

# Thermal Characterization of Ash Deposits in a 1.5 MW Reactor

*Advancing Efficient Fossil Energy Based Power Generation II*

*2015 AiChE Meeting*

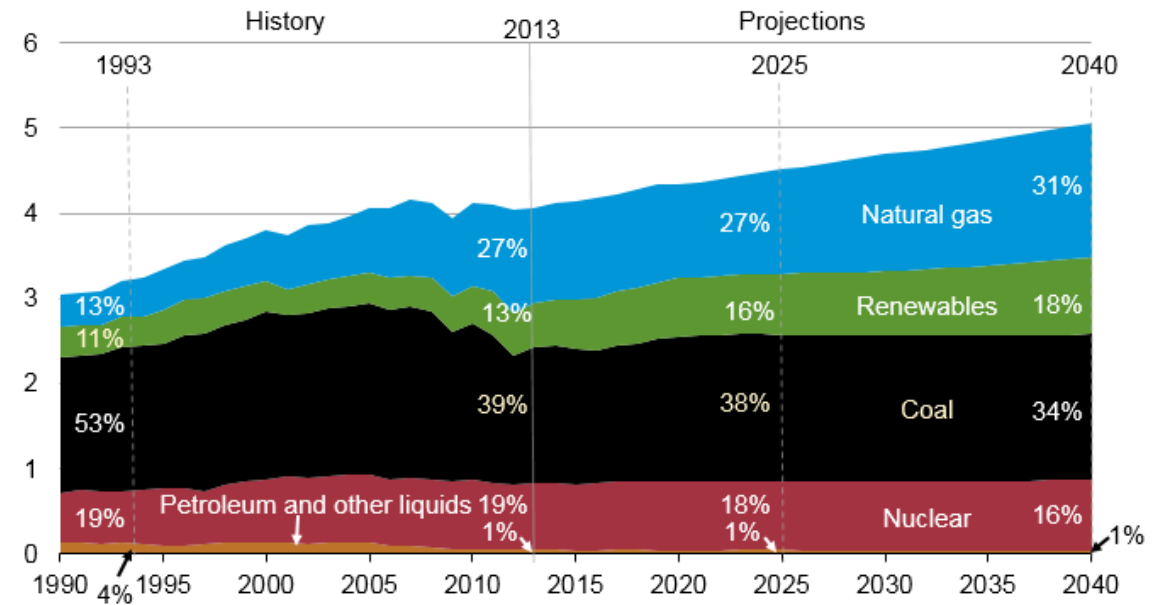
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# Introduction

- The demand for green energy is ever increasing.
- Coal combustion plays (and will continue to play) a significant role in energy production.
- Coal combustion emits  $\text{CO}_2$  – a greenhouse gas – into the atmosphere.
- Oxy-combustion is a developing method enabling easier post-process carbon capture.
- In order to implement oxy-combustion in larger scale systems, accurate predictive models must be made.
- Experimental results from oxy-fired combustors are needed to validate simulations.

## Electricity Net Generation (trillion kilowatt hours)



Source: EIA Annual Energy Outlook 2015 Reference case



# Background

Coal slag and ash coat the inside of the reactor.

SLAG

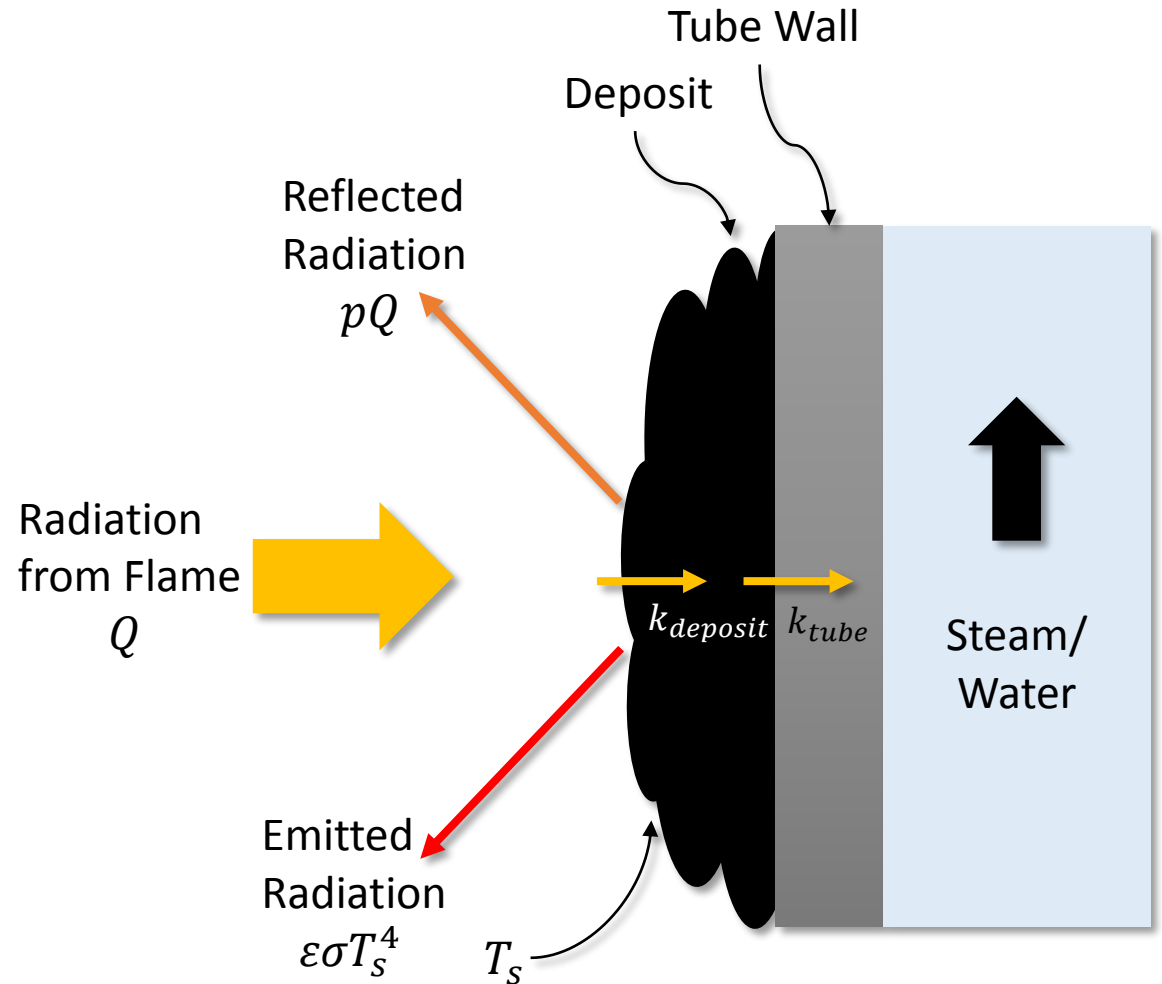


ASH



# Background

- These deposits complicate the heat balance, as the following are unknown:
  - reflectivity,  $\rho$
  - emissivity,  $\varepsilon$
  - thermal conductivity,  $k_{\text{deposit}}$
  - the thickness of the deposit,  $t_{\text{deposit}}$
- Two experiments were performed to characterize the deposits
  - (1) Spectral emissivity measurements
  - (2) Thermal diffusivity,  $\alpha$ , measurements, which contains the thermal conductivity
    - $\alpha = \frac{k}{\rho c_p}$





