CARBON CAPTURE
MULTIDISCIPLINARY
SIMULATION CENTER

Thermal Characterization of a 1.5 MW Pulverized-coal Reactor using Infrared Heat Flux, Total Heat Flux and Measured Heat Loss

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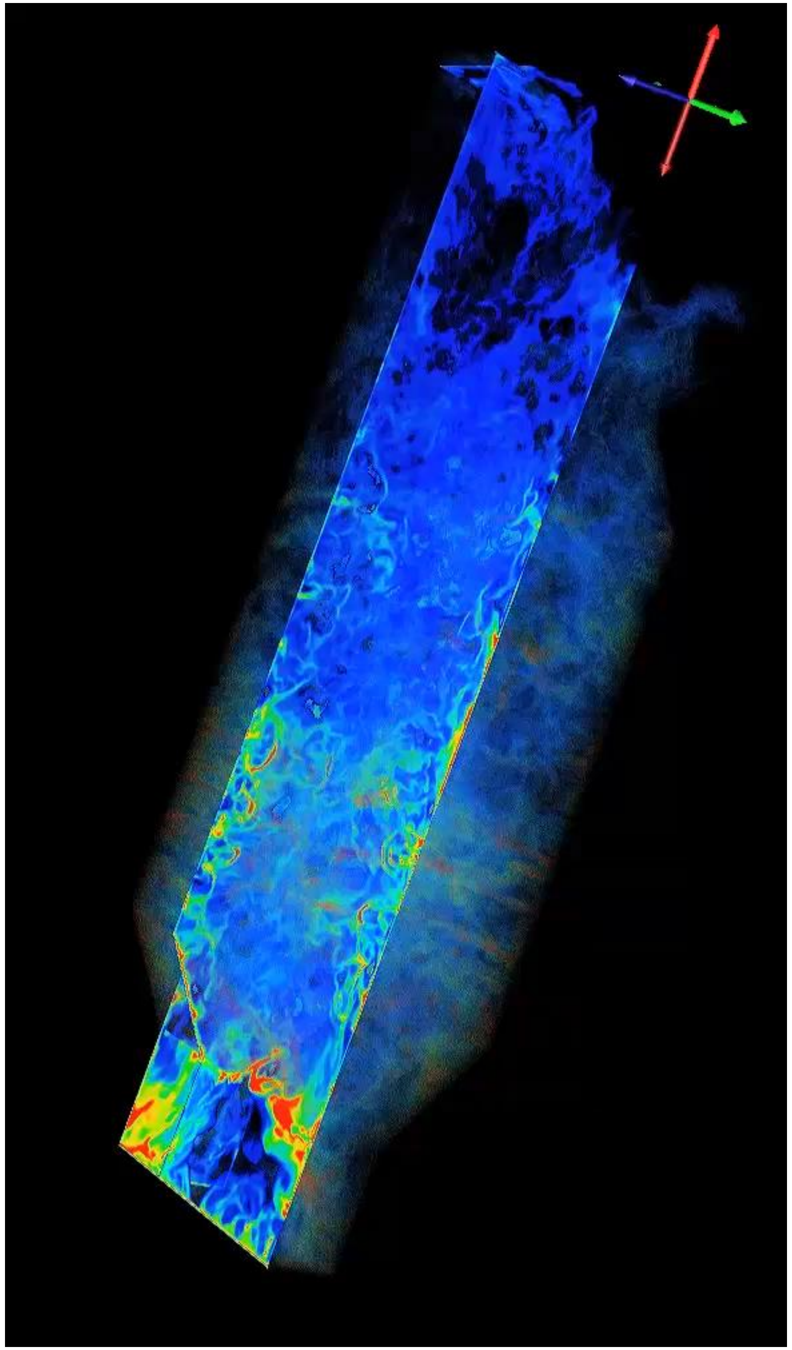
Introduction

- Carbon Capture Multidisciplinary Simulation Center (CCMSC)
  - Part of the Institute for Clean and Secure Energy (ICSE)
- CCMSC Goal:
  - Use exascale computing to advance new electric power generation technology
    - Low cost
    - Low emission
- CCSMC Teams:
  - Exascale
  - Predictive Science/Physics
  - **Validation & Verification/Uncertainty Quantification**
    - **Quantity of Interest: Heat Flux**



http://ccmsc.utah.edu/

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L-1500 Furnace and Conditions

- L-1500 Furnace:
  - Capable of running 5.1 MBtu/hr (1.5 MW)
  - Fires natural gas and/or pulverized coal
  - Air or oxy-combustion capable
- Feb. 2015 Conditions:
  - Oxy-combustion
  - Sufco coal (Bituminous)
  - Coal firing rate: ~3.5 MBtu/hr (1.0 MW)
  - Coal flow rate: 297 lb/hr
  - Excess Oxygen: ~3%

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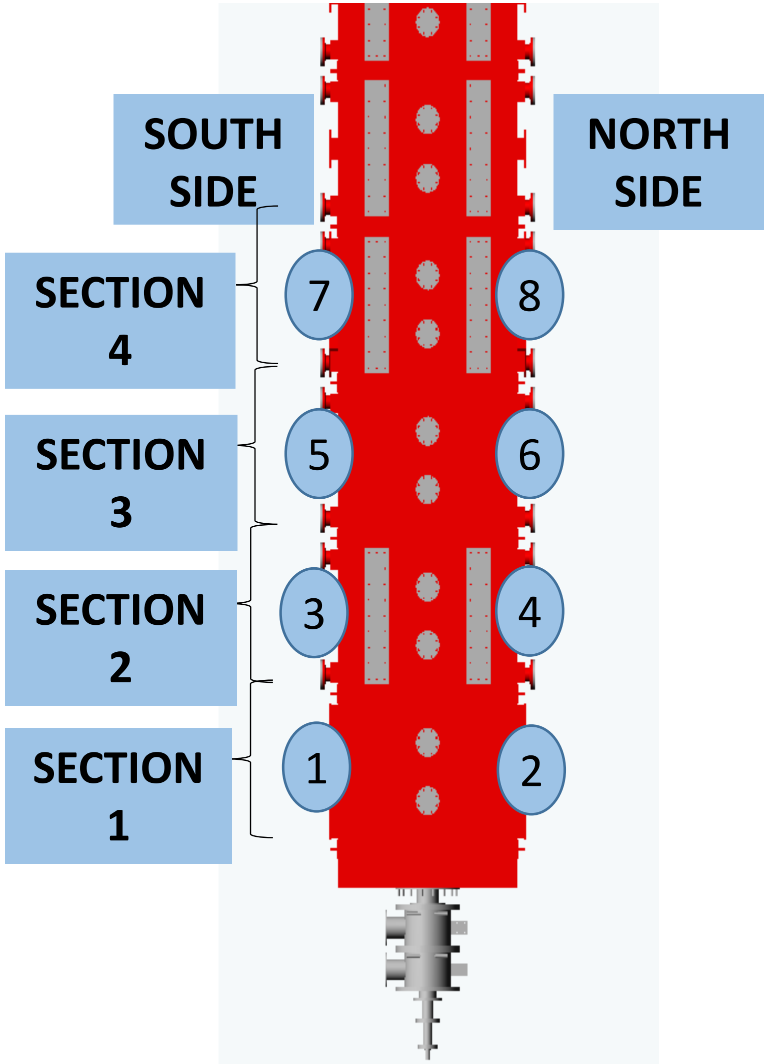
Heat Flux Measurement Techniques

