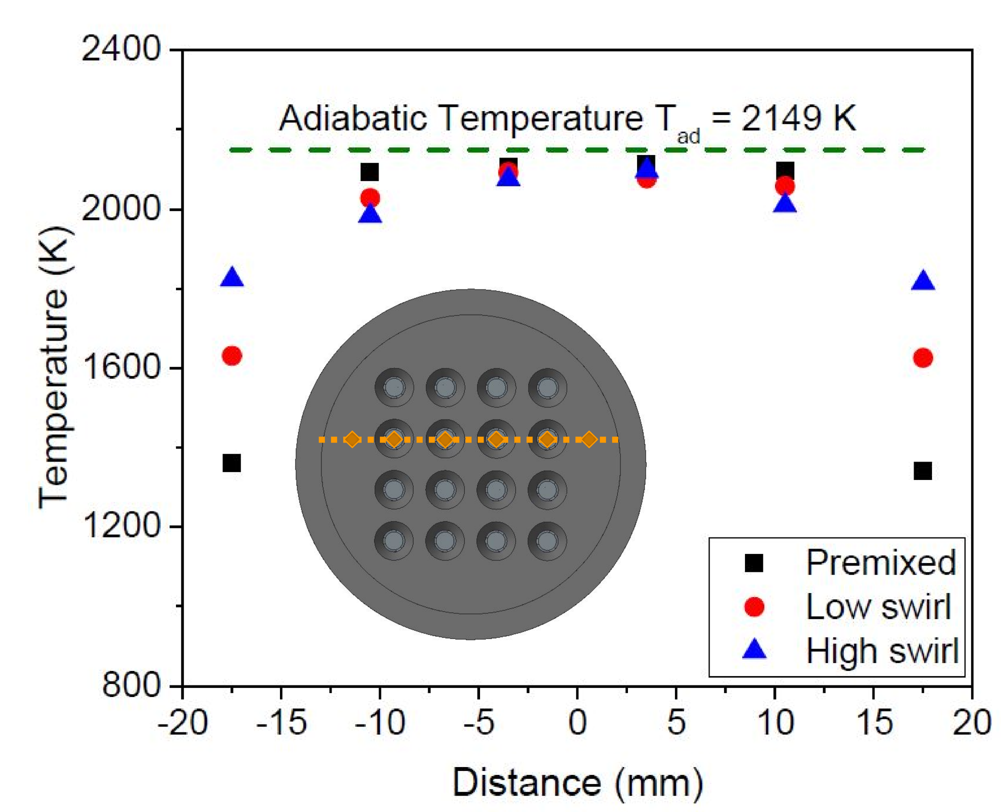

Figure 7: Spatial temperature distribution at 25mm above the burner array surface under various swirl stabilized configurations (ϕ = 0.95 and total flow rate of 10k scc/min)

Conclusion

- Swirl flow was shown to be a viable method of improving flammability limits of small scale flames
- Swirl flow has no significant effect on basic chemistry of a reaction and allows partially premixed flames to be modeled as fully premixed in this configuration
- Interactions between burner elements provides further stabilizing mechanism via inter-element reheating
- Successfully adapted 3D printing to mesoscale burner that produces stabilized mesoscale flames

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