Pilot-Scale Investigation of Heat Flux, Radiation and CO Distribution from an OxyCoal Flame

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U.S. Department of Energy, Agreement # DE-NA0002375

2015 AIChE Annual Meeting

Presentation Road Map

- Project Overview
- Experimental Setup
- Initial Modeling Efforts
- Heat Removal and Radiation Data
- Summary & Conclusions
- Questions

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CARBON CAPTURE
MULTIDISCIPLINARY
SIMULATION CENTER

Project Objective

Implementation of exascale computing with V&V/UQ to more rapidly deploy a new technology for providing low cost, low emission electric power generation

V&V/UQ – Verification & Validation with Uncertainty Quantification

ALSTOM

SCI www.sci.utah.edu

Berkeley UNIVERSITY OF CALIFORNIA

NNSA National Nuclear Security Administration

Institute for CLEAN AND SECURE ENERGY THE UNIVERSITY OF UTAH

BYU BRIGHAM YOUNG UNIVERSITY

Project Objective

- V/UQ performed on data produced at 4 scales
  - Bench-scale, Lab-scale (~100 kWth), Large-scale (~1-5 MWth), Pilot-scale (~15 MWth)
- Ultimate goal to design a next-generation 350 MWe oxy-coal boiler
- Year 1 of a 5 year program is complete
- Focus here will be on a 1.5 MWth data set

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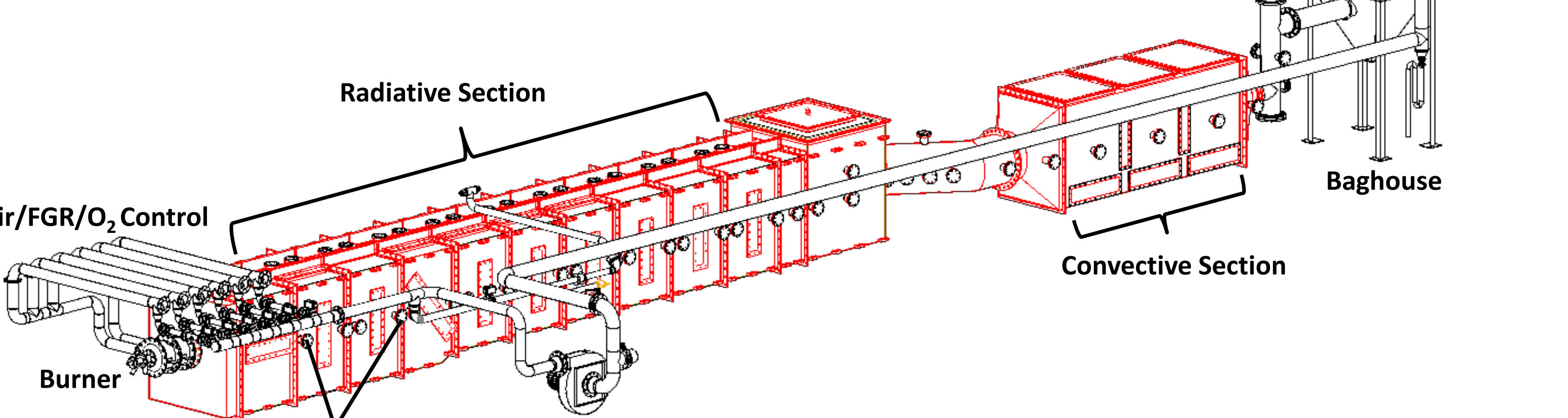
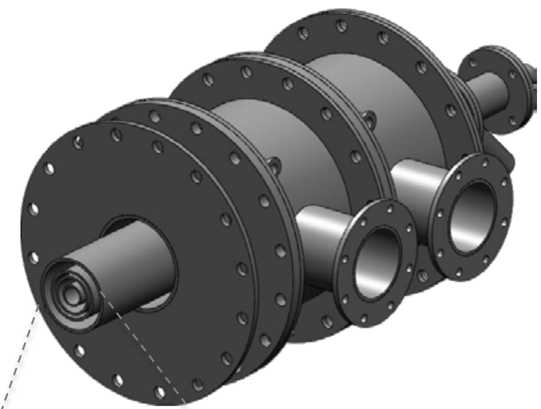
5.0 MBtu/hr Pilot-Scale Furnace (L1500)

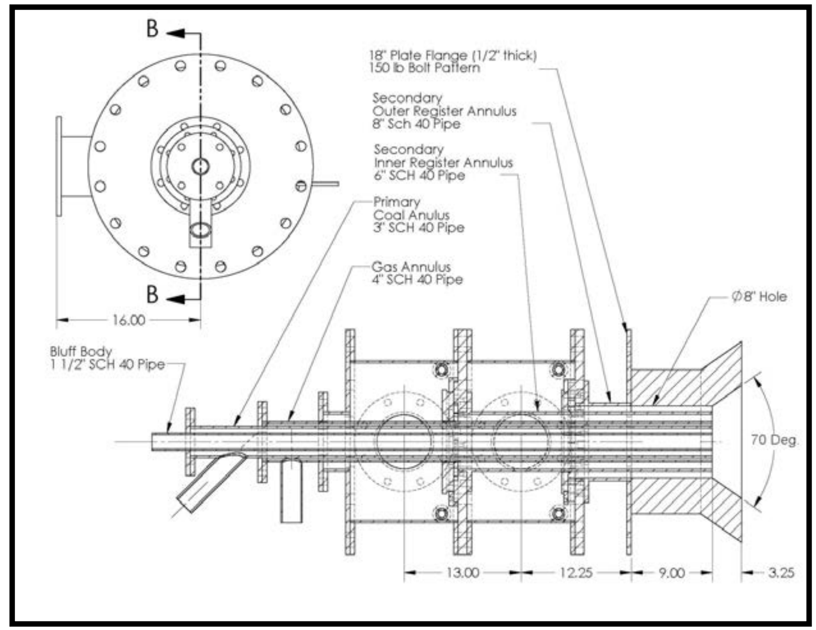
Unique L1500 Capabilities:

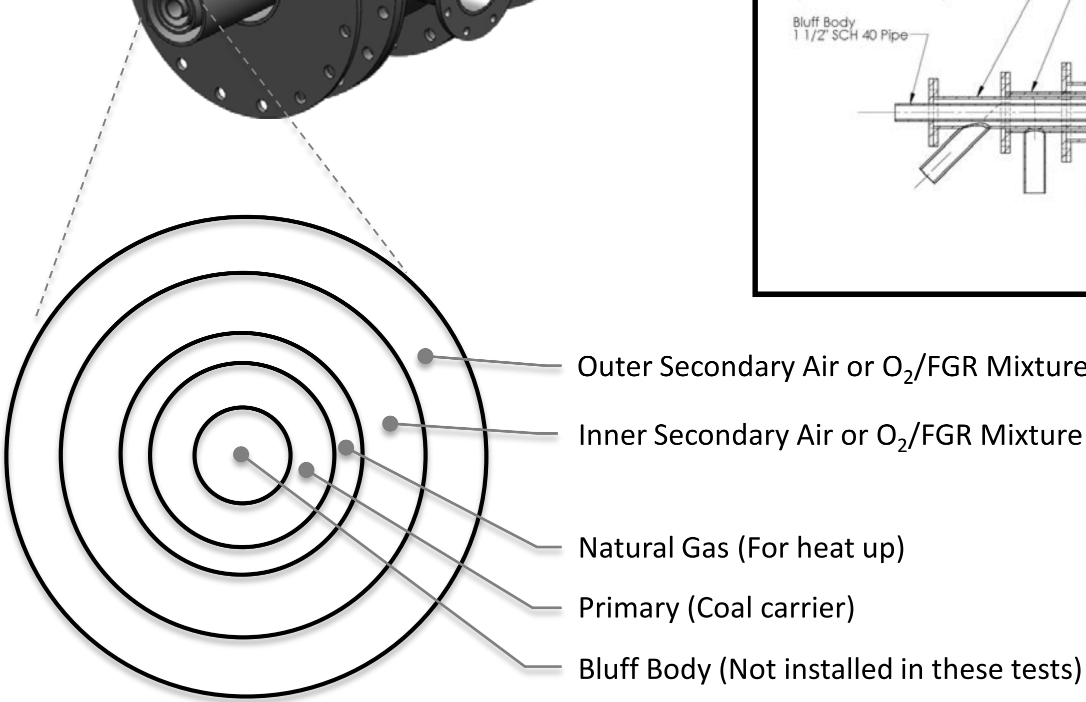
- Realistic Burner Turbulent Mixing Scale
- Realistic Radiative Conditions
- Realistic Time – Temperature Profile



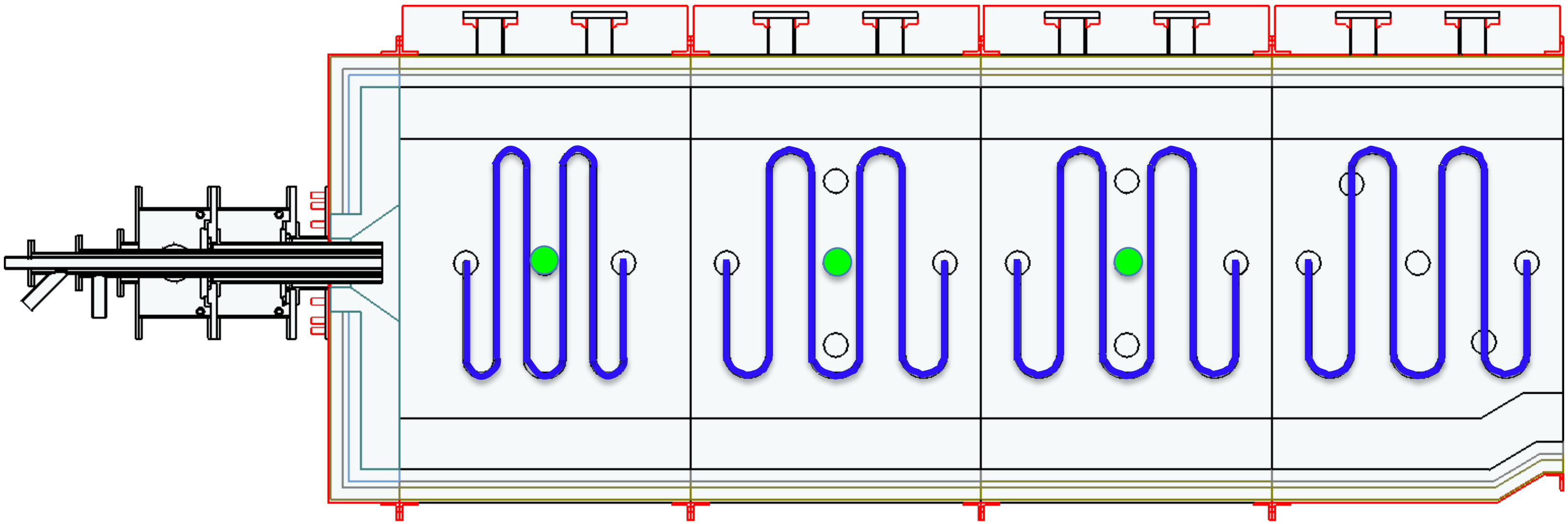
Dual Register Low-NO_x Burner (LNB)







