Quantitative measurements of $CH^*$ concentration in normal gravity and microgravity coflow laminar diffusion flames

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Outline

• Introduction
• SLICE
• Spectral considerations
• $CH^*$ concentration diagnostics
• Results and conclusions
Introduction

Advantages of microgravity experiments:

• Simplification of the flow field due to the absence of buoyancy effects: provides easier test cases to refine computational models.

• Creation of flame conditions that do not exist in 1-g environment, e.g. increasing the flame stability: enables experimental/computational study near flame extinction.

Why CH*:

• Extend the study of microgravity flames from sooty[1] to “blue” flames.

• Chemiluminescent emission from excited state radicals naturally present in flames and easy to collect.

• Representative of flame front position and possible marker for heat release rate.

SLICE

Structure and Liftoff In Combustion Experiments (2012)

Nozzles ID:
- 0.4, 0.8, 1.6, 2.1, 3.2 mm

Fuels: (N$_2$ diluted)
- 40%, 70%, 100% CH$_4$
- 20%, 100% C$_2$H$_4$

Velocity:
- Fuel: up to 320 cm/s
- Coflow air: 15 - 70 cm/s

Diagnostic tool:
- Nikon DSLR D300s with BG7 color filter

SLICE hardware on the ISS

- Introduction • Spectral considerations • CH* diagnostics • Results
**DSLR camera characterization**

- The Nikon blue channel signal was seen to be representative of the \( CH^* \) emission of the \( A^2\Delta \rightarrow X^2\Pi \) transition centered around 431 nm.

- The blue channel radial profile is broader than the interference filter one.
- The broadband blue filter will collect light emitted from species other than \( CH^* \).
Spectral considerations

- Spectral analysis of a target nitrogen-diluted 65% methane flame (7.5 mm above the burner).

- The integration over the entire blue spectral range results in a broader radial profile.
Spectral considerations

- The additional $C_2^*$ and $CO_2^*$ chemiluminescence will contribute to the blue counts recorded by the camera.

- If uncorrected, the blue signal would overestimate the peak $CH^*$ concentration by a factor of ~3.3.
Soot correction

- If not accounted for, soot luminosity will result in corruption of the blue channel signal.

70 % CH₄ – Fuel 89 cm/s; Coflow 17 cm/s – Nozzle 3.2 mm
**CH* concentration diagnostics**

- Chemiluminescence emission $S_{em}$ collected by a detector:

$$S_{em} = \frac{1}{4\pi} A_{21} \tau V_{em} N^* K C \gamma_{CH}$$

- $A_{21}$: Einstein A coefficient
- $\tau$: exposure time
- $V_{em}$: pixel volume
- $N^*$: number density
- $K$: intensity calibration constant
- $C$: contribution from other emitting species
- $\gamma_{CH}$: transmitted energy of a photon in the blue channel

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Results: fuel flow variation

\[ CH^* \text{ mole fraction} \]

\[ HAB \text{ [mm]} \]

\[ \begin{array}{cccc}
F: 17 \text{ cm/s} & \text{C: 17 cm/s} & 0 \text{ g} & 1 \text{ g} \\
F: 25 \text{ cm/s} & \text{C: 17 cm/s} & 0 \text{ g} & 1 \text{ g} \\
F: 50 \text{ cm/s} & \text{C: 17 cm/s} & 0 \text{ g} & 1 \text{ g} \\
F: 89 \text{ cm/s} & \text{C: 17 cm/s} & 0 \text{ g} & 1 \text{ g} \\
\end{array} \]

\[ \text{Radial coordinate [mm]} \]

\[ x 10^{-12} \]

\[ x 10^{-12} \]

\[ 40\% \text{ CH}_4 \]

\[ \text{Coflow: 17 cm/s} \]

\[ 40\% \text{ CH}_4 – \text{ Fuel 17 to 89 cm/s; Coflow 17 cm/s – Nozzle 3.2 mm} \]

- Introduction
- Spectral considerations
- \( CH^* \) diagnostics
- Results
Results: coflow variation

70 % CH₄ – Fuel 62 cm/s; Coflow 14 to 34 cm/s – Nozzle 1.6 mm

- Introduction
- Spectral considerations
- CH* diagnostics
- Results
Results: local heat release rate

- Flame numerical simulations are available to complement the experimental data

40 % CH\textsubscript{4} – Fuel 25 cm/s; Coflow 17 cm/s – Nozzle 3.2 mm
Results: total heat release rate

40% CH₄
Coflow: 17 cm/s

70% CH₄
Fuel: 62 cm/s

Integrated CH* concentration – 0 g
Integrated computed heat release – 0 g
Integrated CH* concentration – 1 g
Integrated computed heat release – 1 g
Conclusions

- Quantitative measurements of $CH^*$ concentration have been performed on selected microgravity and normal gravity SLICE flames.

- The spectral characterization of the SLICE color camera allowed the blue channel to be considered representative of the $CH^*$ emission around 431 nm.

- A reference diffusion flame was analyzed to investigate the influence of emitting species other than $CH^*$, and to validate the proposed approach.

- The measured peak $CH^*$ concentration displayed higher sensitivity to coflow rather than fuel variations, and it was generally higher in normal gravity flames.

- In laminar diffusion flames, the integrated radial $CH^*$ concentration scales proportionally to the integrated flame heat release rate.

- The two-dimensional $CH^*$ and heat release rate distributions agree reasonably well, but the variations in spatial intensities and gradients do not match.
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Imaging consideration

Radial chemiluminescence profiles obtained through an Abel deconvolution:

- Assumes the collected rays to be parallel.
- If rays are not parallel the reconstructed profile is broadened and the peak value is underestimated.

SLICE flame images were taken with f-numbers of 2 or 4 to minimize exposure time.