



AN INTEGRATED APPROACH TO PREDICTING ASH DEPOSITION AND HEAT TRANSFER IN COAL-FIRED BOILERS

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DOE FE R&D Project Review Meeting
University Coal Research

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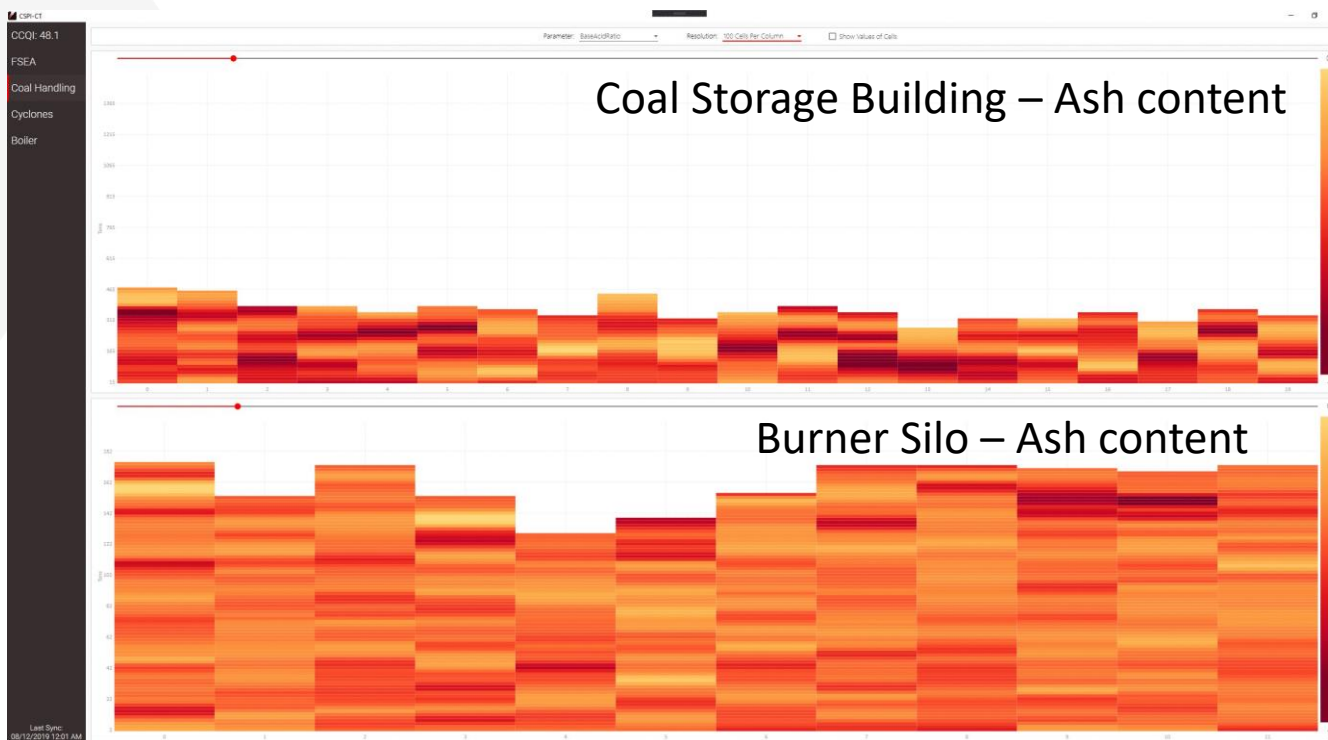


Presentation Overview

- Project Objectives
- Background
- Solution
- Scope of Work
- Accomplishments
- Project Timeline
- Project Organization
- Acknowledgments
- Q&A

Objectives

Advance **on-line** technology to **predict, monitor** and **manage** fireside ash deposition allowing for more efficient operations under a range of **load** conditions and **fuel property** variability

