Continued Analysis of Freely Propagating Dimethyl Ether Cool Flames

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Personal Background

- 2nd-Year Mechanical Engineering Student
- Undergraduate Research Scholar
  - Have worked with Dr. Belmont since Fall 2014
    - Assistant to Ph. D student M. Hajilou's Dimethyl Ether Cool Flame experimentation, Fall 2015 to Present
- Anticipated Graduation: Spring 2018

Overview

- Background
  - The importance of cool flames
  - DME cool flames
- Materials and Methods
- Results
- Conclusions
- Looking ahead

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Background

- Cool flame presence has profound impact in engine performance
  - Cool flames a likely source of engine knock[1]
    - Engine “knock” is the result of a sudden pressure rise in the cylinder due to auto-ignition of gases
    - Studies have found evidence of cool flames in exhaust gas samples of engines experiencing knock
    - Understanding the nature of cool flames can help to eliminate unwanted presence in engine systems

1. Lignola, P.g., and E. Reverchon. "Cool Flames." *Progress in Energy and Combustion Science*

Background

- While evidence of cool flames has been found in engines and other systems, relatively little is known about them.

- Prior studies of cool flames include:
  - Cool flames in engines[1,2]
    - Relating cool flames and engine knock
  - Fuel droplet combustion aboard the ISS[3]
    - Cool flame phenomenon explored in microgravity

1. Lignola, P.g., and E. Reverchon. "Cool Flames." *Progress in Energy and Combustion Science* 13.1 (1987): 75-96
2. Malmberg, E.w., M.l. Smith, J.e. Bigler, and J.a. Bobbitt. "A Study of Cool Flames and Associated Reactions in an Engine." *Symposium (International) on Combustion* 5.1 (1955): 385-92.
3. Dietrich, Daniel L., Vedha Nayagam, Michael C. Hicks, Paul V. Ferkul, Frederick L. Dryer, Tanvir Farouk, Benjamin D. Shaw, Hyun Kyu Suh, Mun Y. Choi, Yu Cheng Liu, C. Thomas Avedisian, and Forman A. Williams. "Droplet Combustion Experiments Aboard the International Space Station." *Microgravity Science and Technology Microgravity Sci. Technol.* 26.2 (2014): 65-76

Background

- There is a need for a low temperature combustion experimental platform which can be used to investigate global combustion property measurements such as:
  - Temperature profiles
  - Speciation
  - Flammability limits

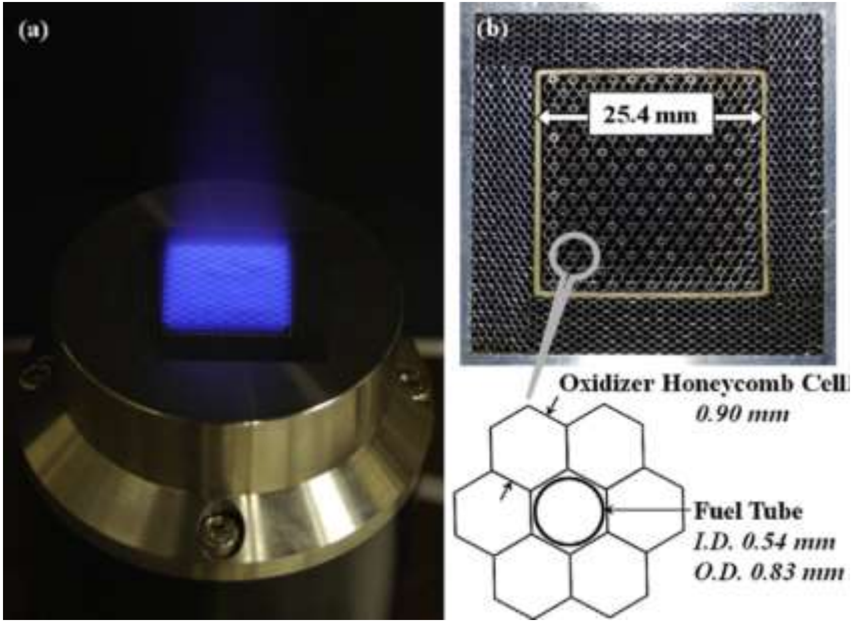
- Desired analysis is of a low temperature, stabilized, freely propagating cool flame

Background

Recent studies of hot flames using a low pressure Hencken burner:

- Flames are well-approximated as:
  - Nearly adiabatic
  - Freely propagating

- Speciation and flame speeds can be readily analyzed



Ombrello T, Carter C, Katta V. *Combust Flame* 159 (2012) 2363-2373.