# Experimental Design

- Reactor description
  - Fire oxy-coal at 1.5 MW
  - 1.1 m x 1.1 m internal cross section and 13.1 m in length
- Data description
  - Data was taken in two sets – before and after a week-long campaign
  - Before the campaign, both experimental methods were being developed; therefore, less data was taken.
- Emissivity measurements
  - Pre-campaign: 7 samples were removed at random
  - Post campaign: Collected 396 samples in a 1'x1' grid on the two walls and ceiling of reactor to depth of 45 feet
- Thermal diffusivity measurements
  - Pre-campaign: Analyzed 36 points in a 1'x1' grid on the two walls and ceiling of reactor to depth of 4 feet. **Some** points analyzed three times (78 total sets).
  - Post campaign: Analyzed 36 points in a 1'x1' grid on the two walls and ceiling of reactor to depth of 4 feet. **All** points analyzed three times (108 total sets).

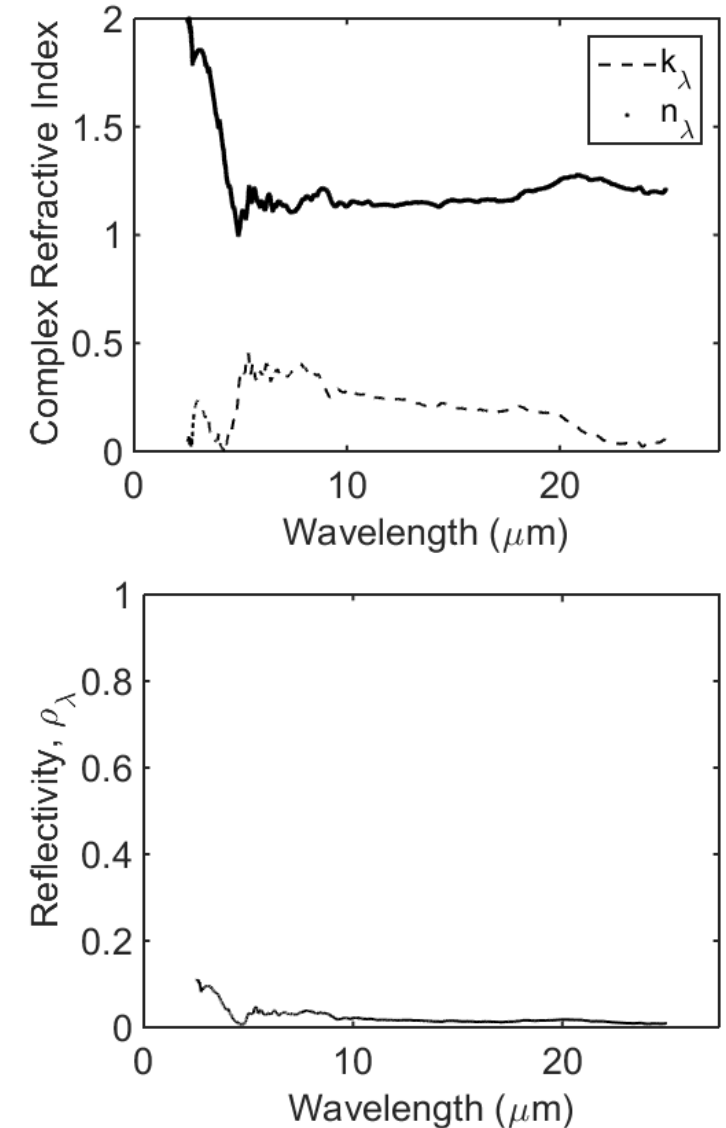


Image of L1500 Reactor.

# Method: Emissivity

- Deposit samples were chipped/scraped off the interior walls of the L1500 reactor
- A diffuse reflectance cell was used in conjunction with an FTIR to measure the complex refractive index,  $n_\lambda$  and  $k_\lambda$ , of the deposits at room temperature
- The spectral reflectivity was found using the following equation for ambient air at near normal incidence:

$$\rho_\lambda = \frac{(n_\lambda - 1)^2 + k_\lambda^2}{(n_\lambda + 1)^2 + k_\lambda^2}$$



# Method: Emissivity

- Using Kirchhoff's law ( $\epsilon_\lambda = \alpha_\lambda$ ) and the radiation balance, we find that spectral emissivity and reflectivity are coupled:

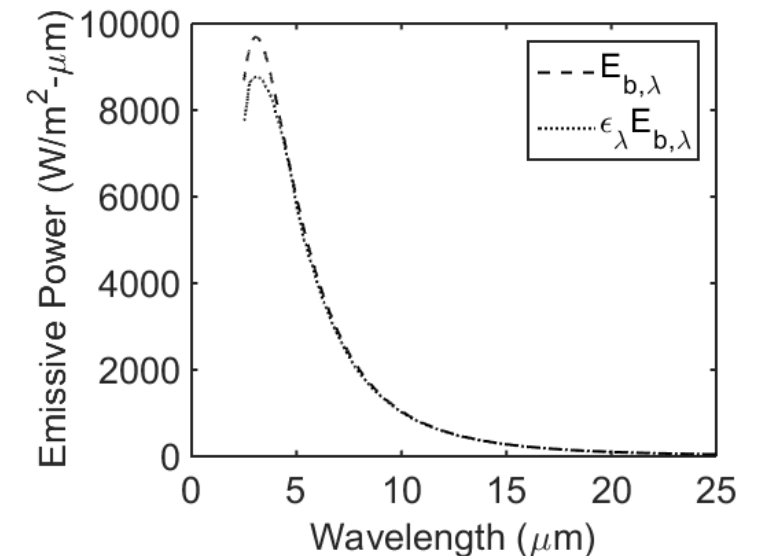
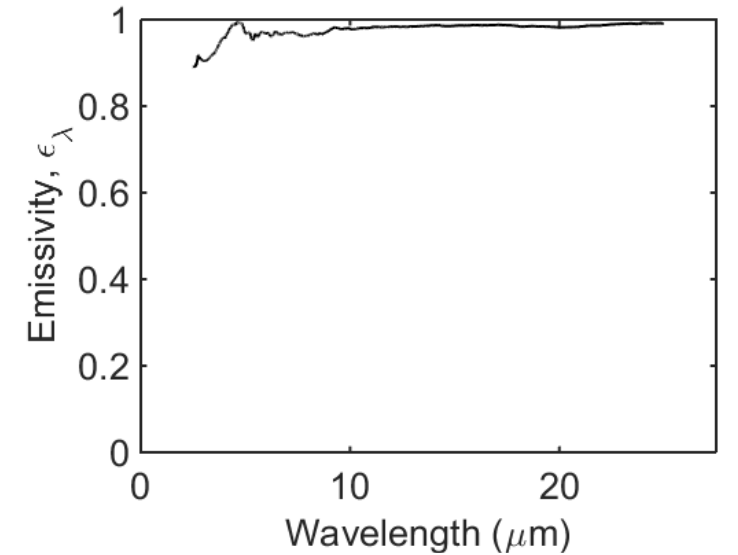
- $\epsilon_\lambda + \rho_\lambda + \tau_\lambda = 1$