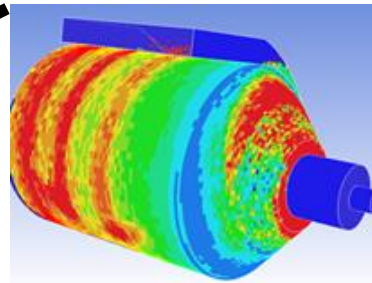
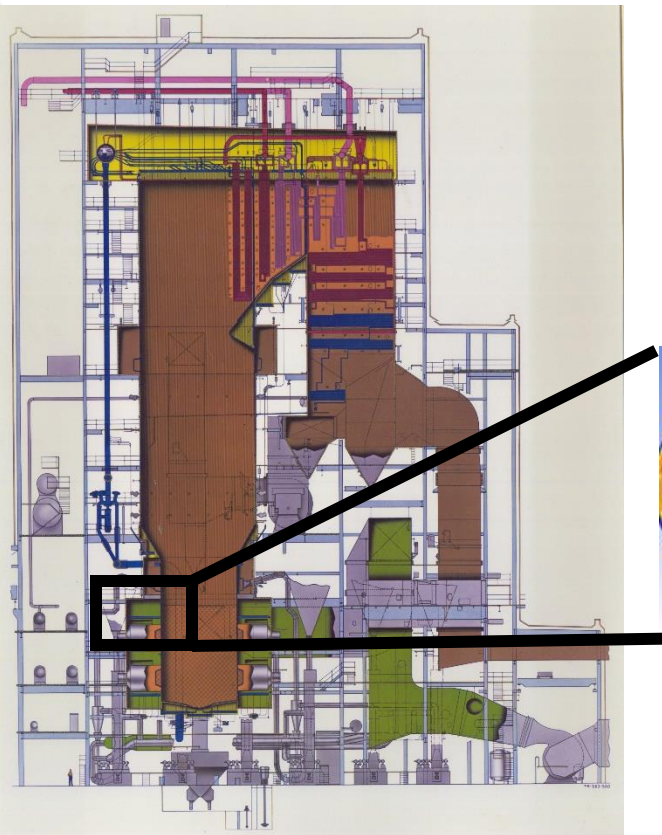


Management Strategy

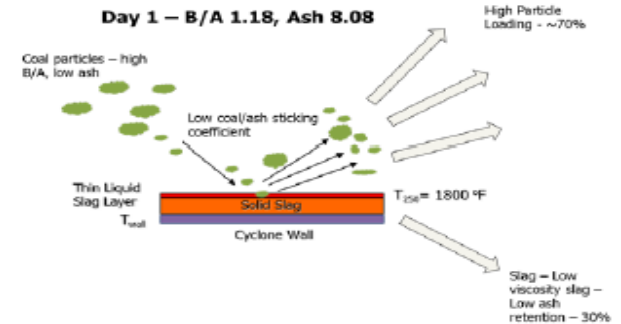
- Fuel sorting and blending can be done upstream
- Optimize operations to compensate for load and fuel properties
- Optimized composition of coal delivered to each burner

Inorganic Transformations and Partitioning in Burner

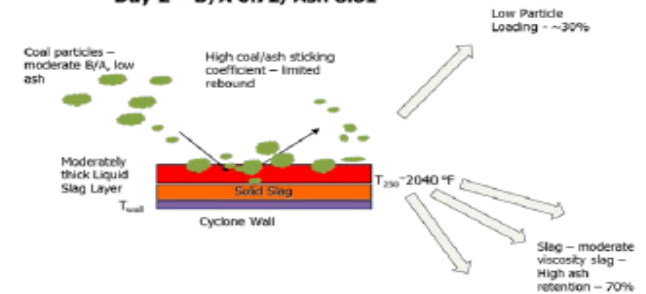
$$(B/A = (\text{Na}_2\text{O} + \text{CaO} + \text{MgO} + \text{K}_2\text{O} + \text{FeO}) / (\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{TiO}_2))$$