Background

- Prior Hencken burner studies provide a pathway to an experimental platform to study freely propagating cool flames

- This study integrates:
  - Low pressure laminar flat flame Hencken burner
  - Cool flame stabilization method by O_3 activation

- Outcome: an experimental platform for the study of freely propagating DME cool flames.

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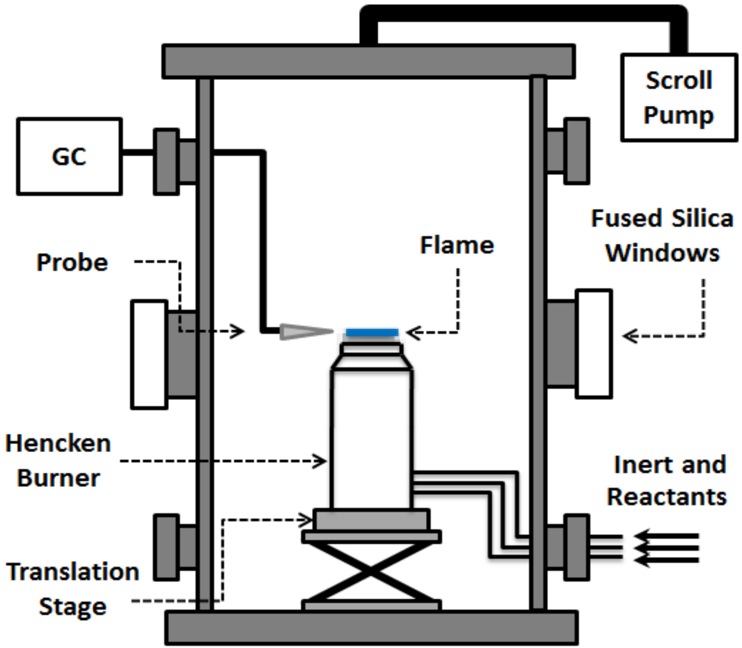
Materials and Methods

- Experimental setup:



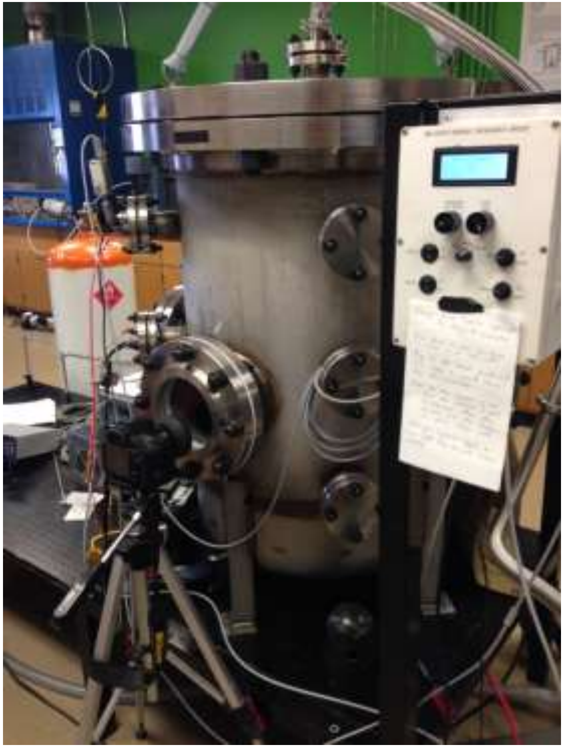
Materials and Methods

Experimental Setup:

Translation stage, thermocouples, and other probes powered by white control box (far right)

Camera can view burner and flame through window

Vacuum pulled by pump from the top of the chamber. Pressure kept at 50 Torr, or 6.7 kPa