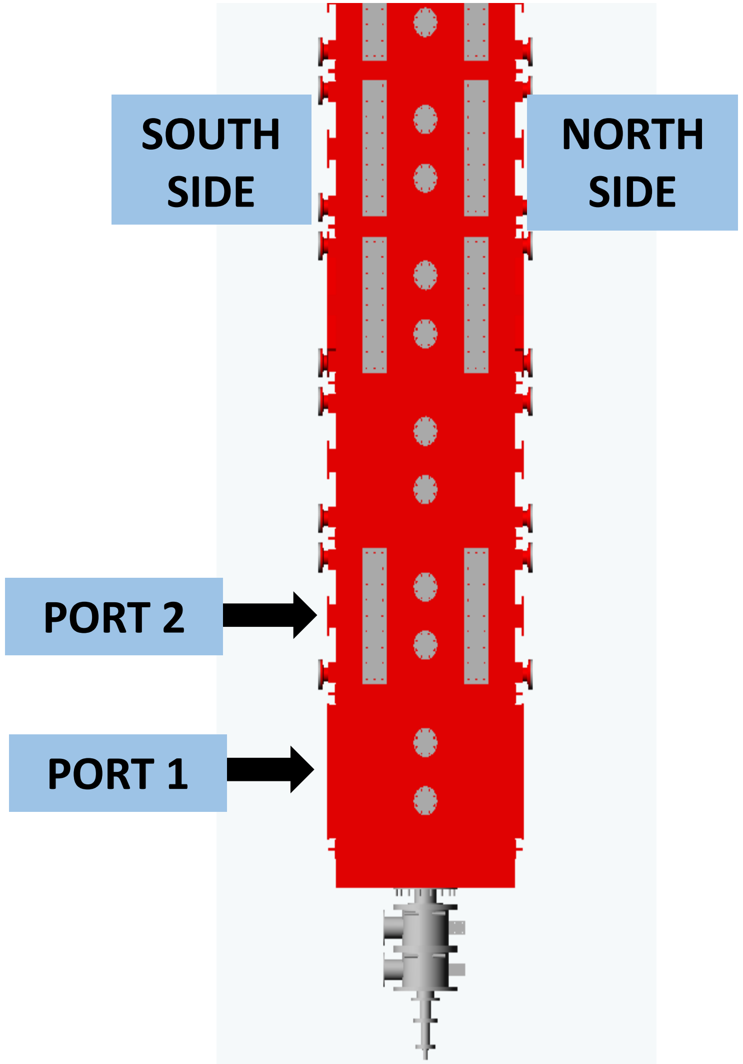
COOLING COILS

*continuously taking data



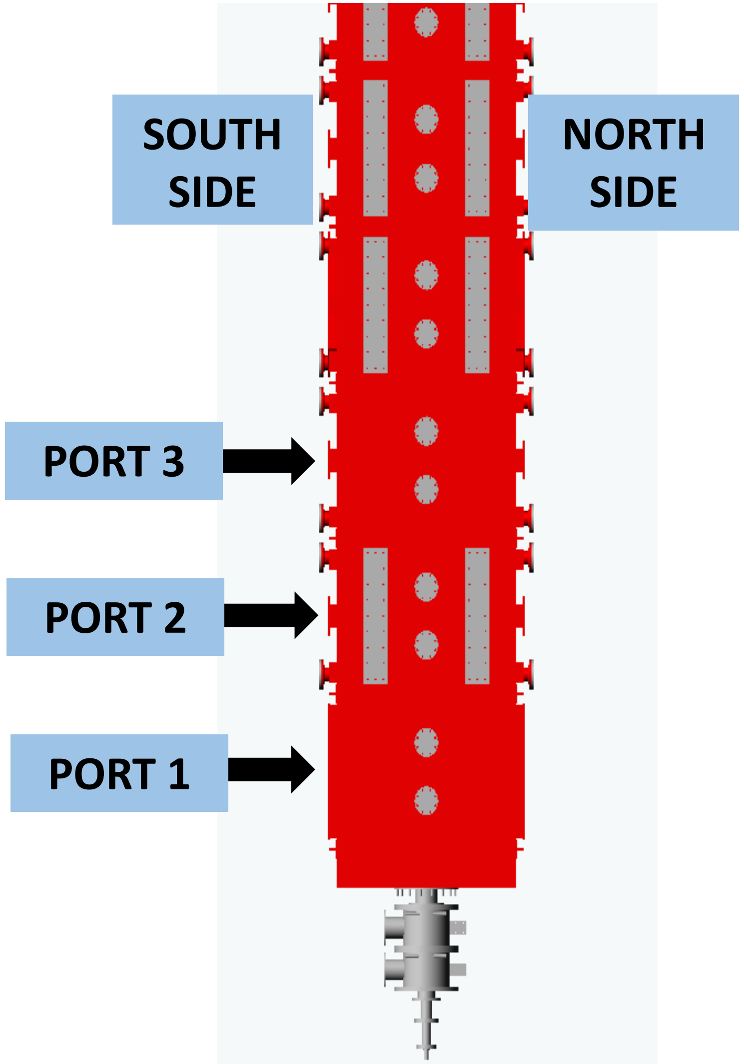
IR CAMERA

*takes limited data



RADIOMETERS

*continuously taking data



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Cooling Coil Description

- Eight cooling coils in the furnace (in 4 Sections and on North and South Sides)
- Flows liquid water
- Made of ½" Sch. 40 stainless steel pipe (0.84" OD)
- Protrudes ~2" from the reactor wall
- Heat Removal Calculation:

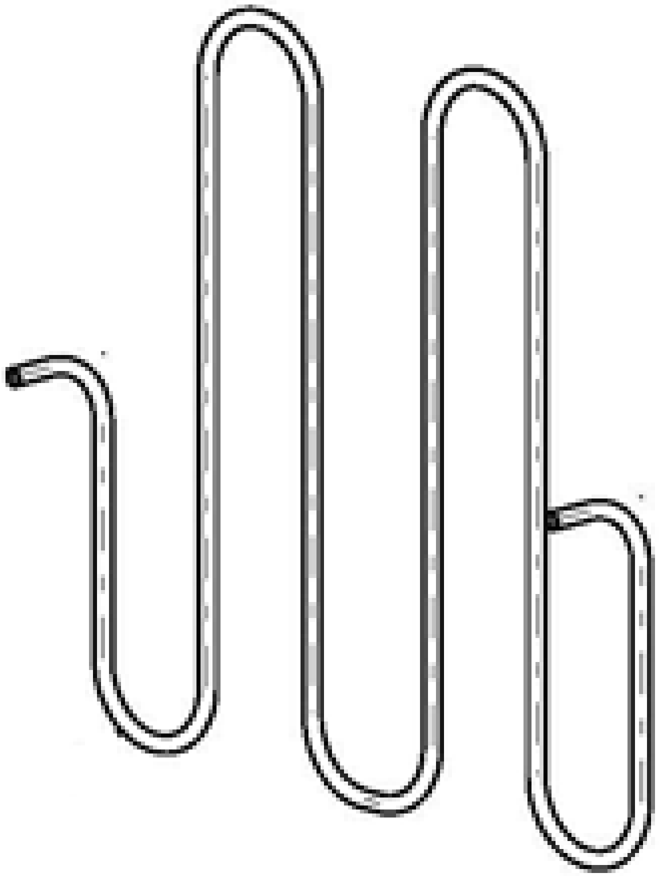
$$Q_{removed}\ [kW] = \dot{m}c_p(T_{outlet} - T_{inlet})$$

- Surface Area Calculation:

$$SA\ [m^2] = \pi(OD)(Length)$$

- Heat Flux Calculation:

$$q"_{removed}\ [kW/m^2] = \frac{Q_{removed}}{SA}$$



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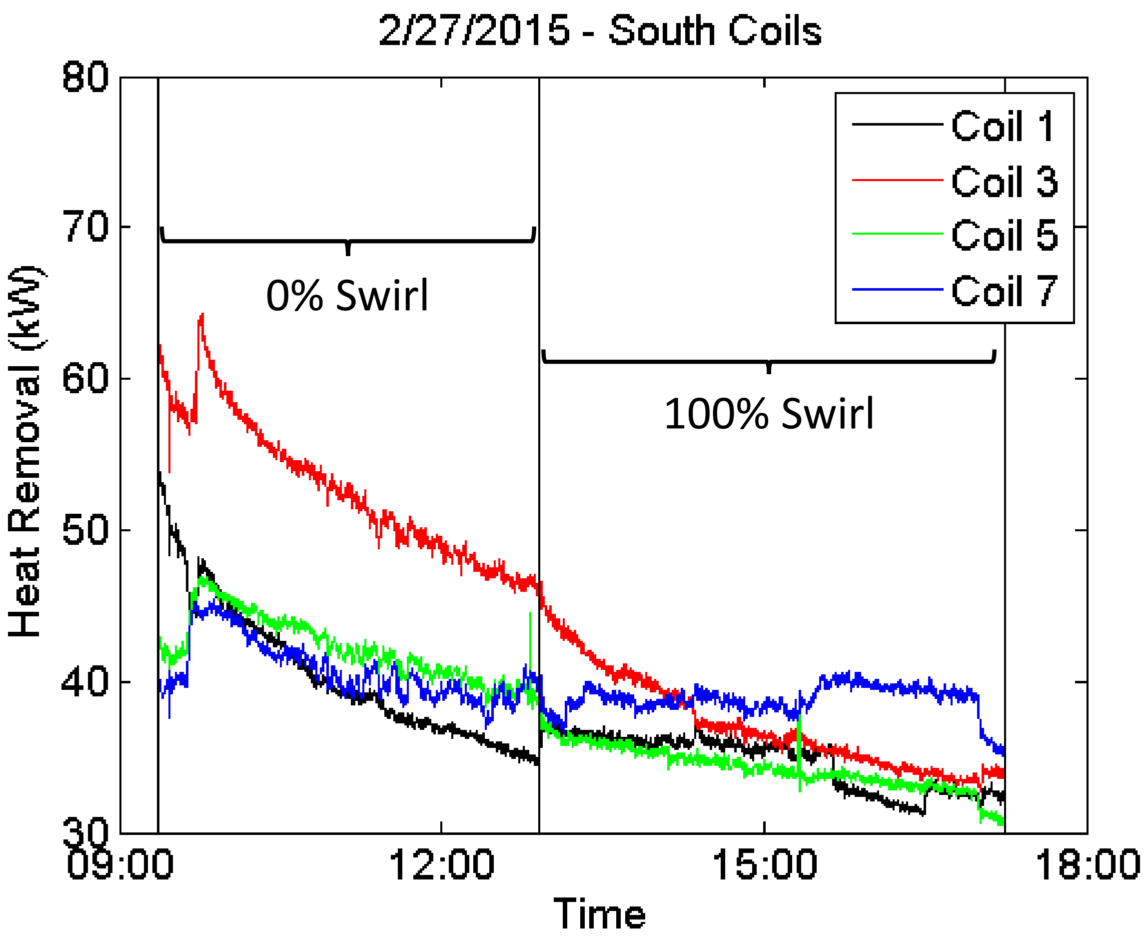
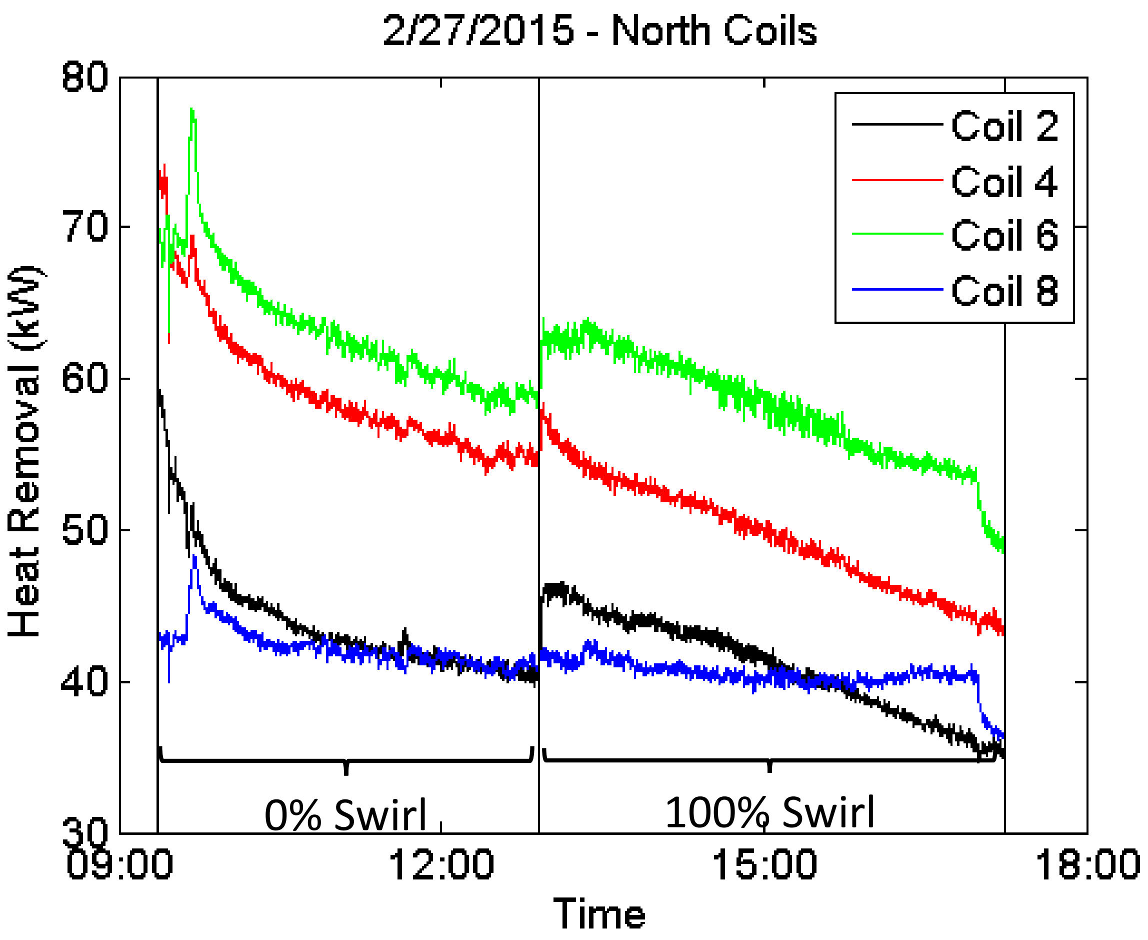
Cooling Coil Heat Removal