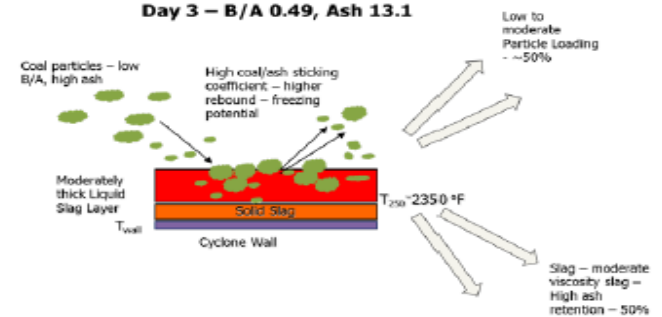
Day 1 – B/A 1.18, Ash 8.08



Day 2 – B/A 0.72, Ash 8.81



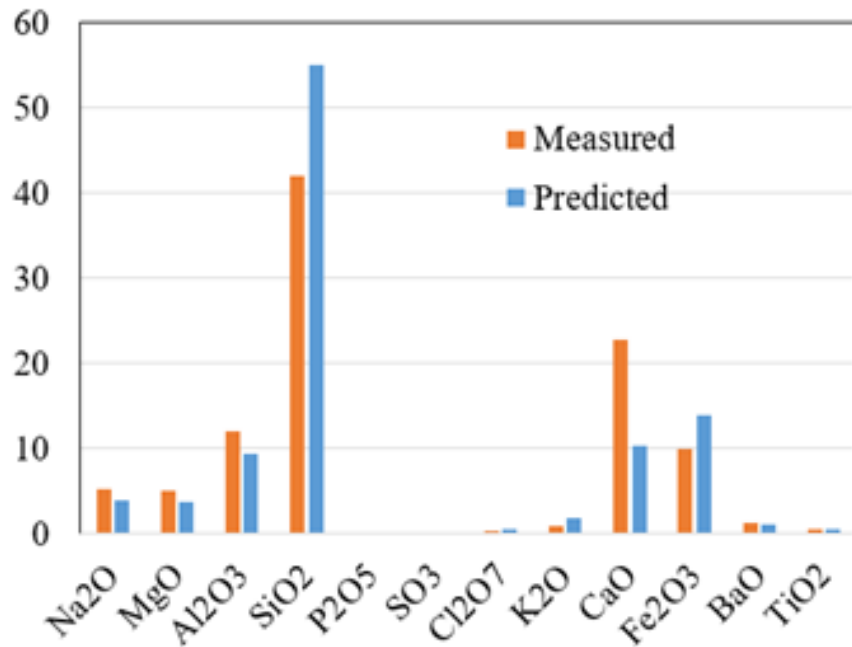
Day 3 – B/A 0.49, Ash 13.1



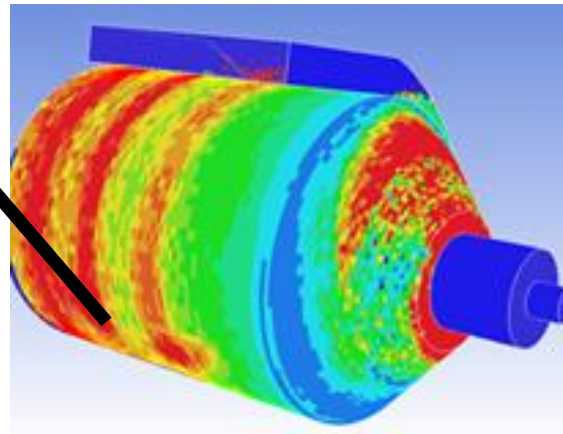
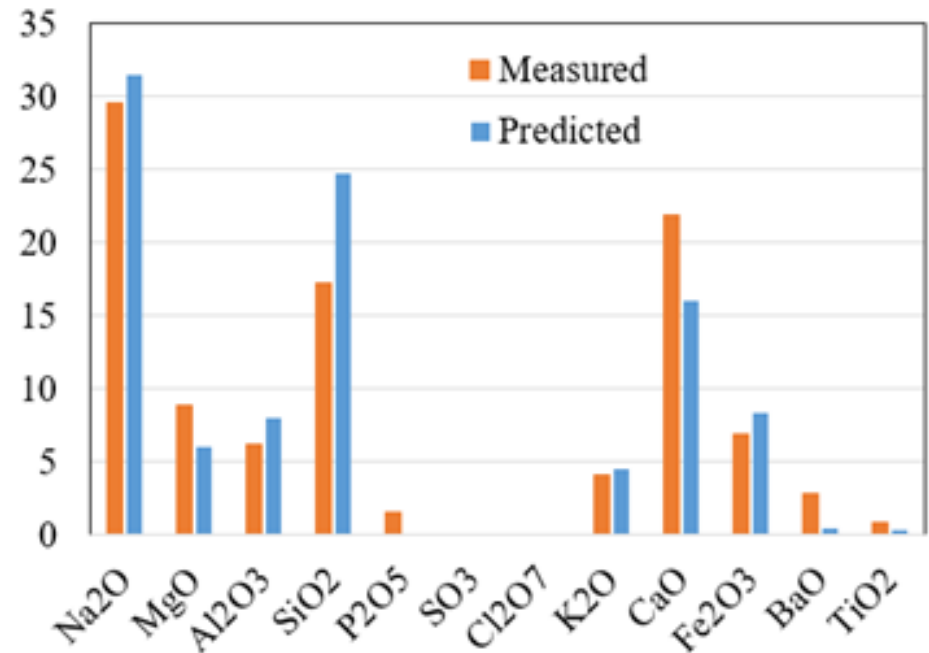
Slag layer thickness as a function of fuel properties.