Furnace Cooling Coils and Plates

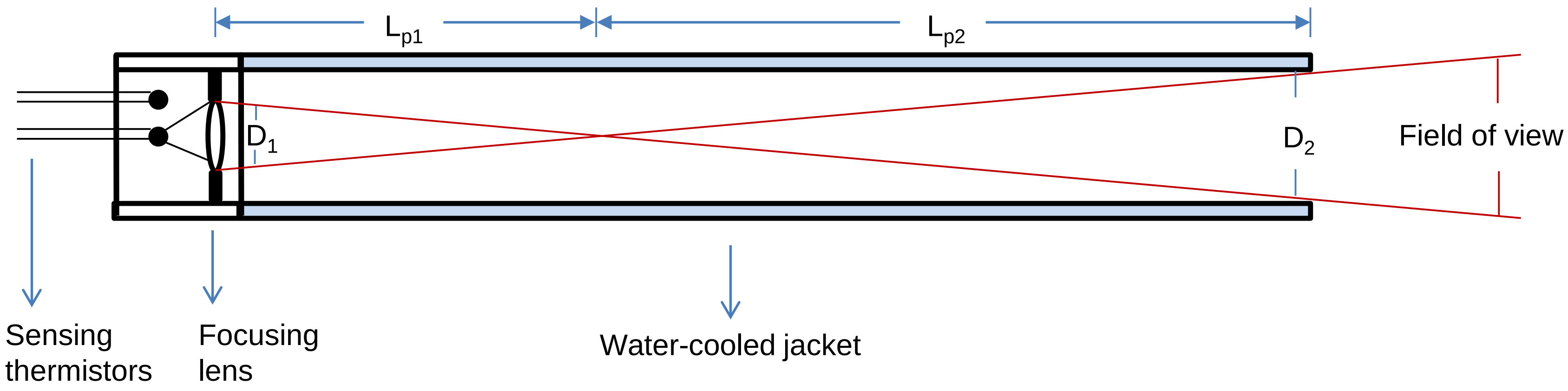


Cooling Coils (8 installed)

Cooling Plates (3 installed)

Heat removal by cooling surfaces is determined by measuring cooling water flow and temperature in and out

Radiometer Configuration



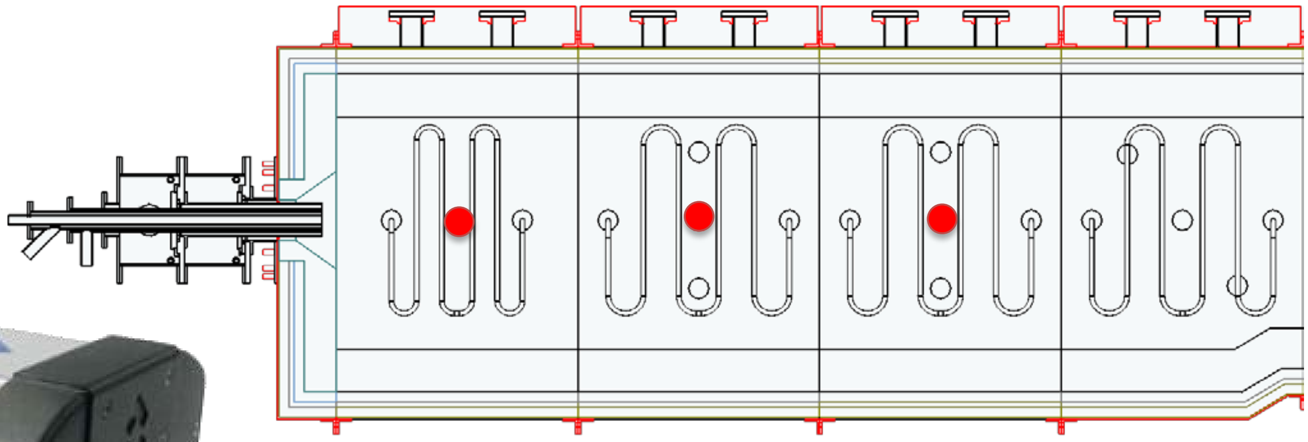
$$\alpha_{\text{field of view}} = 2 * \text{Tan}^{-1}((D_2/2)/L_{p2}) = 2.74$$

Three radiometers are installed opposite the cooling plates. Angle of view Includes only the cooling plate surface

Black body radiator was used to calibrate these devices

Radiometer Configuration

Infrared Heat Flux Measurement



At times placed in one of the first three sections
Across from the cooling plates

FLIR infrared camera in the wavelength range of 3825–3975 nm. The camera was calibrated with a blackbody generator, which is a source of known emission, in order to obtain infrared heat flux data.