- Assuming the medium is opaque (a good assumption for typical coal slag), the emissivity and reflectivity are related by:

- $\epsilon_\lambda = 1 - \rho_\lambda$

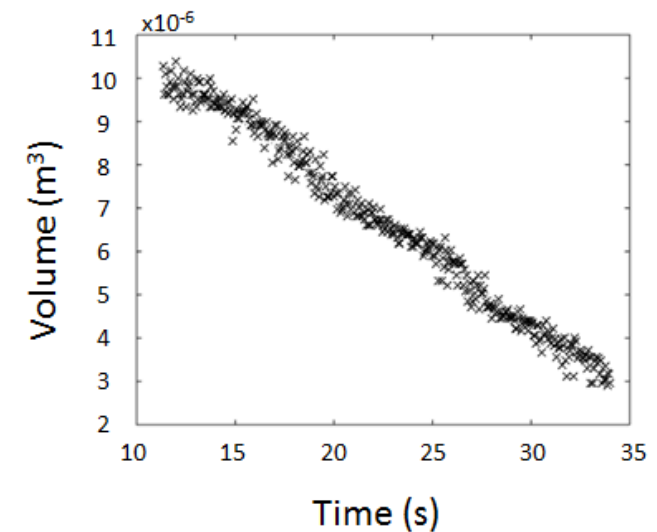
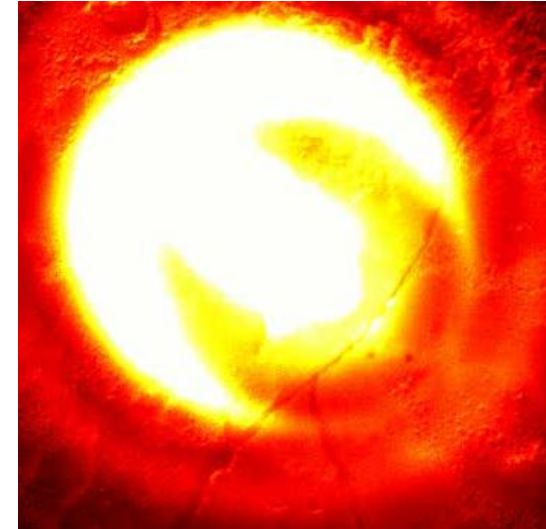
- The total emissivity was approximated using:

- $$\epsilon \approx \frac{\int_{2.5 \mu m}^{25 \mu m} \epsilon_\lambda E_{b,\lambda} d\lambda}{\int_{2.5 \mu m}^{25 \mu m} E_{b,\lambda} d\lambda}$$



# Method: Thermal Diffusivity

- A small area on the interior wall of the L1500 reactor was heated using an oxy-acetylene torch.
- A video of the heated area was taken with an infrared camera.
- Using a threshold value, the diminishing area of the heat was tracked with MATLAB.
- The radius of the two-dimensional area was used to approximate the hemispherical volume of the dissipating heat.
- The slope of the heat volume versus time was compared to a COMSOL simulation of pure refractory and related to yield the thermal diffusivity.





# Results: Pre Campaign Emissivity

- The samples are displayed in ascending order of their emissivity
- There is not an obvious correlation between the physical appearance of the sample and the emissivity
- Average emissivity for the seven samples is 0.9514