Cyclone Performance - Slag and Fly-Ash Partitioning

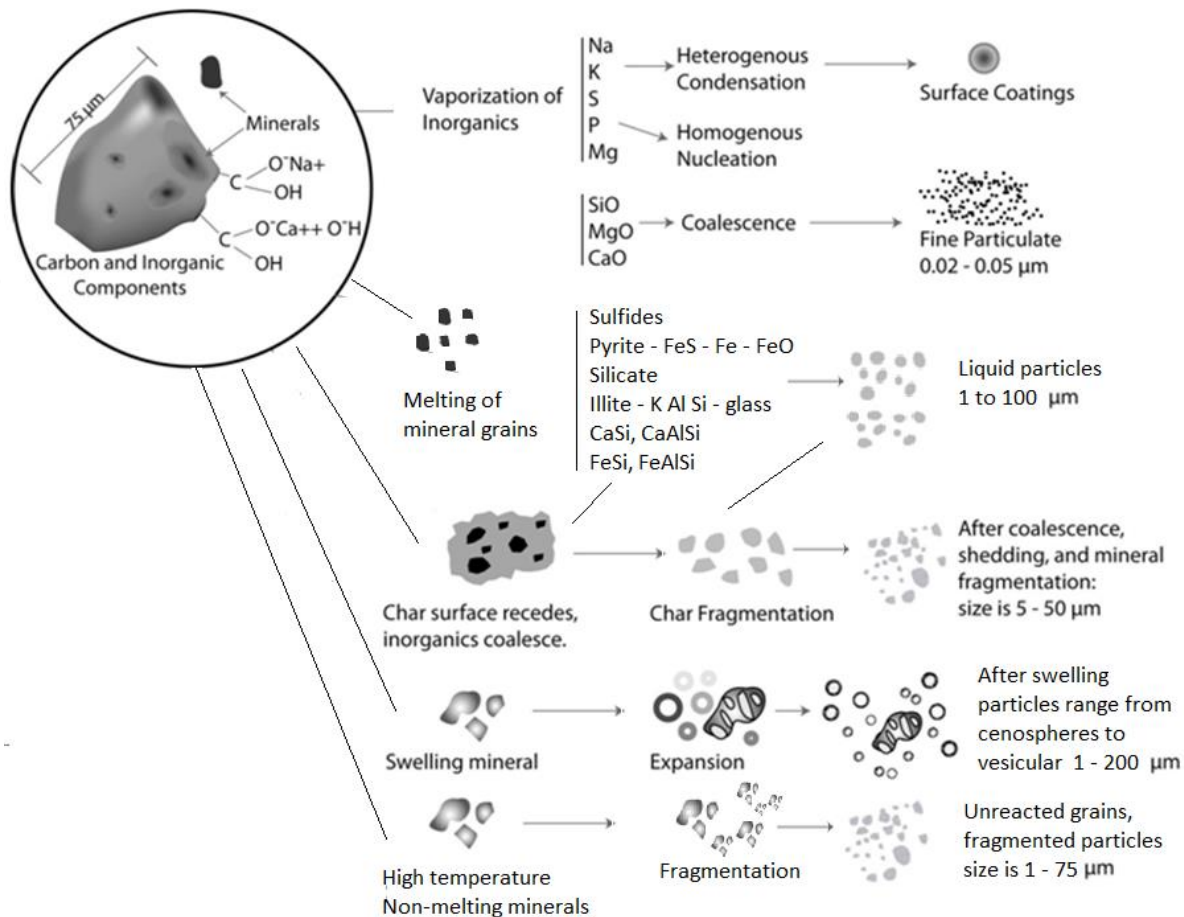
Slag Composition