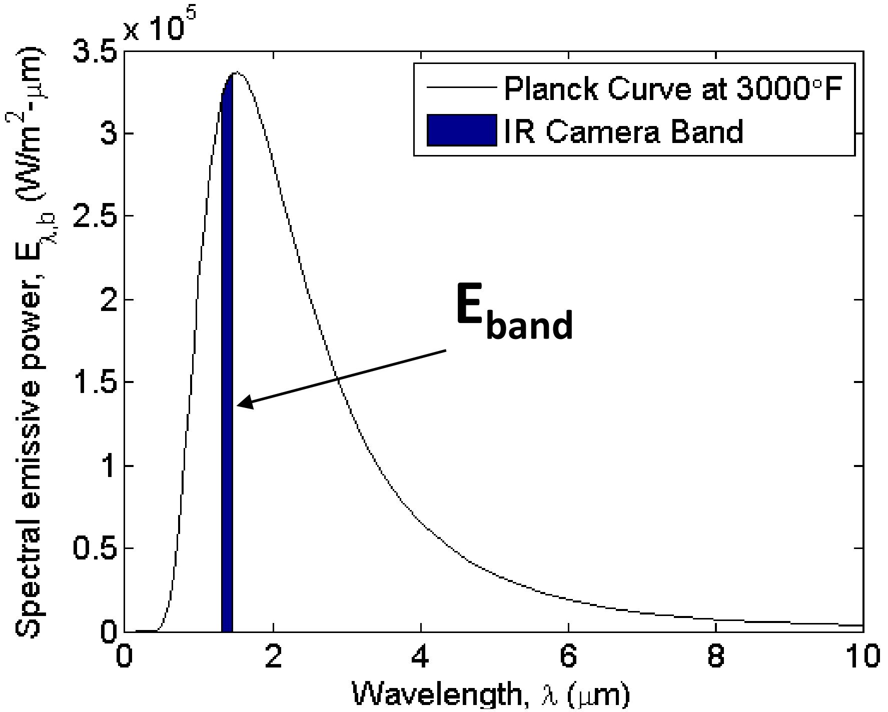


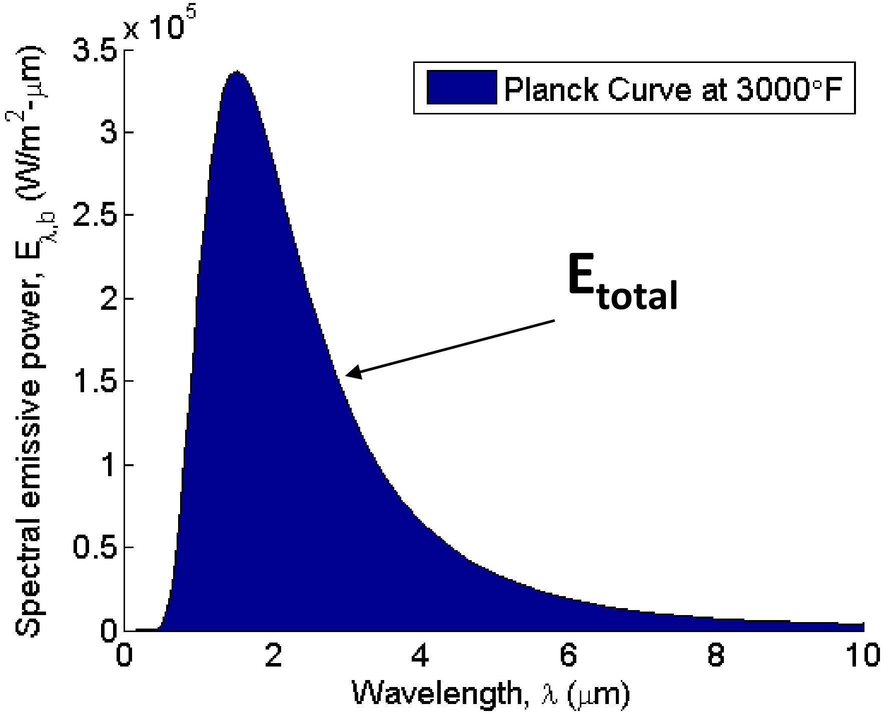


- Section 1 – Coil 1 and 2 – increase abruptly as swirl goes to 100% as flame retracts into Section 1
- Section 4 – Coil 7 and 8 – stays flat – further downstream from the flame – less effect from swirl and deposition

IR Camera Description

- Measures radiation in a narrow, spectral band (1.315-1.465 µm)
- Output pixel response from the calibrated is calibrated with a blackbody generator to produce an IR emissive power, or IR heat flux (W/m^2)
  - $E_{band} = \int_{1.315\ \mu m}^{1.465 \mu m} \frac{C_1}{\lambda^5 * \exp({}^{C_2}/_{\lambda T} - 1)}$
- E_{band} is converted into total heat flux by first solving for the temperature
- This temperature is used to calculate a total, blackbody heat flux:
  - $E_{total} = \sigma T^4$
- Since the emissivity is unknown, this total heat flux is the blackbody heat flux, which represents a lower limit of what the heat flux from the furnace might be
  - If the emissivity from the flame is high, this is a good approximation





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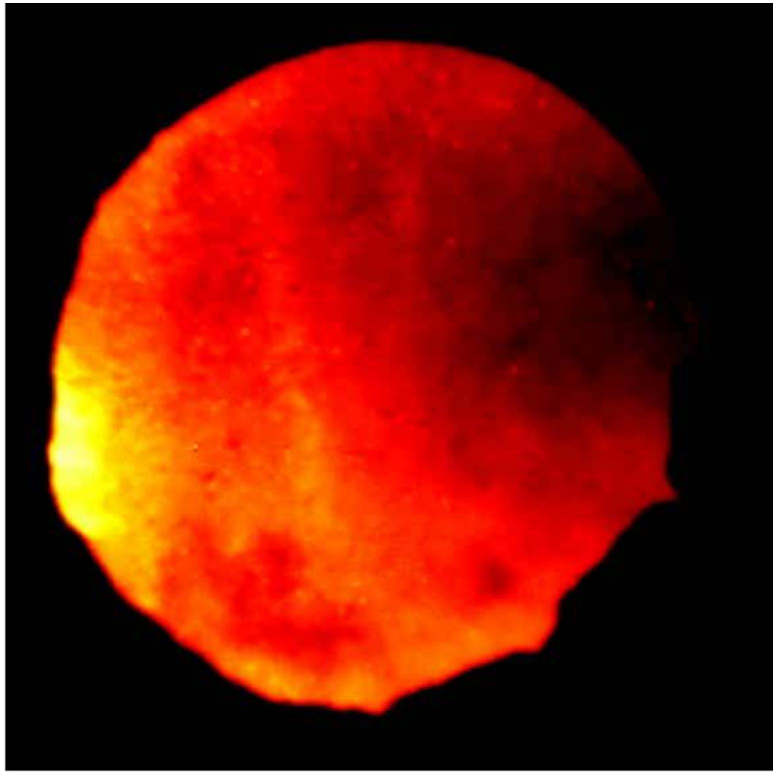
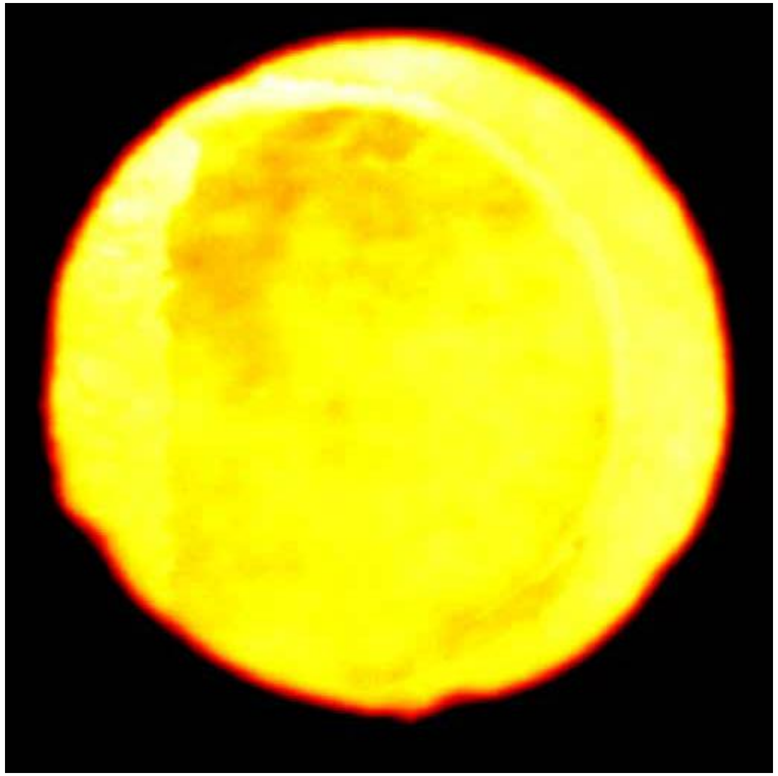
High Speed Infrared Videos