.8938



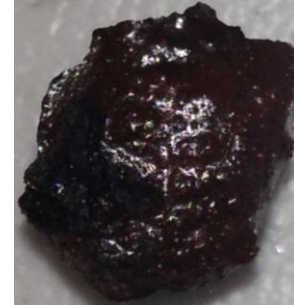
0.9433



0.9544



0.9560



0.9585



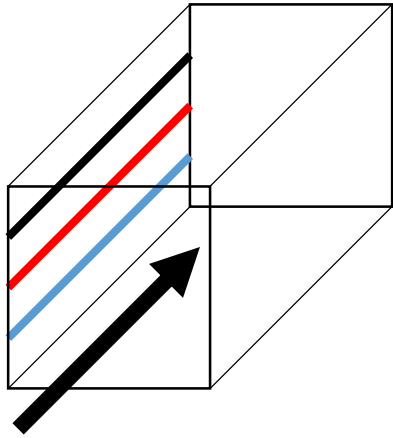
0.9669



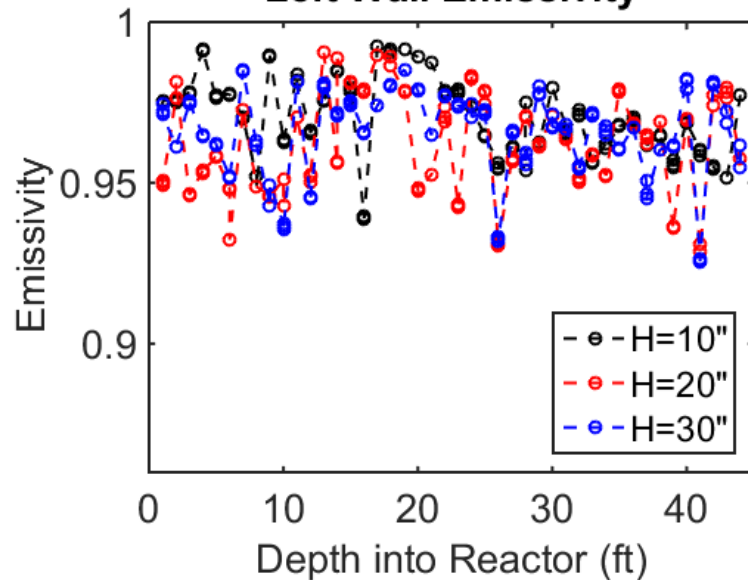
0.9869

# Results: Post Campaign Emissivity

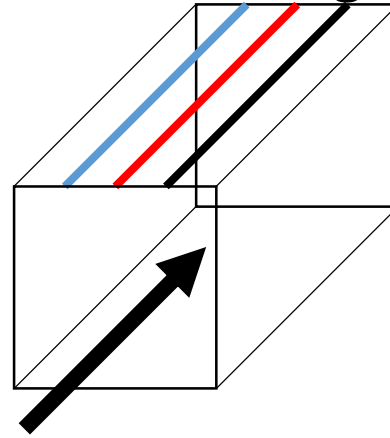
Left Wall



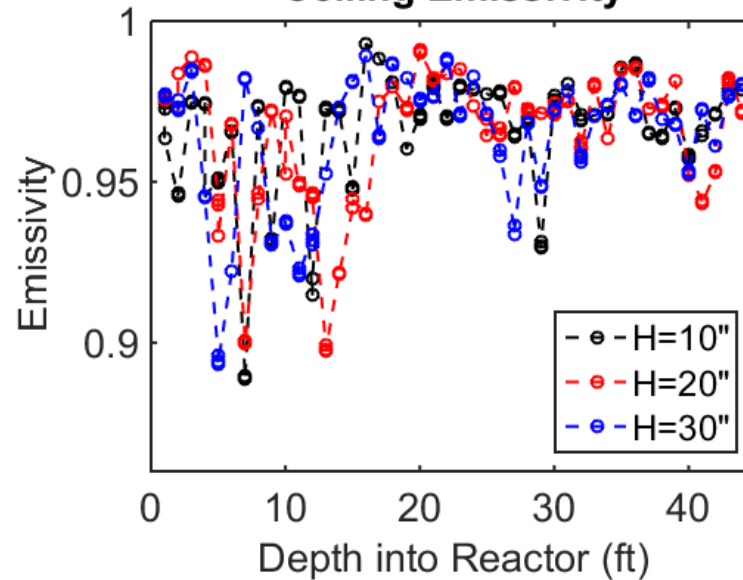
Left Wall Emissivity



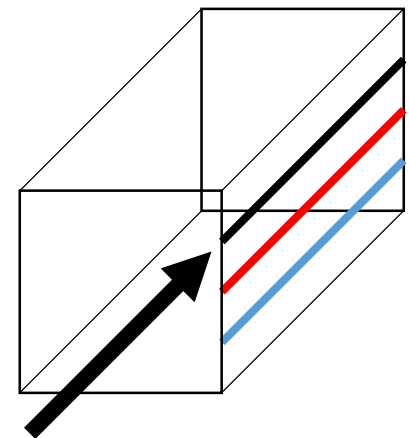
Ceiling



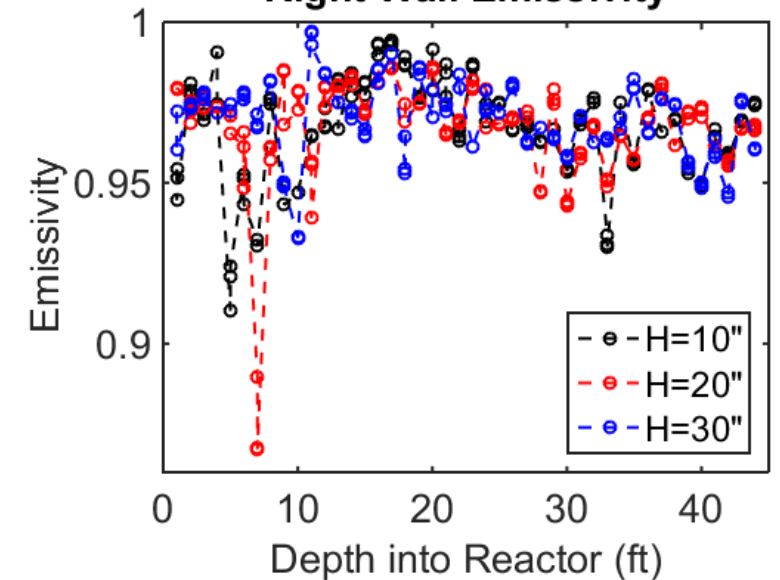
Ceiling Emissivity



Right Wall

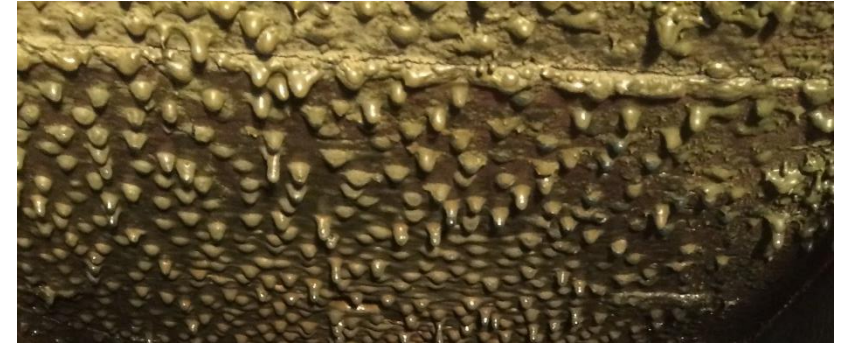


Right Wall Emissivity

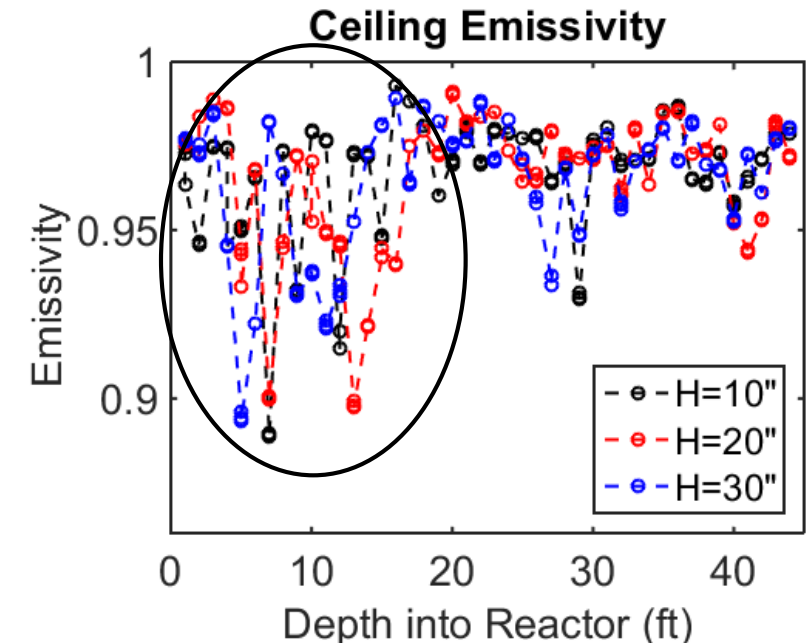


# Results: Post Campaign Emissivity

- Emissivity does not appear to be a function of height
- Appears to be a 10 foot region (3-13 feet) of slightly lower emissivity on ceiling measurements
  - Possible explanation is that the ceiling deposits at this depth were more glassy in nature as this is where the flame is
- Data is close to black – average over all points is 0.966 (similar to pre-campaign average of 0.9514)
  - These values are very high.
  - The data was taken in a FTIR at room temperature.
  - Typically in coal ash samples, the emissivity decreases as a function of temperature.
  - Current work is being done to construct an apparatus that can measure the spectral emissivity of a sample heated to operating furnace temperatures.