Experimental Conditions

Targeted and Actual Conditions

	Units	Target	0% Swirl	100% Swirl
Firing Rate	Btu/hr	3.5		
Coal Rate	lb/hr	297.0	297.0	296.9
Primary FGR	lb/hr	450.2	461.9	461.7
Primary O_2	lb/hr	85.3	86.4	86.3
Inner Secondary FGR	lb/hr	361.9	362.0	362.0
Inner Secondary O_2	lb/hr	105.9	114.0	106.3
Inner Secondary Temp	˚F	500.0	496.2	502.3
Outer Secondary FGR	lb/hr	1448.6	1440.3	1449.2
Outer Secondary O_2	lb/hr	422.6	418.2	418.4
Outer Secondary Temp	˚F	500.0	498.6	501.9
O_2	%	3.0	2.6	2.9
CO_2	%	96.1	85.7	88.2

Difference in CO_2 concentration due to air leakage, which occurs mainly through the FGR recycle fan and is a function of back pressure through the burner. More leakage occurs at 0% swirl condition

Utah Sufco Coal Composition

C	66.9
H	4.5
N	1.2
S	0.4
O	13.6
Ash	7.9
Moisture	5.6
Volatile Matter	40.4
Fixed Carbon	46.1
HHV, Btu/lb	11,765

* all values in mass % unless otherwise specified

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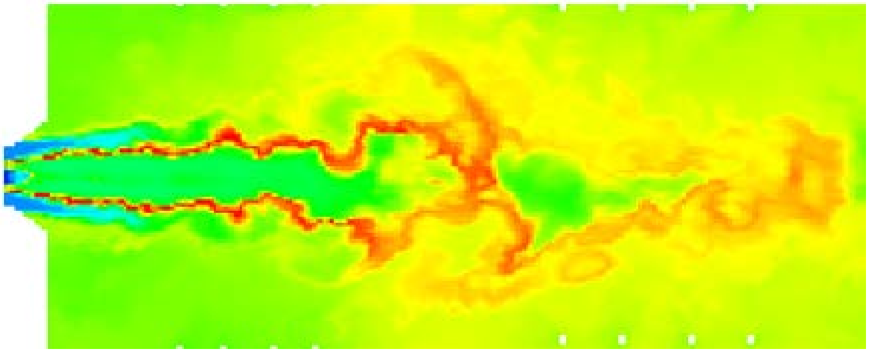
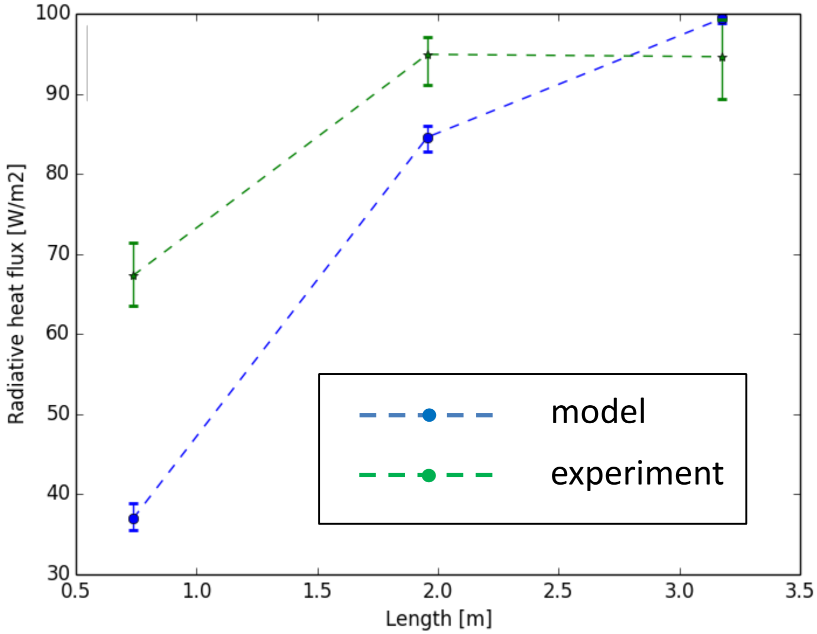
Experimental and Predicted Values

Gas temperature profile predictions using LES model



Prediction and measurement of cooling coil heat flux



We have high confidence in our ability to accurately represent gas-phase and entrained particle properties (emissivity, heat capacity)

Why then the disconnect between model and experiment?