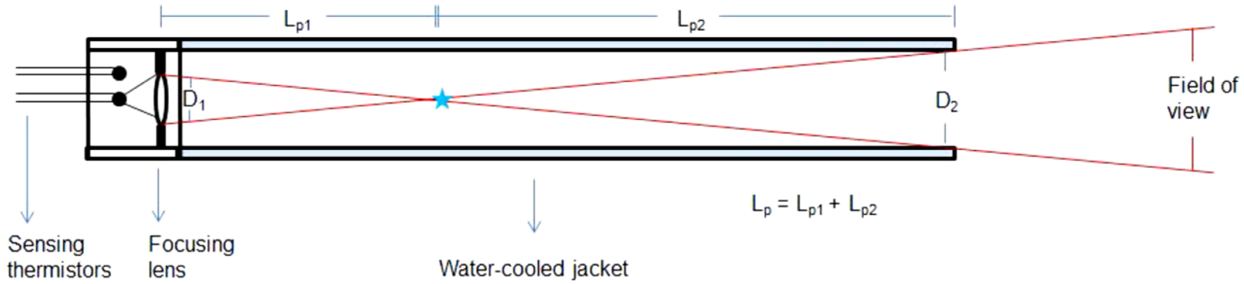
Section 1
2/26/2016
Swirl: 0%
Gain: 1

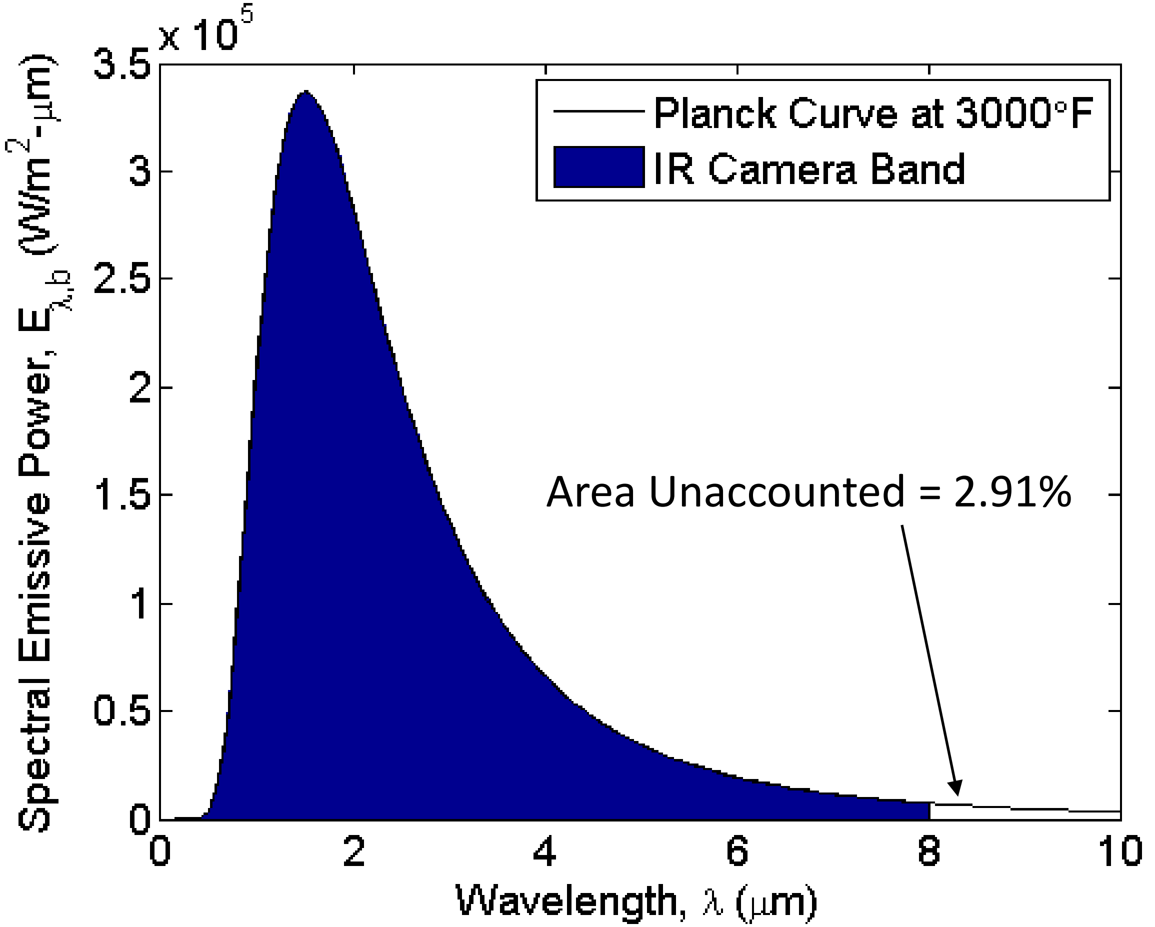


Section 1
2/27/2016
Swirl: 100%
Gain: 1.16

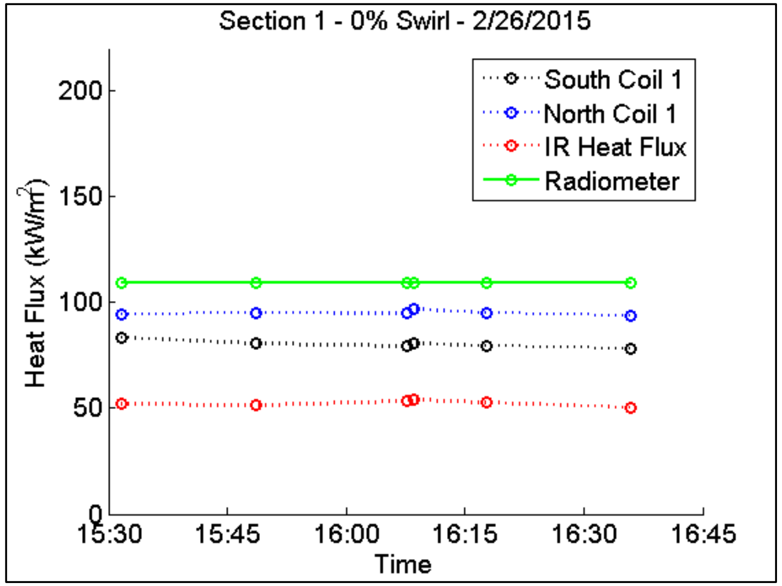
Radiometer Description

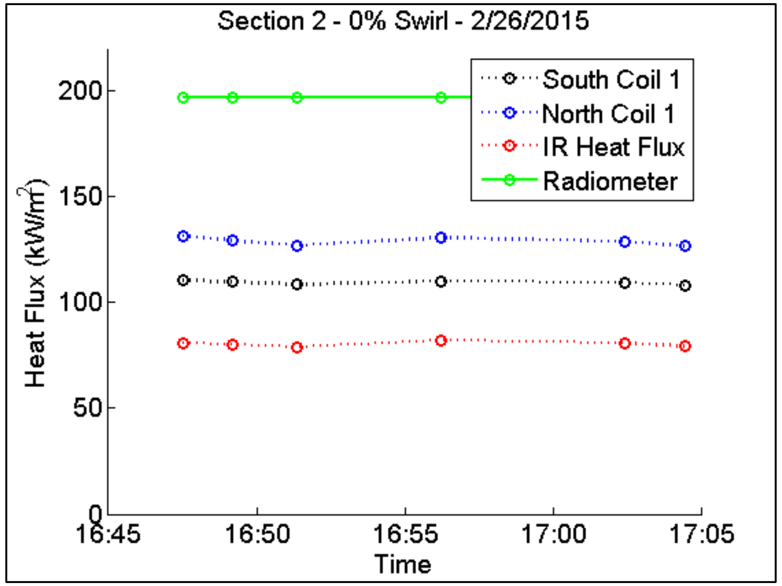
- The entire apparatus is contained in a long, water-cooled sheath
- A CaF_2 lens focuses radiation from the flame onto a thermistor
- A second thermistor accounts for any changes in ambient conditions
- Output voltage from the thermistor is calibrated with a blackbody generator to produce total emissive power, or total heat flux (W/m^2)
  - The wavelength band for the transmittance of the lens is fairly high. Assuming radiation from a flame of 3000°F, this leaves only 3% of the radiation unaccounted.
- Three radiometers took continuous measurements –
  - Except when the IR camera was taking data