Glassy section of ceiling

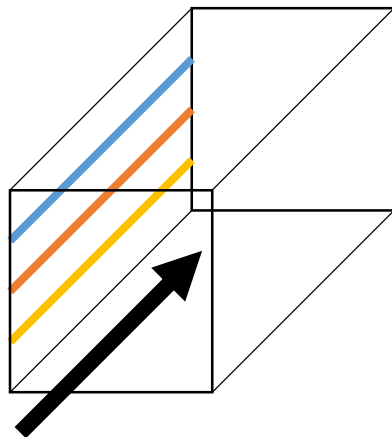




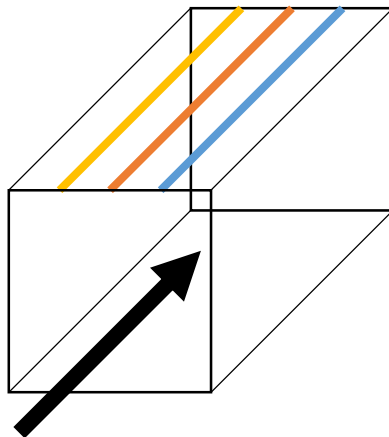
# Results: Pre Campaign Thermal Diffusivity



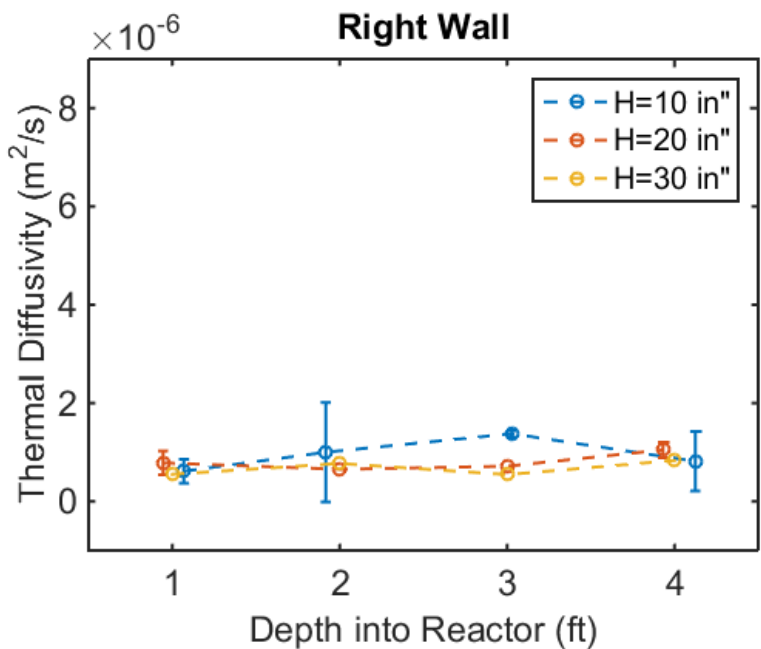
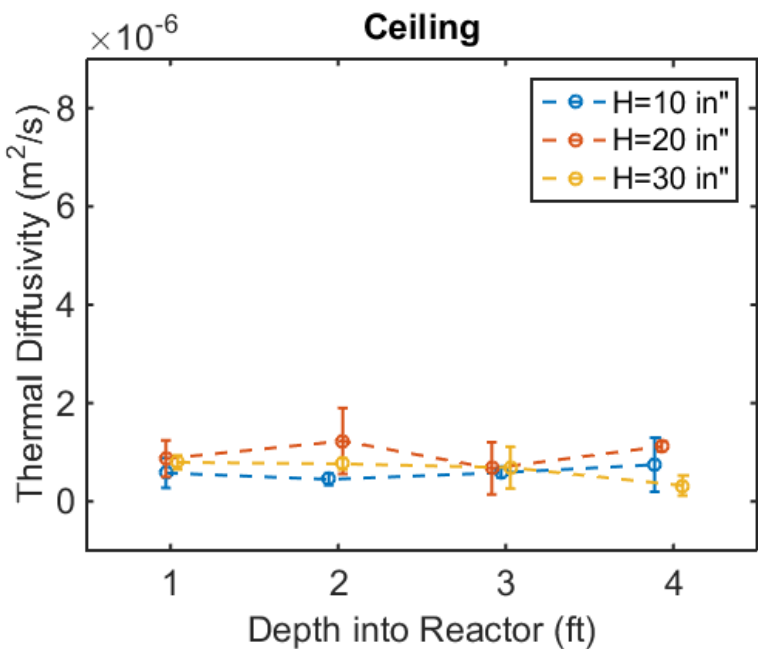
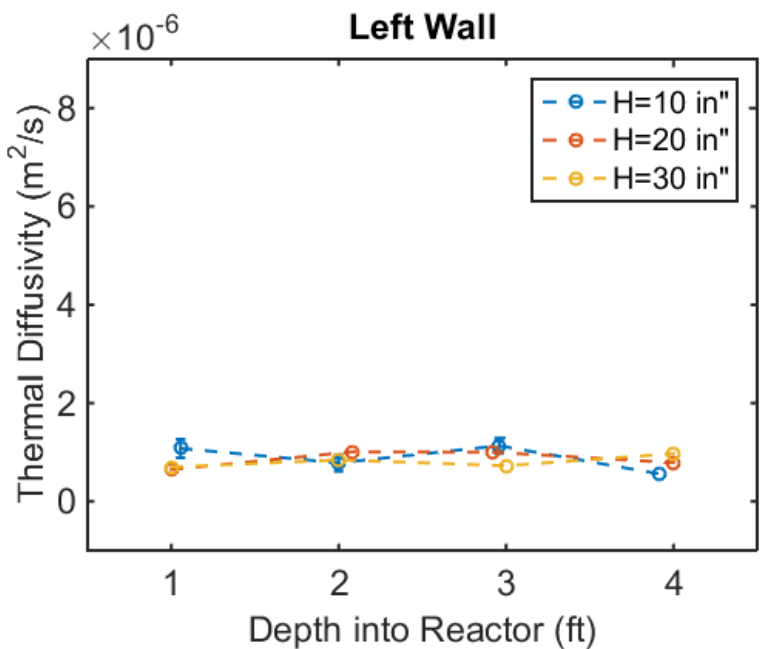
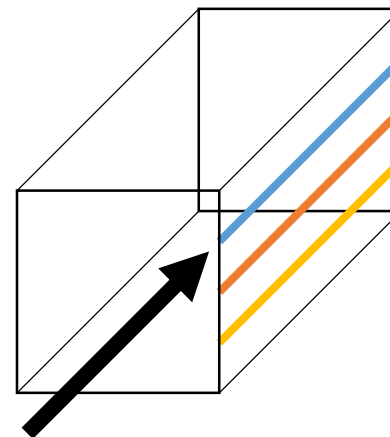
Left Wall