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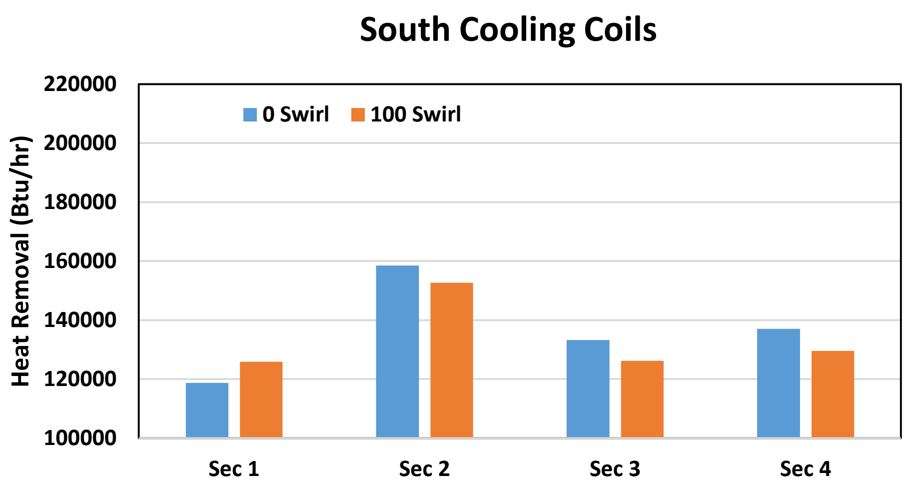
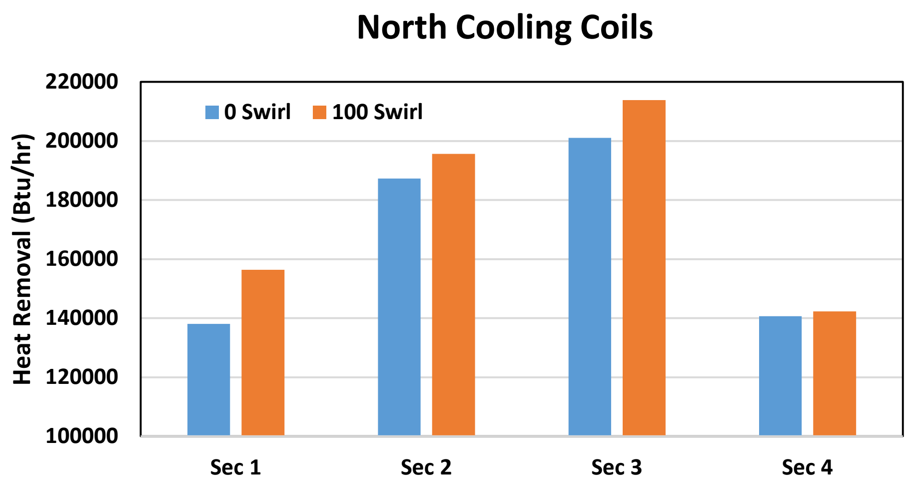
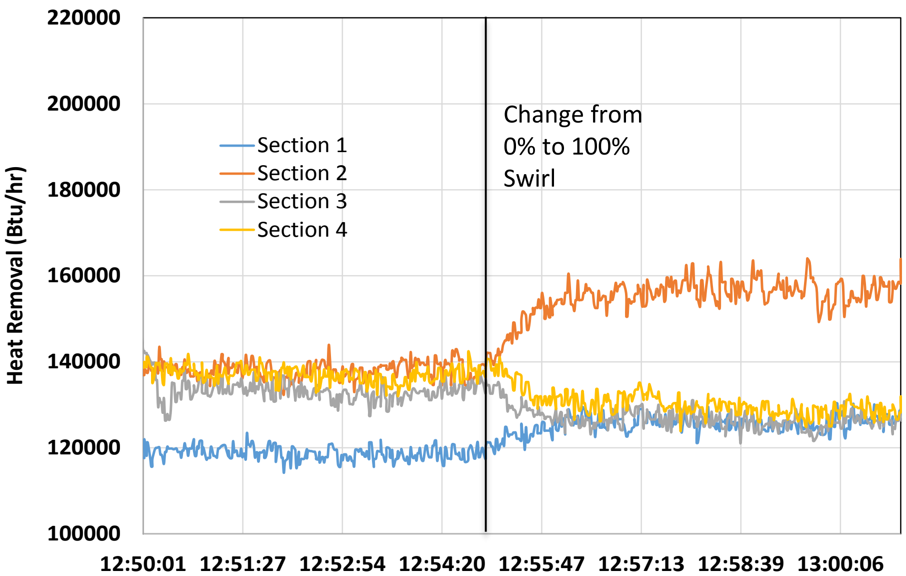
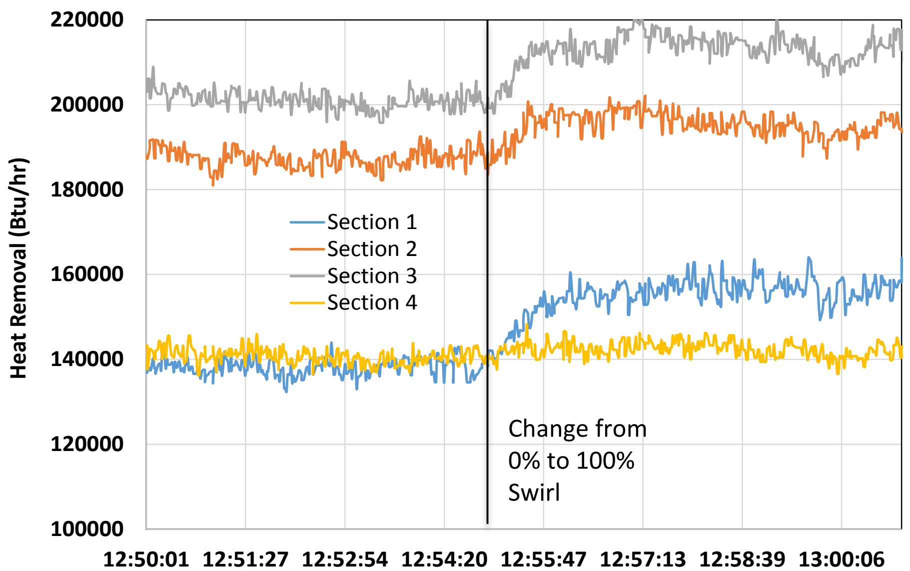
Cooling Coil Data (Change from 0 to 100% Swirl)