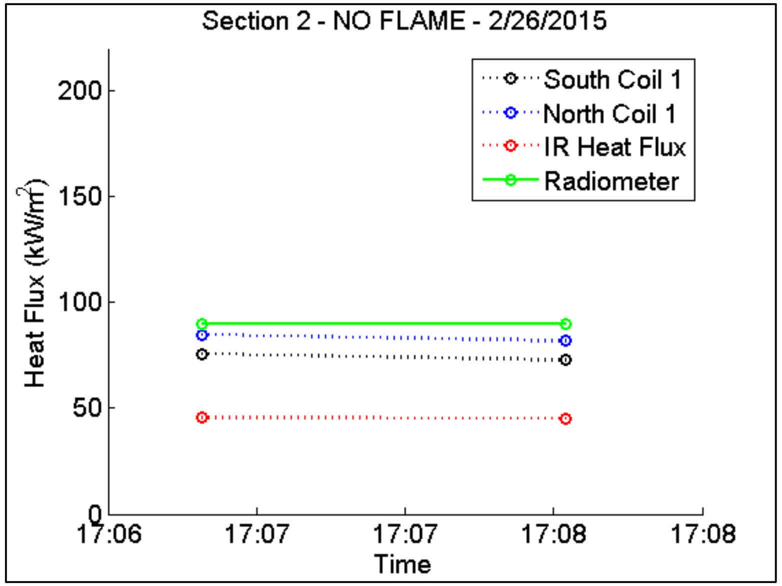


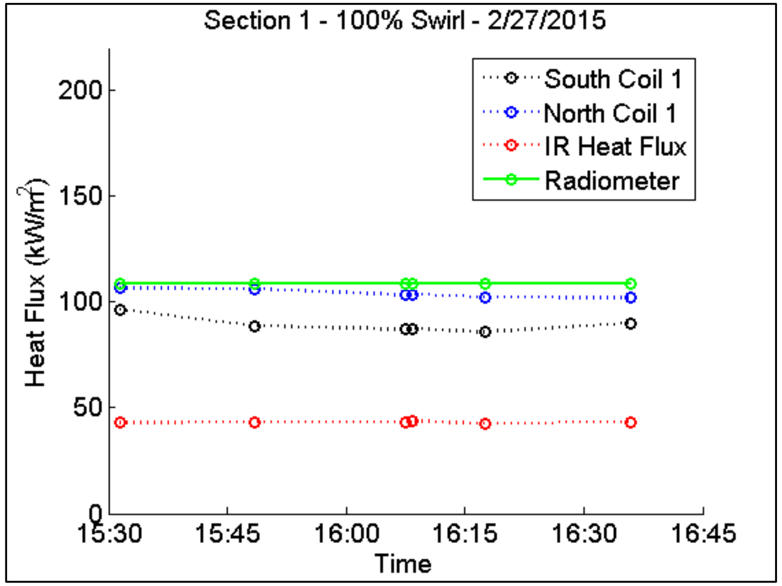


Heat Flux Measurements



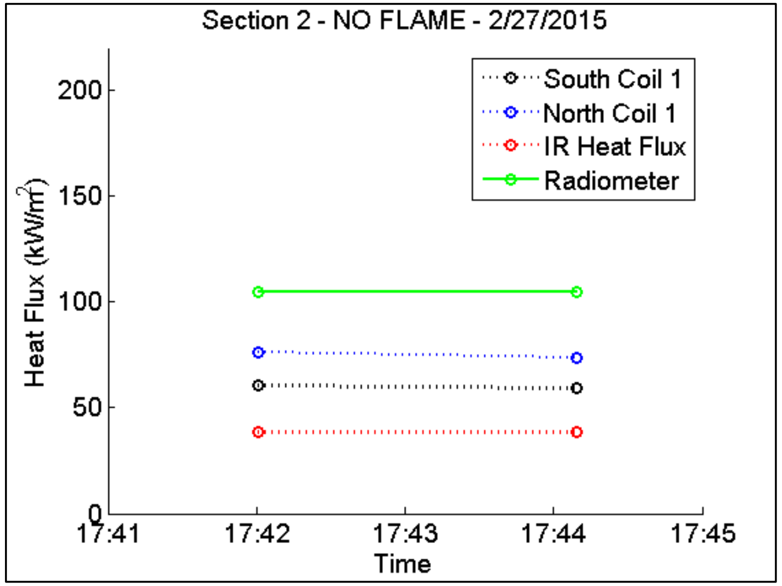






Section 2 – 100% Swirl – 2/27/2015

In changing ports to get the IR measurements, the furnace entrained air and valid measurements could not be taken



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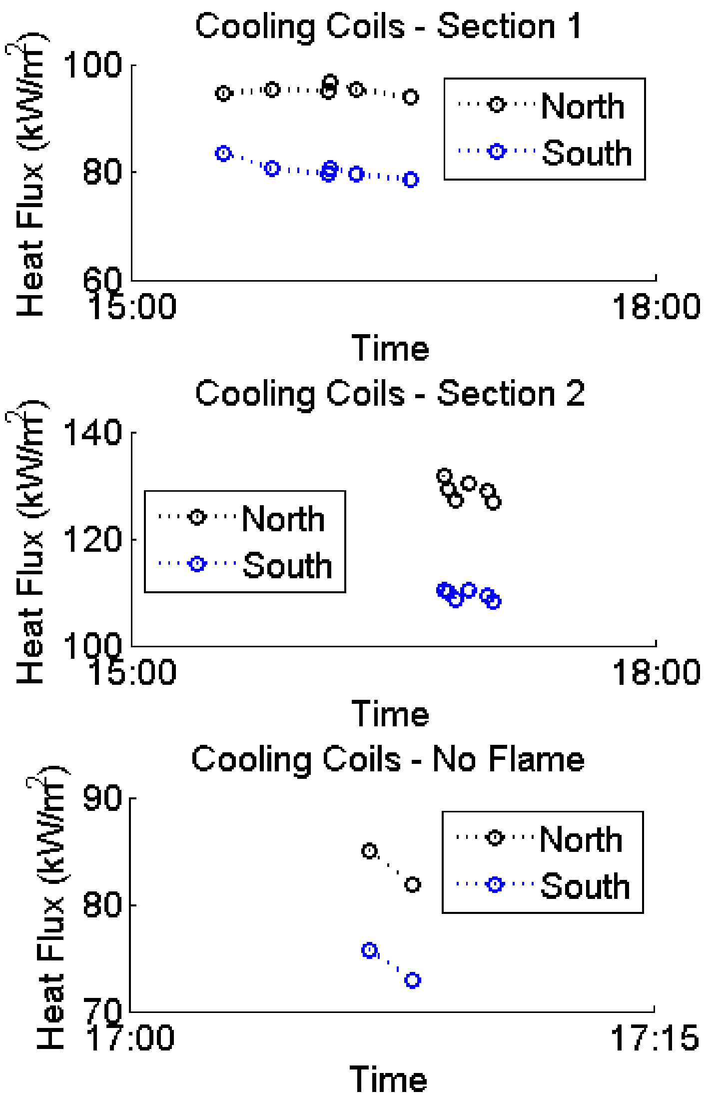
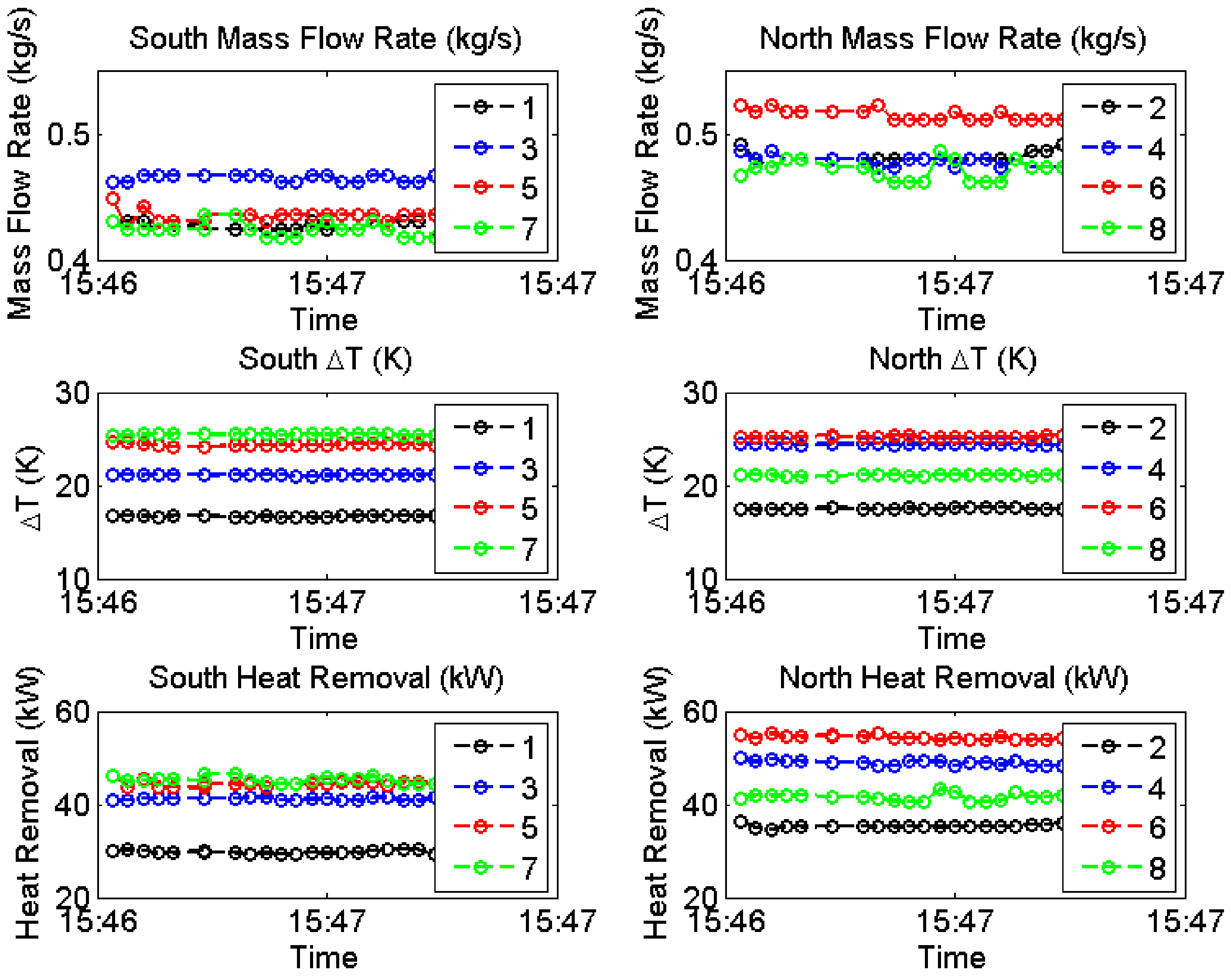
Coils – North vs. South