Ceiling



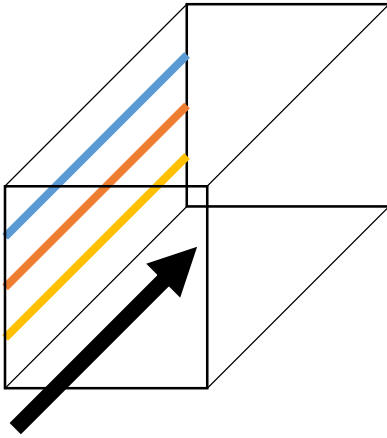
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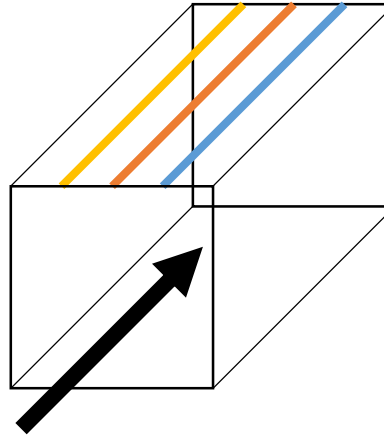
# Results: Post Campaign Thermal Diffusivity



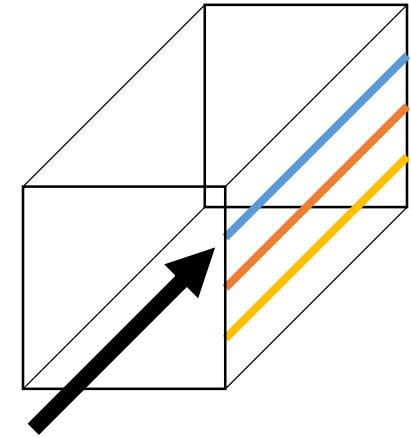
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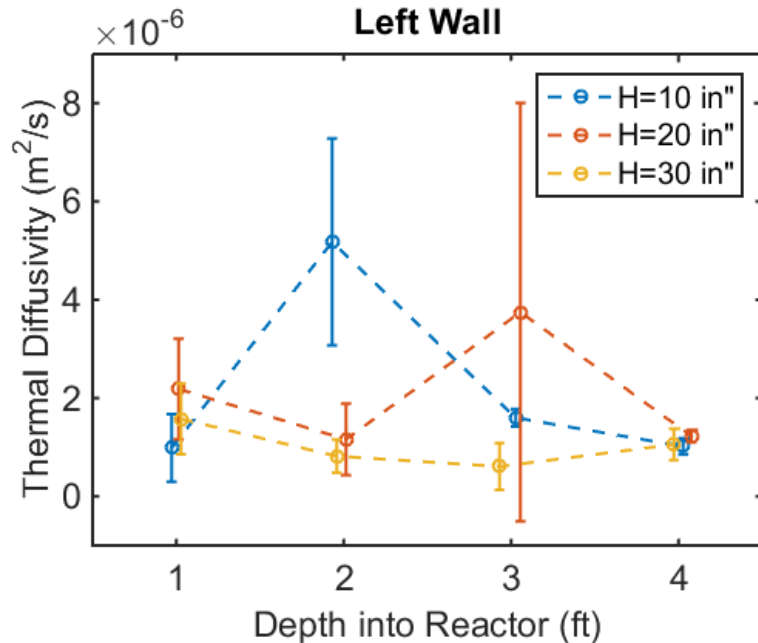
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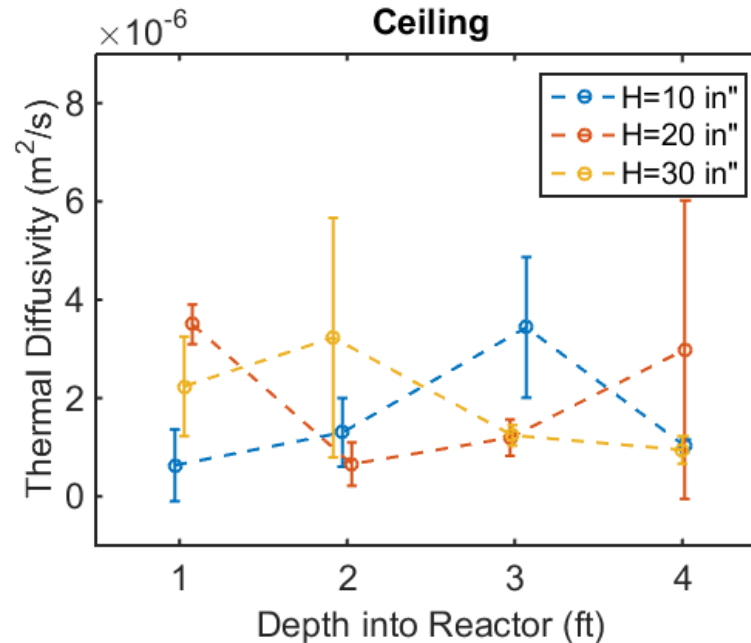
