Effect of Secondary Flow Area on Diffusion Flame Stability

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Abstract
The focus of this research was to understand the effects of varying the secondary flow area in a single coaxial injector on flame stability in an experimental non-premixed flame burner. Gaseous methane and gaseous oxygen were utilized as reactants, with the oxidizer being the primary flow and the fuel being the secondary (annular) flow. The reactants were ignited in an optically-accessible combustion chamber with a retractable spark plug, and the product flame behavior and flame standoff distance were observed. Results on flame stability based upon equivalence ratio (ϕ) and primary reactant Reynolds number (Reₜ₀) are presented.

Introduction
Background
- Non-premixed hydrocarbon/oxygen combustion results in a diffusion flame.
- Diffusion flames are used in industrial furnaces, gas turbines, rocket engines, and gas production purposes.

Motivations for Studying
- Diffusion flames can be unstable and the parameters controlling the flame stability are not entirely known.
- Examining the conditions to encourage stable flames can improve combustion efficiency, start-up operations, safety, and decrease soot formation.

Project Objectives
- Design/fabricate coaxial injectors with varying secondary flow areas.
- Map the effects of injector secondary flow area and reactant gas flow parameters on diffusion flame stability.

Significance on Field / Society
- Diffusion flames are utilized in industrial types of furnaces for heating, electricity generation, and gas production purposes.

Fuel + Oxidizer → Products of Combustion

Table of Reactants and Oxidizers

Detached Flame – pulsing flame; standoff distance from injector
Anchored Flame – stable; efficient
Blowoff Flame – large oscillations; least efficient; not burning all of fuel

Results - Diffusion Flame Stability Maps

Single Coaxial Injector Designs
- Three coaxial injectors were designed and fabricated having an impingement angle of 30° and primary flow diameter of 10.54 mm.
- Evaluated variances in the secondary flow area based upon hydraulic diameter (Dₕ) of 2.58 mm (baseline), 1.55 mm, and 4.09 mm.

Diffusion Flame Behaviors
- Ignition – using retractable spark plug
- Igniter Fusion

Diffusion Flame Stability Map

Experimental Method of Approach
- An existing horizontally-mounted, stainless-steel combustion chamber with a single, coaxial injector and retractable spark plug igniter (for ignition) was utilized.
- Primary flow was gaseous oxygen (GO₂), and secondary flow was gaseous methane (GCH₄). Primary flow diameter was held constant, & system purged between tests with nitrogen.
- Mass flow meters measured the flows, and the product flame behavior was recorded at 30 fps through a viewing window.

Experimental Results
- Various phenomena were observed
- Over 600 experiments were performed
- Ignition stability maps were created for each injector based upon flame behavior.
- Equivalence ratios (ϕ) ranged from 0.24 (fuel-to-air) to 5.13 (fuel-rich) operation.
- Reynolds number of GO₂ ranged from 1640 (faminar flow) to 29747 (turbulent flow).
- For all three injector cases, at high Reₜ₀, and ϕ > 1 (fuel-rich), detached and blowoff flames were the most common flame types.
- More frequent instances of no ignition observed as Dₕ decreased (Injector #2c).
- For ϕ > 2 and Reₜ₀ < 7500, predominantly anchored and near-blowoff flames

Future Work
- Create detached flame standoff distance maps.
- Effect of varying impingement angle and secondary flow area on diffusion flame stability.
- Effect of chamber volume on flame stability.

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Conclusions
- An experimental, non-premixed diffusion flame burner was successfully tested using GCH₄ and GO₂ to study the effects of injector secondary flow area on flame stability for a constant DO₂ and impingement angle of 30°.
- For all injectors tested, the results demonstrated three distinct, diffusion flame behaviors: anchored, detached, and near-blowoff flames.
- Distinct boundaries were observed between flame behaviors for all three injector cases.
- As reactant flow increased, difficult for flame velocity to overcome to keep flame at injector.
- The increase in secondary flow area shifted the stability map depending on the flow conditions and the mixing that occurred between the fuel and oxidizer reactants.
- Injector #2c, which had the largest secondary flow area, produced the largest regime of anchored, stable diffusion flames.
- As secondary flow area decreased and Vₑ increased (due to smaller flow area), flame behavior transitioned to more prevalent cases of detached, near-blowoff, and even non-ignition behaviors.