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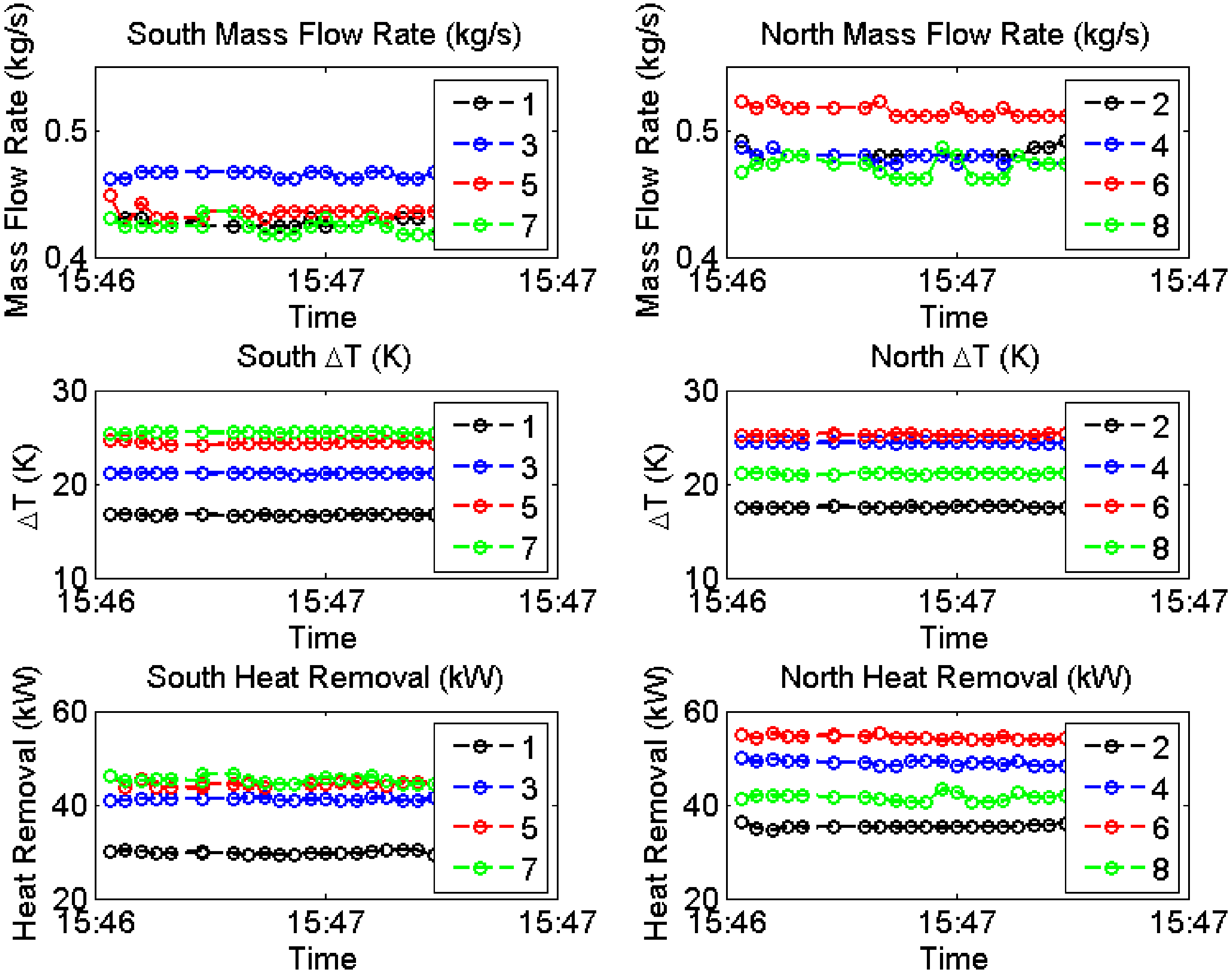
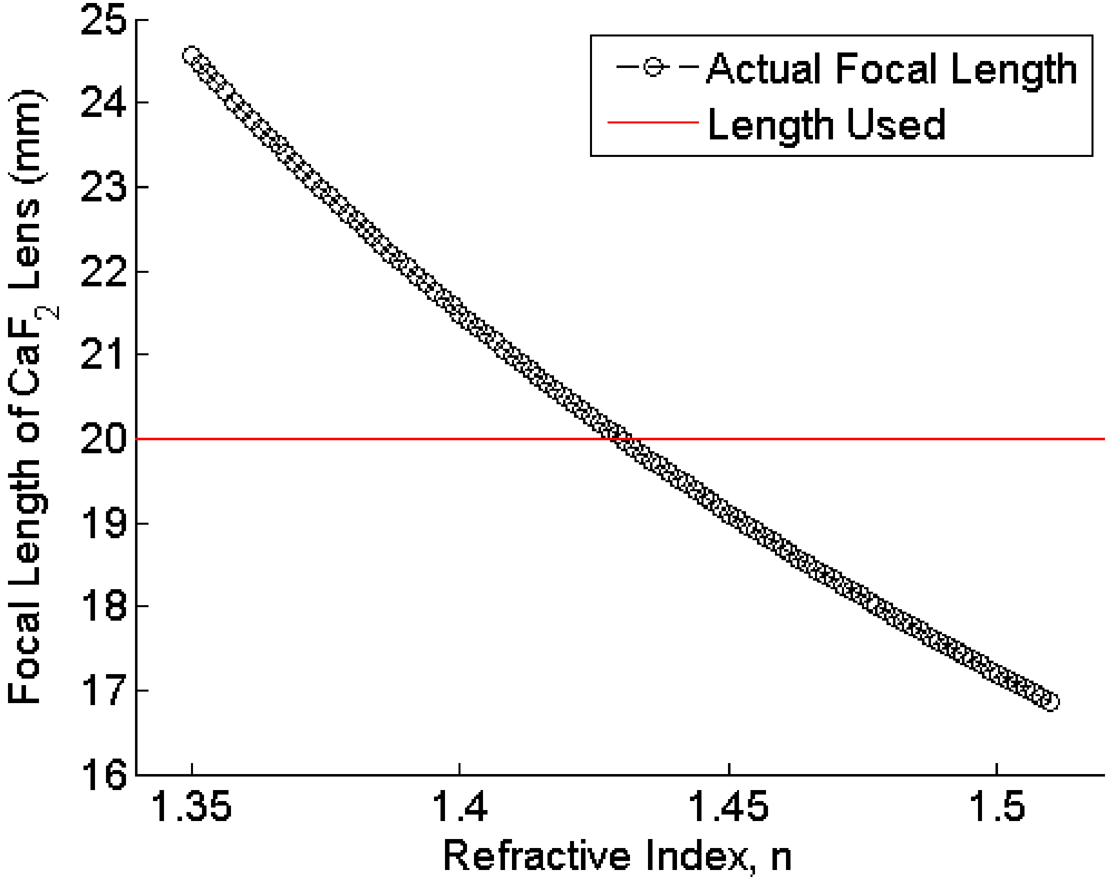
Coils – North vs. South

- Mass flow rates are significantly higher between the South and North coils
- The change in temperatures are fairly similar between South and North coils
- Thus, there is significantly larger heat removal on the North side
- This discrepancy points to an asymmetry in the flame, which can cause either:
    - A leaning of the flame to one side, resulting in an increase in heat transfer to one side
    - An increase in deposition to the coils on one side, resulting in less heat transfer to the coil



Radiometer Upgrades

- The results from this campaign led to an increased scrutiny of the radiometer measurements.
- For the next campaign (June 2016), the following updates have been made:
  - Temperature control of the Wheatstone bridge circuitry
    - In this campaign, the circuitry was not temperature controlled and changes in ambient temperature caused significant errors in the reading
  - Controlled thermistor and lens alignment
  - Regulated the excitation voltage for the Wheatstone bridge
- Also, will analyze the change in focus area as a function of wavelength to ensure that the thermistor remains in focus