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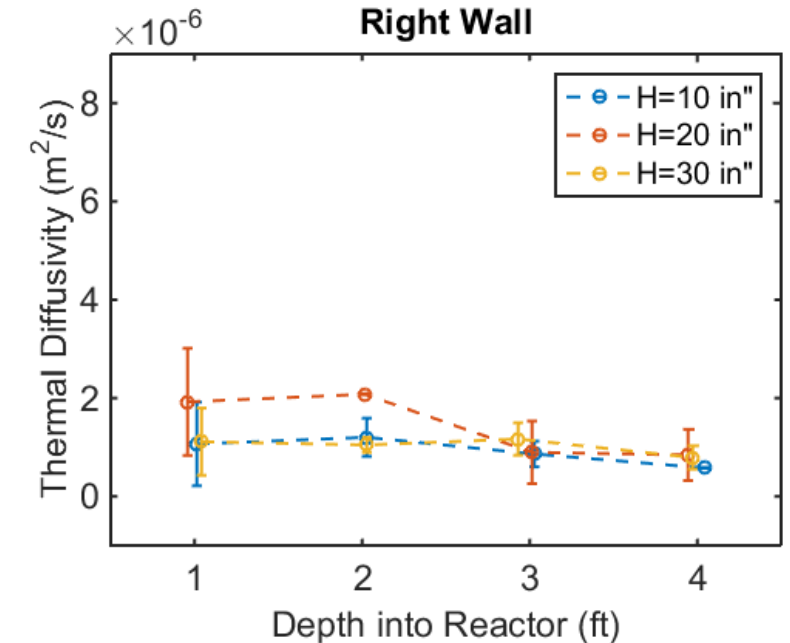
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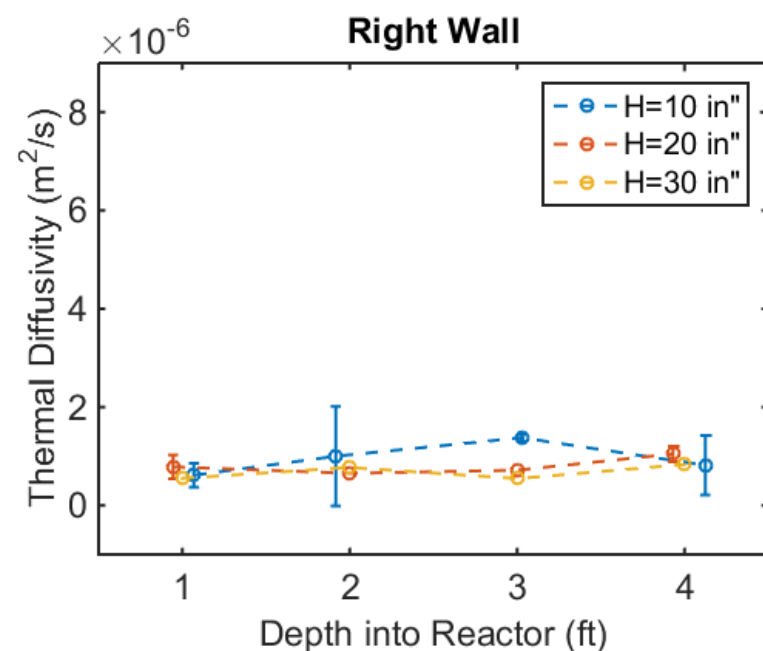
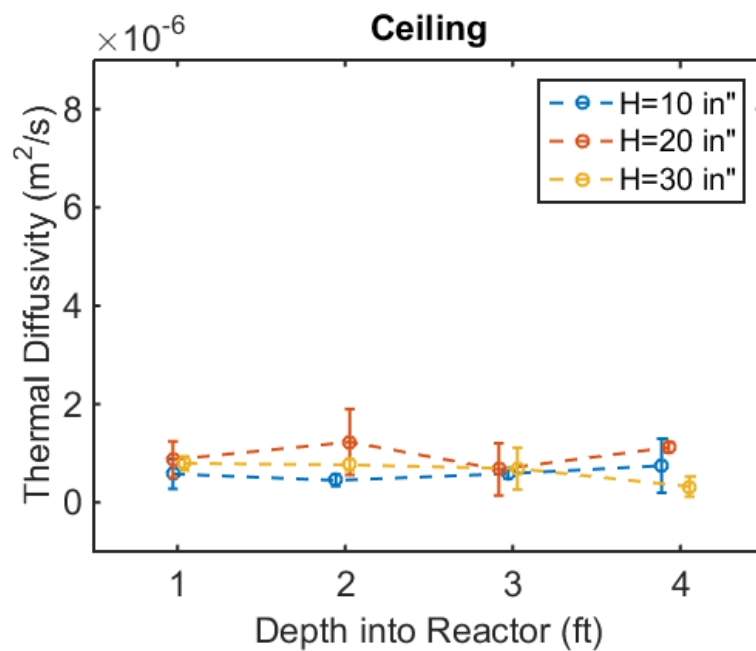
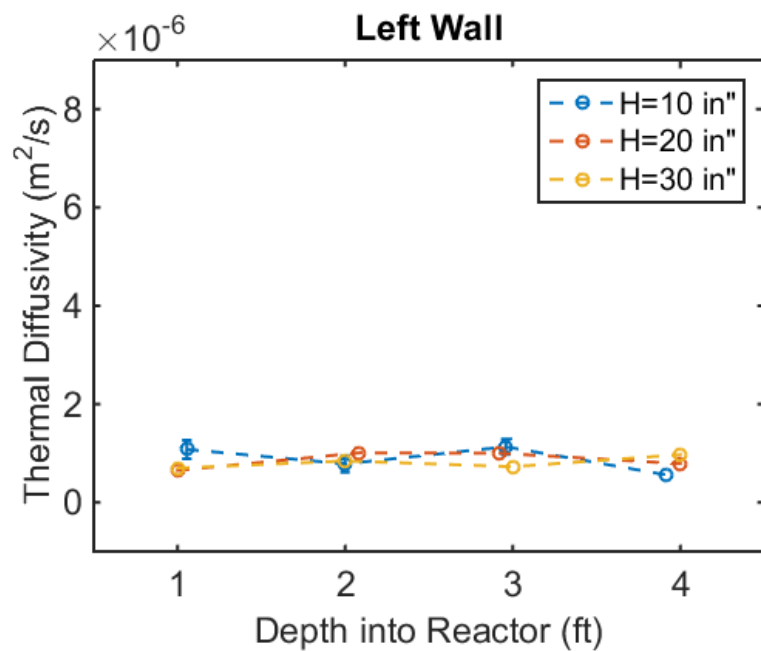
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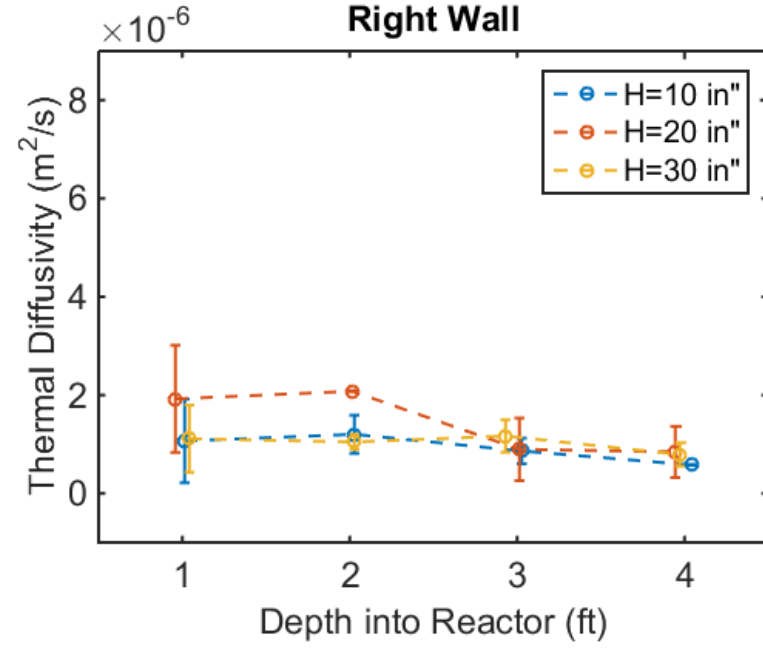
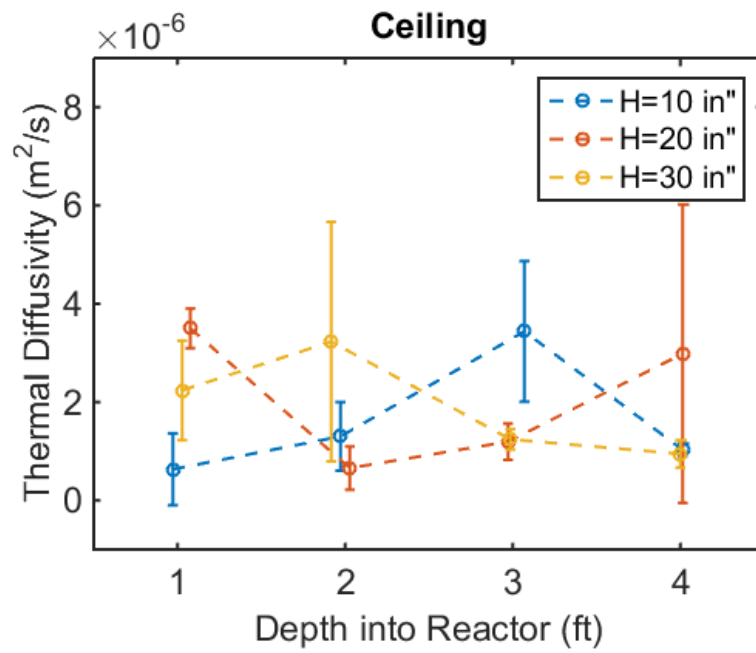
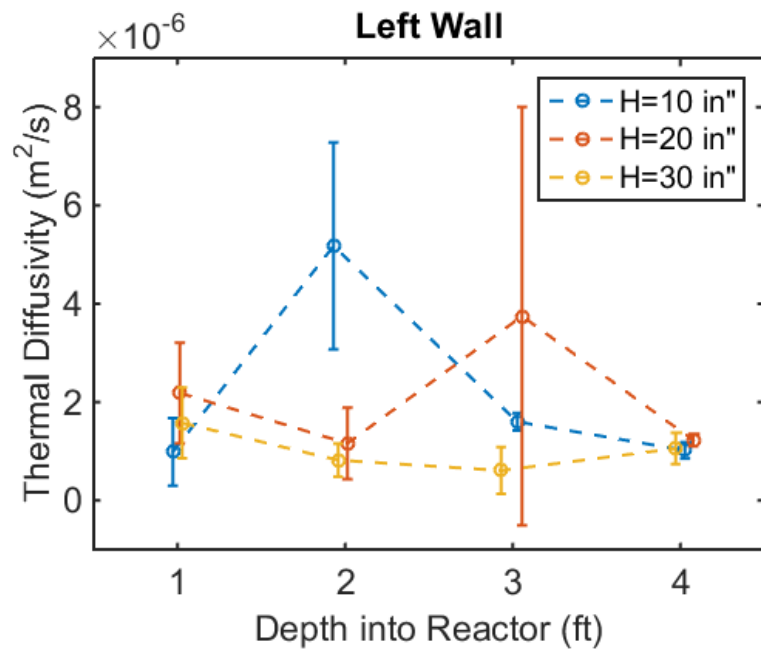
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Pre-campaign