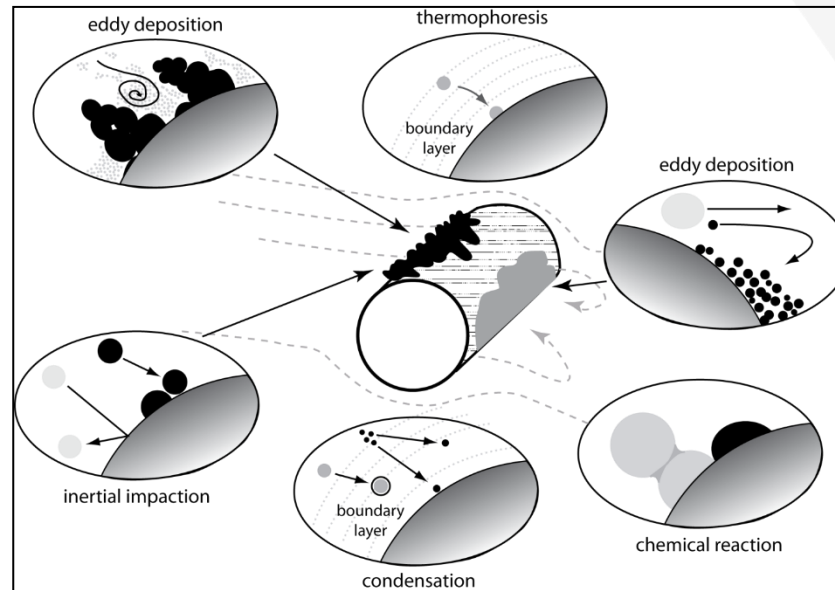
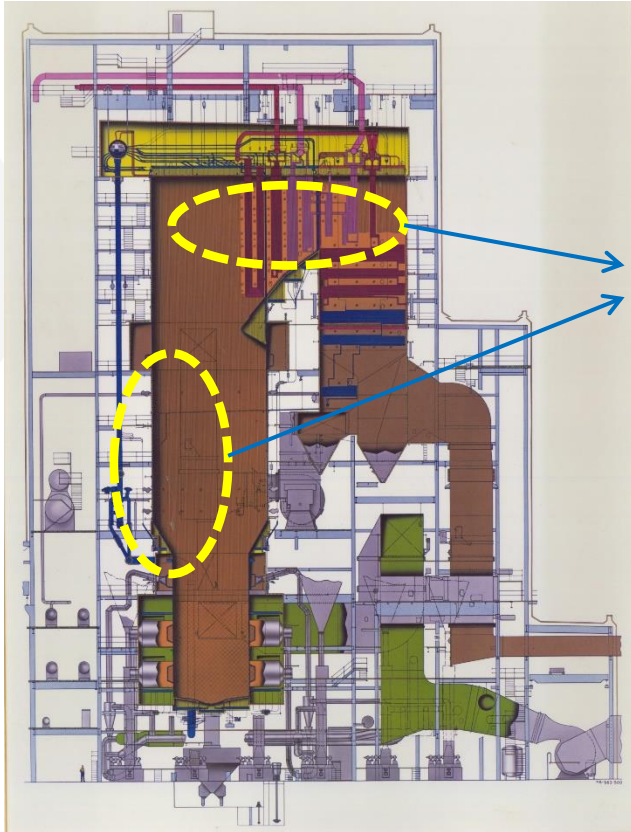
Fly Ash Composition