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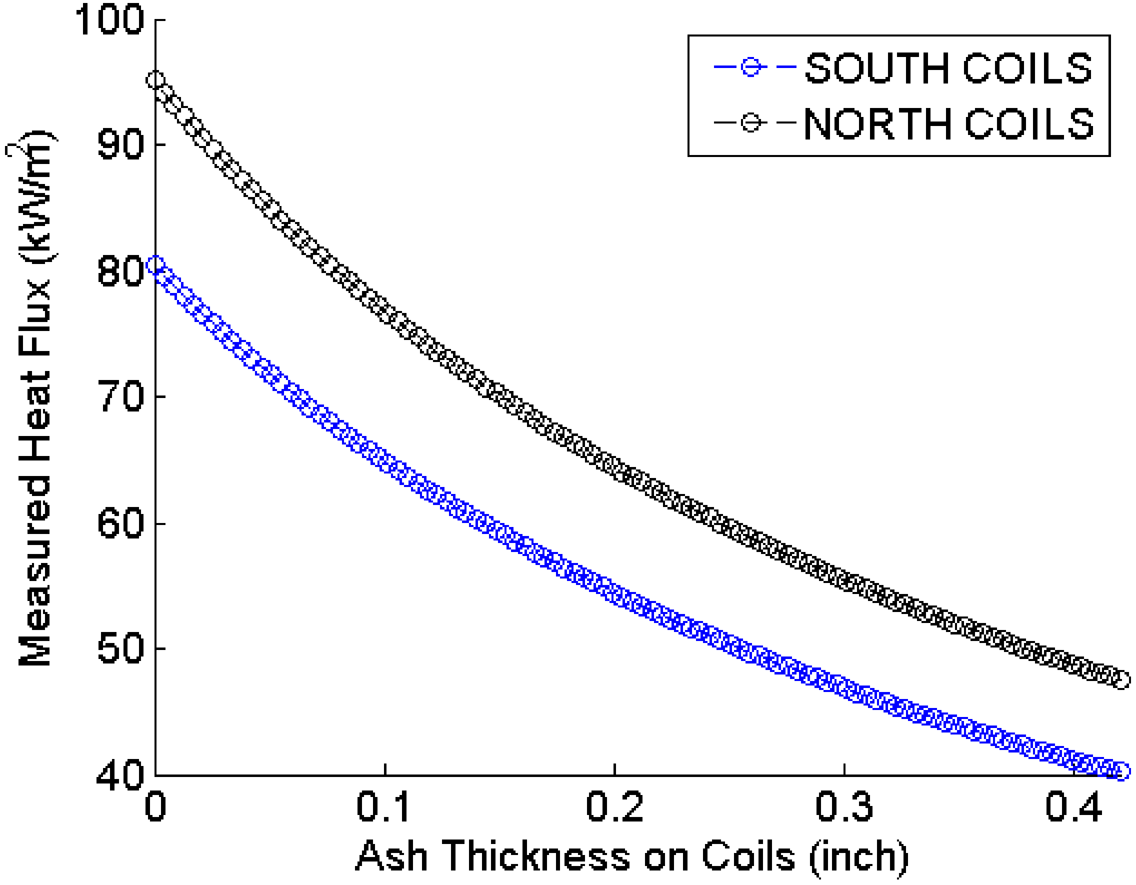
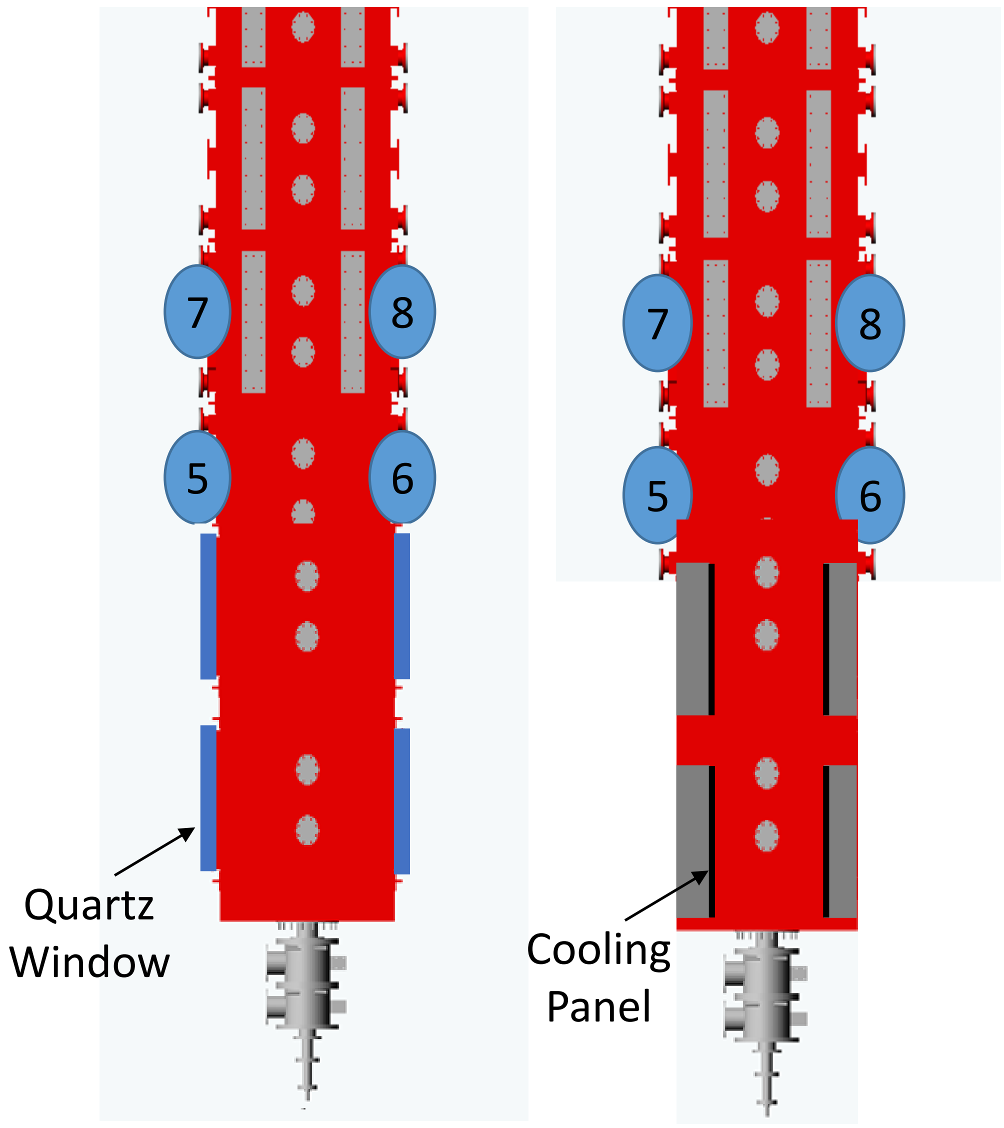
Coil Heat Removal to Heat Flux

- In order to be converted into heat flux, the heat removal of the cooling coils needs to be divided by the surface area:
  - $q"_{removed}\ [kW/m^2] = \frac{Q_{removed}}{SA}$
- However, the surface area of the coils is constantly changing as the deposits continually build and slough off
- This deposit thickness has a significant effect on the heat flux calculation
- An instrument model for the cooling coils – one that accounts for the deposits as a function of time– is needed
  - The thicker the deposit, the higher the surface temperature and the lower conductivity, which results in a lower net heat flux to the coil



Conclusions and Future Work

- **Conclusions**
  - There are significant differences in the results recorded by the three different methods
    - Updates to the instruments and instrument models are needed in order to reconcile the different magnitudes recorded by the various instruments
  - North and South coils had uneven heat removal
    - This may be a result of an asymmetry in the flame which could result in an asymmetry in heat transfer and deposition on the cooling coils
  - Radiometer results led to increased scrutiny of the technique
    - Upgrades to the instrument have been made
  - The surface area of the cooling coils had a strong impact on the calculation of heat flux to the coils
    - As this surface area varies during operation, a better way to estimate this area and the effect on heat transfer is needed
- **Future Work**
  - Campaign: June 2016
    - New optical access
    - New, soot-blown, cooling panels to measure heat flux
    - Newly upgraded radiometers
  - Detailed instrument models for all techniques



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