Post campaign

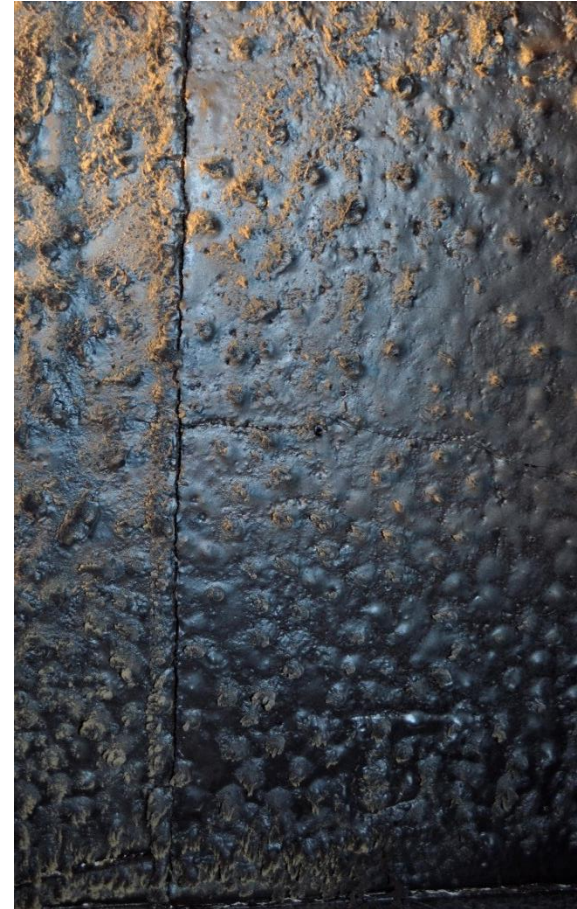




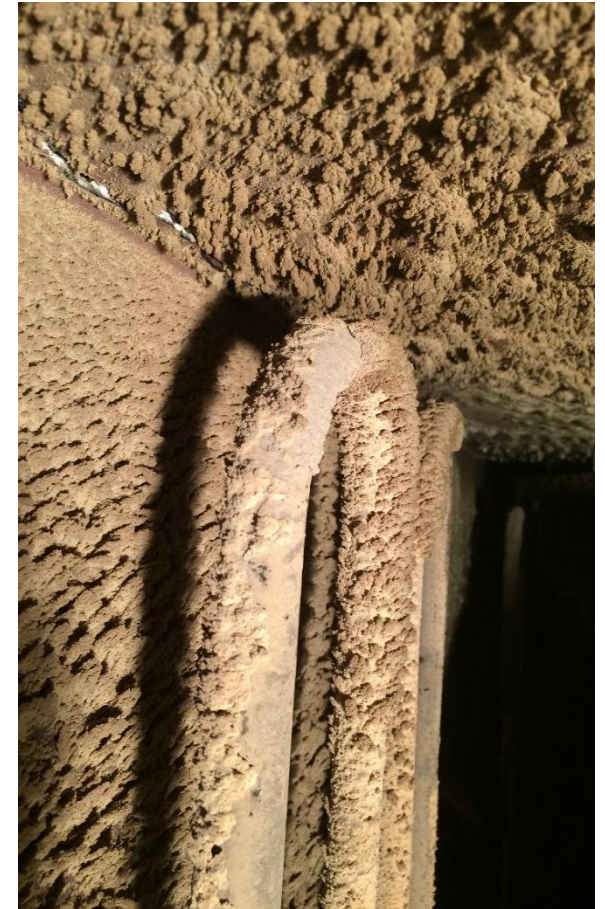
# Results: Thermal Diffusivity

- Diffusivity does not appear to be a function of depth or height
- Diffusivity changed significantly before and after the campaign
  - The reactor was coated with thick layers of dusty ash after the campaign
  - Post campaign had larger average values
    - While thermal conductivity would be expected to be lower with dusty ash versus slag, thermal diffusivity also includes the density term.
      - Density for ash is much lower than for slag, which could be responsible for the increase seen.
    - Cracks/irregularities in the deposit surface can make the heat front appear to stand still, making the measured diffusivity appear higher
  - Post campaign had larger standard deviations
    - Measurements with a great deal of surface irregularities will result in higher variation.

Pre Campaign Reactor Wall



Post Campaign Reactor Wall



# Conclusions and Future Work

- Two measurement techniques were presented that assist in the characterization of thermal deposits
  - ***Emissivity***
    - Before and after campaign results were very similar and very black
    - Most results were very similar as a function of height and depth into the reactor although the ceiling deposits were the flame was were slightly lower in emissivity due to their glassy nature
    - Future work: measure same deposit samples at furnace temperatures
  - ***Thermal diffusivity***
    - Is not a function of depth or height into the reactor
    - Before and after campaign results changed significantly. The post campaign results had higher values, which are attributed to the lower density of the ash deposits. The post campaign results also had higher standard deviations, which are attributed to the greater amount of irregularities in the deposit surfaces.
    - Future work: Find a way to account for irregularities in deposit surface



# Acknowledgements

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## Thank you.