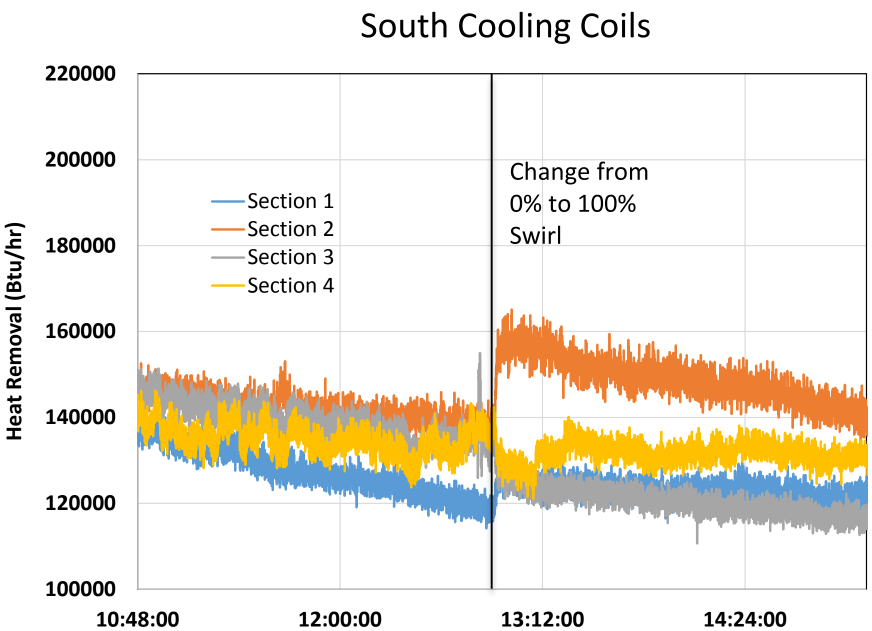


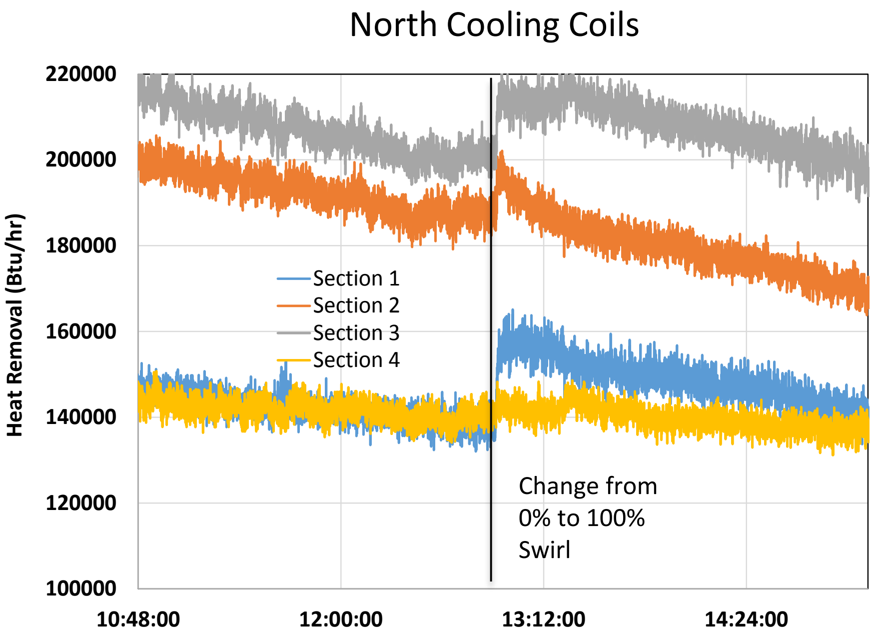






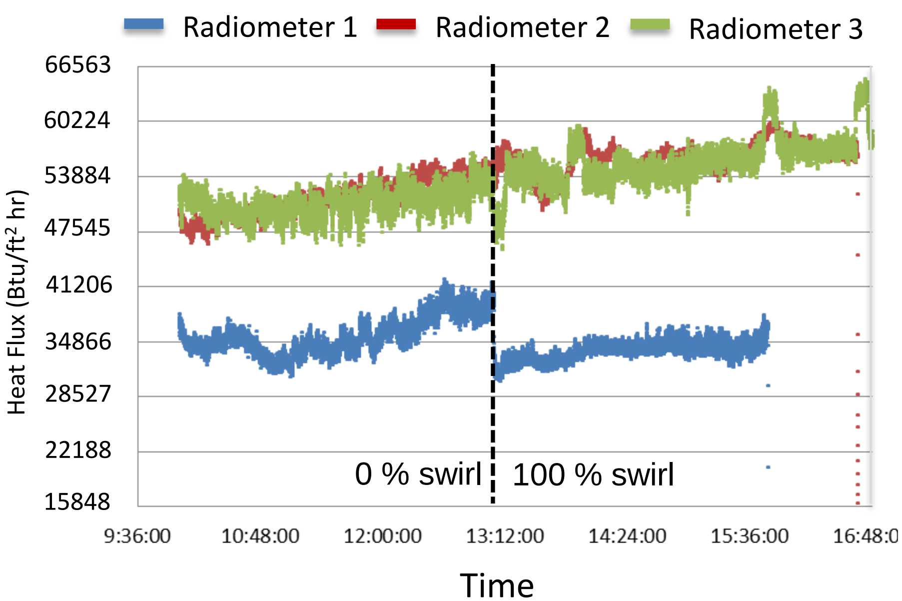
Cooling Coil Data (Long Times)