Ash formation during coal combustion



Deposit Formation – particle transport to walls and convective surfaces



Laursen K, Frandsen F, Larsen OH. Ash deposition trials at three power stations in Denmark. *Energy & Fuels* 1998;12:429–42.

Impaction

Gas velocity

Particle size distribution

Deposition

Gas/particle temperature

Particle composition

Scope of Work

Task 1: Project Management and Planning

Task 2: Combustion Simulations within a Full-Scale Boiler (Otter Tail Power Company (OTPC))

Task 3: Simulation validation using ash deposition data from plant

Task 4: Combustion System Performance Indices and Coal Tracker (CSPI-CT) Tool Refinement

Task 1 Updates

- Kick-off Meeting – October 7th, 2019
- 7 Quarterly Reports submitted to DOE.
- Milestone changes

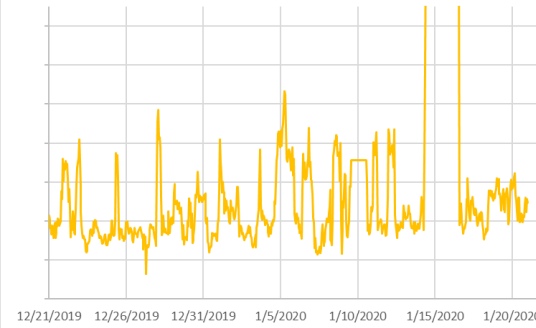
Milestone	Task/ Subtask	Milestone Title and Description	Planned Completion Date	Verification Method
3	Task 2	Combustion simulations within cyclone barrels	4/31/2020 05/31/2021	Completion of simulations within cyclone barrels encompassing 12 representative operational scenarios
4	Task 2	Combustion simulations within a full-scale boiler employing the results from the cyclone barrel simulations	7/31/2020 05/31/2021	Completion of simulations encompassing 12 representative operational scenarios
5	Task 3	Thermal modeling refinement with validation against data from plant	7/31/2021	Thermal modeling refinement and validation of the simulations encompassing the 12 representative scenarios selected in Task 2

Task 2. Combustion Simulations within a Full-Scale Boiler (Otter Tail Power Company (OTPC))

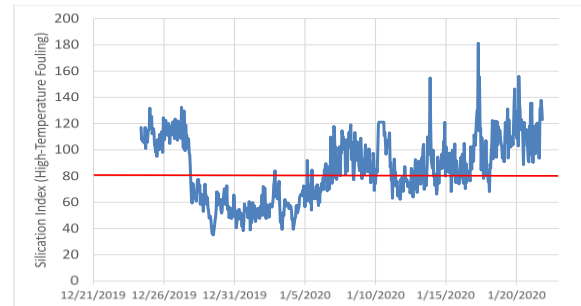
- Database Development
- Cyclone Burner Modification and Testing
- Boiler Geometry Modification and Particle Tracking