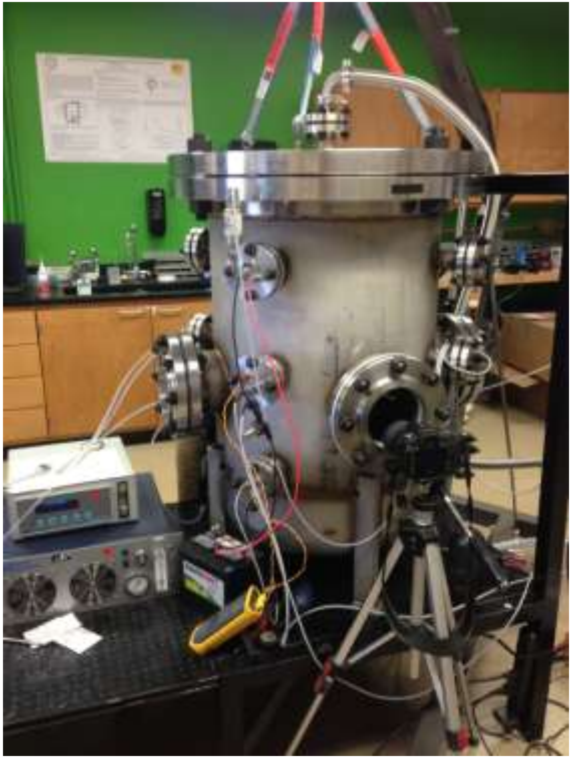
Materials and Methods

Experimental Setup (cont):

Fuel, oxidizer, and other inputs to chamber enter through sealed lines (left side of chamber)

Agilent Micro 490 gas chromatograph (GC) probe measures species of gases

- Adjusting height of burner allows for species measurements throughout the flame

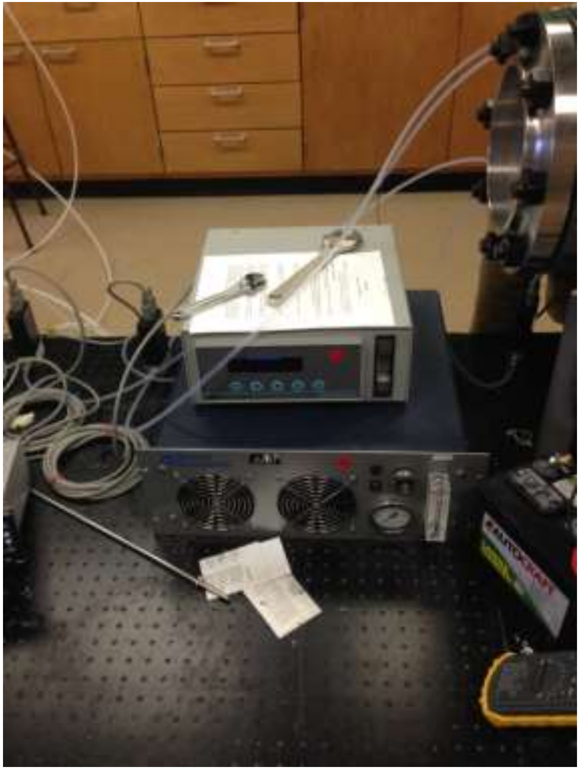


Materials and Methods

Experimental Setup (cont):

Ozone generator and analyzer are used to control the amount of ozone added to the fuel

- ➢Ozone is used to stabilize the cool flames
- ➢ The addition of ozone increases the flammability limits of cool flames, making it easier to create observable, stabilized flames



4. Won, Sang Hee, Bo Jiang, Pascal Dievart, Chae Hoon Sohn, and Yiguang Ju. "Self-sustaining N-heptane Cool Diffusion Flames Activated by Ozone." *Self-sustaining N-heptane Cool Diffusion Flames Activated by Ozone (2014)*

Materials and Methods

Overview:

- O_3-enchanced DME/O_2 flames of equivalence ratios (ϕ) 0.6 and 1.0

- O_3 concentration of 130 g/Nm^3 in O_2 - no cool flame was attained without O_3 addition

- Low pressure operation at 6.7 kPa ensured rapid diffusion and premixing of fuel and oxidizer at the exit of the burner

- Cool flames ignited using a glow plug downstream of the burner surface

Materials and Methods

- Three cool flame properties were measured:
  - Lift-off heights
  - Speciation
  - Temperature Profiles