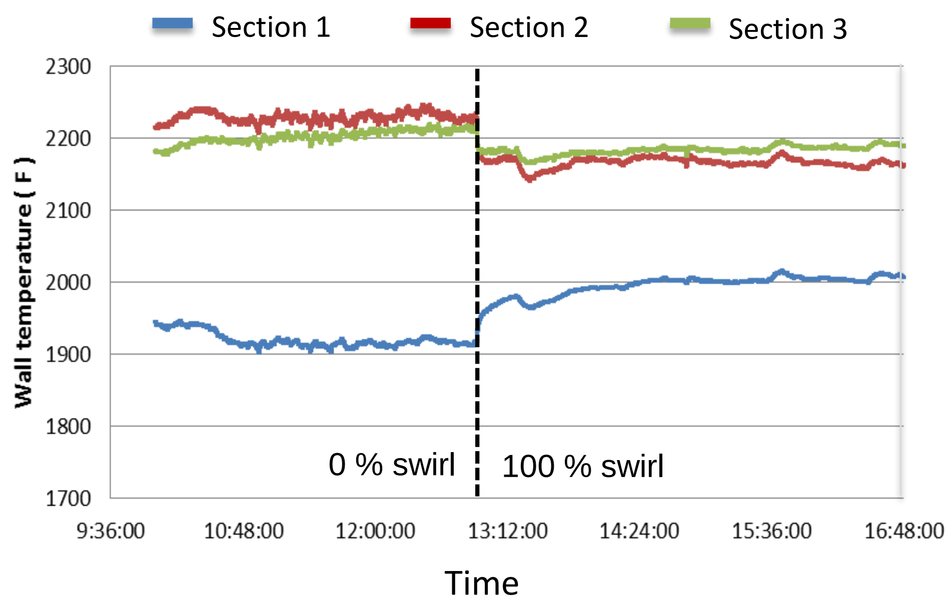




Heat removal through the cooling tubes steadily decreases
This is consistent with increasing insulating layer thickness due to deposition

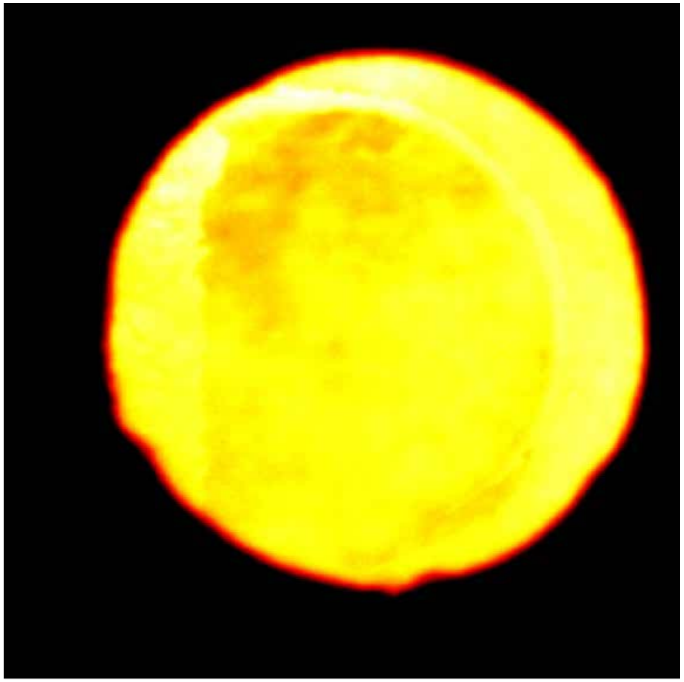
Radiometer Data (Long Times)



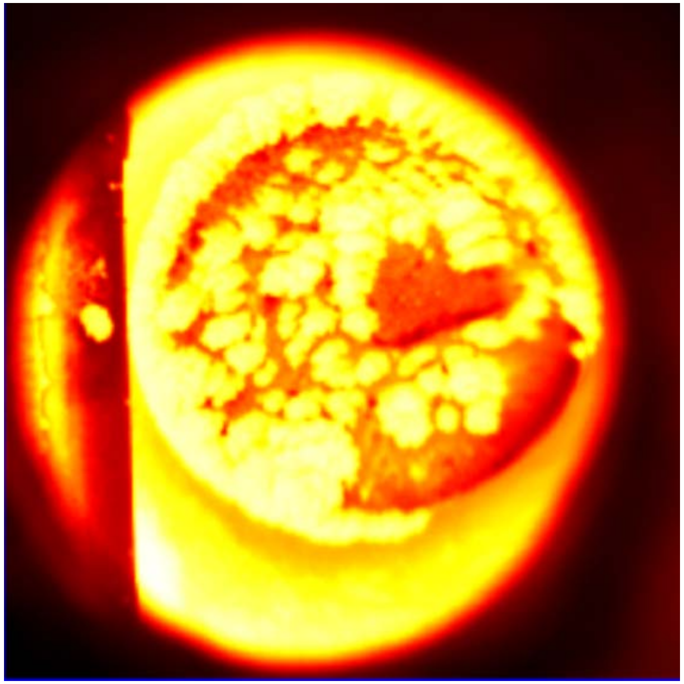


Heat flux to radiometers increases steadily over time
Wall temperatures are stable
Why?

Infrared Heat Flux Data



FLAME



NO FLAME

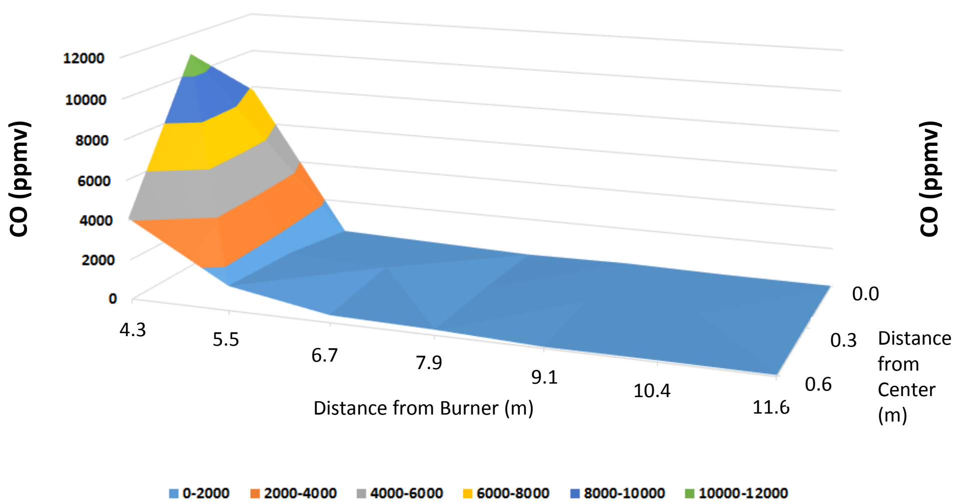
Ash Deposits

Deposit is extensive
For 1 week of testing

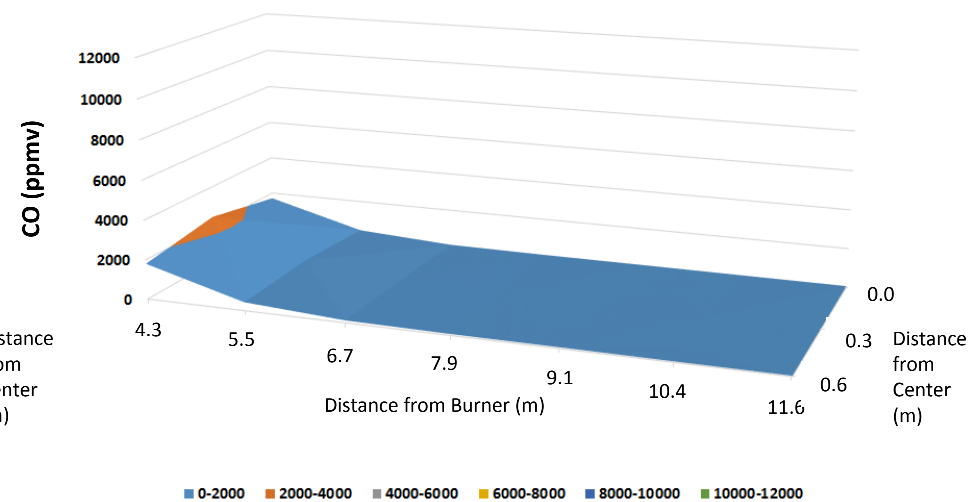
Probably peeled off
during shut down

CO Distribution

0 % Swirl



100 % Swirl



Observations

- An accurate prediction of heat flux through heat exchange surfaces requires:
  - Accurate representation of surface properties which are dominated by deposited mineral mater
  - Emissivity, thermal conductivity and deposit thickness must be known accurately
- Predictive tool must include accurate representation of deposit rate and mineral composition

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Summary & Conclusions

- An oxy-coal combustion data set was produced to be used for V&V/UQ
- Air Leakage was higher than desired and occurs primarily in the recycle fan
- Heat removal through the coils is sensitive to burner changes and consistent with expected flame behavior

Summary & Conclusions

- Heat removal through the coils decreases continuously due to ash deposition on heat transfer surface
- Radiometer data increases continuously due to ash buildup and change in surface emissivity
- CFD Modeling is Underway
  - Trends in heat flux and temperature are well represented
  - Magnitude is not exact
  - Most likely due to assignment of surface boundary conditions (emissivity, conductivity, etc.)

Summary & Conclusions

- Current efforts include:
  - Measurement of the physical properties of the ash containing surfaces
- For the next round of testing the following modifications will be made:
  - Upgrade of recycle fan to reduce air inleakage
  - Addition of soot blowing for cooling tubes and plates

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