Materials and Methods

Measurements: Lift-off heights

- Flame height above the burner surface (lift-off height) measured
- Pictures taken with Nikon D90 camera and analyzed with ImageJ software
  - Using the ImageJ software, a conversion of pixels to a measureable distance could be made to determine lift-off height of flames
- Lift-off height results used to determine operating conditions for freely propagating regime for speciation of cool flames

Materials and Methods

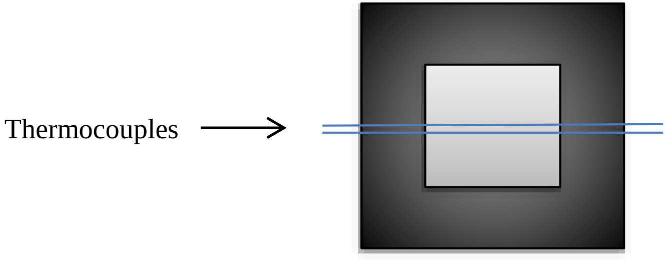
<u>Measurements: Speciation</u>

- Species measurements were taken at heights below lift-off heights, across flame, and above the top of flame
- Extractive samples taken by quartz probe and sampling pump
- Agilent Micro 490 gas chromatograph (GC) used to measure DME, O_2, CO_2, CO, H_2

Materials and Methods

Measurements: Temperature Profiles

- Temperature profiles were measured using a Two-Thermocouple Method for increased accuracy [5]



5. Stein, Jeffrey. "Uncertainties in Radiation Correction for Thermocouples in High Temperature Gases." (2007): 22-23

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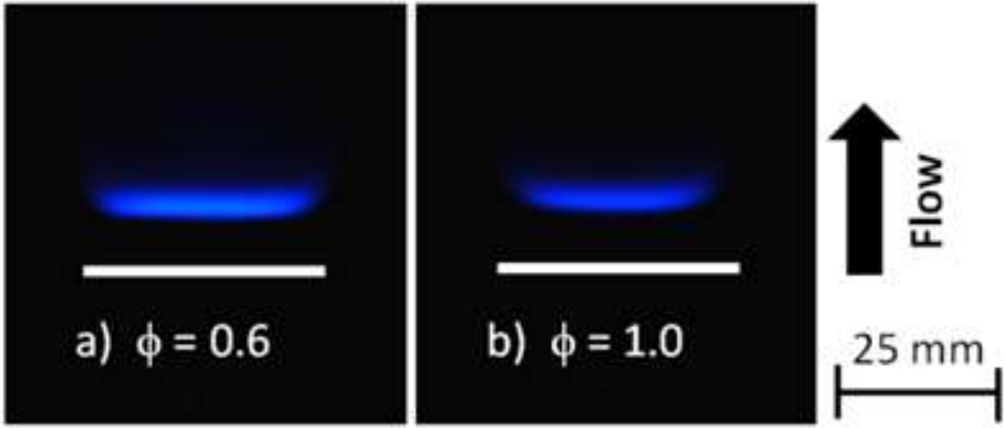
Results and Discussions



- Freely propagating DME cool flames at ϕ=0.6 and ϕ=1.0
- Nikon D90 camera and Nikkor 50mm/f.1.8 lens
- Shutter speed: 4 seconds

Results and Discussions

- Successful platform for stabilized, freely propagating cool flames established
- Successful measurements of lift-off heights, temperature profiles, and speciation of DME cool flames recorded
- These are the results of experimentation in the Fall semester of 2015
- Repeatability of experiments has been successful for Spring 2016

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Conclusions

- Experimental platform to stabilize nearly freely-propagating and adiabatic cool premixed flame
- Lean and stoichiometric DME cool flames successfully stabilized at 6.7 kPa and 7.3 kPa pressure
- Lift-off heights measured and flame speeds calculated at intersection of burner-stabilized and freely propagating regimes
- Temperature and species profiles measured to investigate structures of freely-propagating cool flames

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Looking Ahead

- The next steps include:
  - Continuing repetition of experiments to verify reproducibility of results
  - Explore flammability limits by adjusting Ozone concentration

Questions?