Task 2. Slagging and fouling event specific database development and data analysis

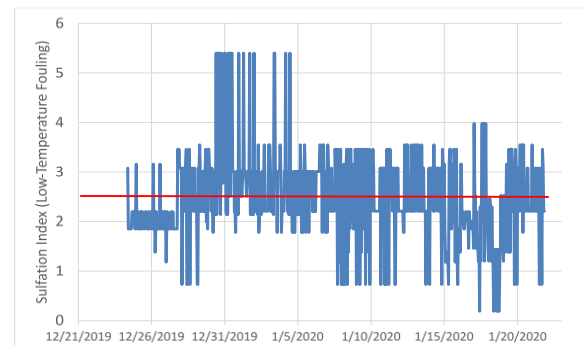
- Database of Plant Operating Parameters/coal properties
- Performance data – CSPI-CT
 - Heat Rate
 - Fireside performance indices
- 12 Cases for simulations
 - Load
 - Boiler Cleanliness
 - Coal Properties
 - Ash Content
 - Base/Acid Ratio (sodium Level)



Heat Rate



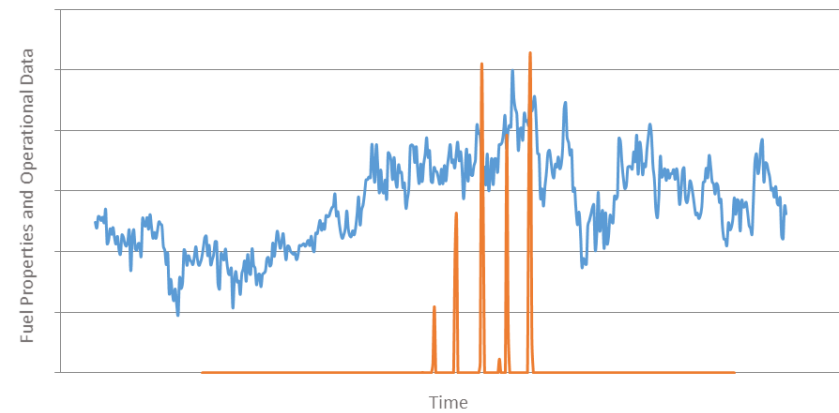
High Temperature Fouling - Index



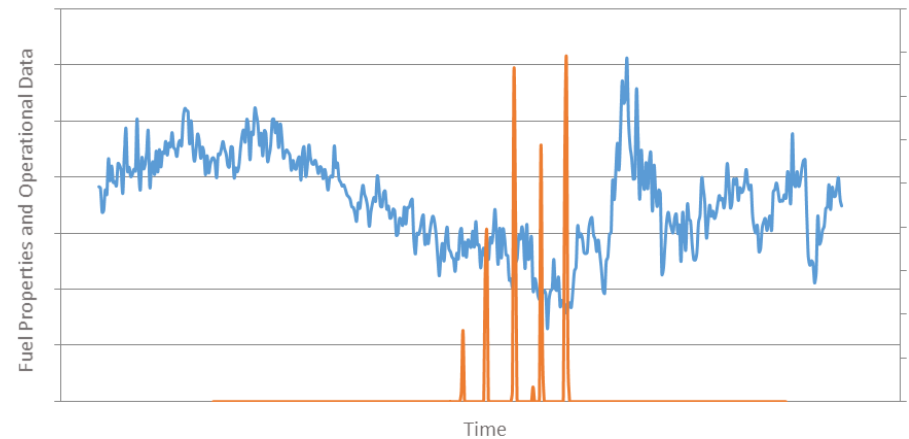
Low Temperature Fouling - Index

Supplementary Fuel Flow

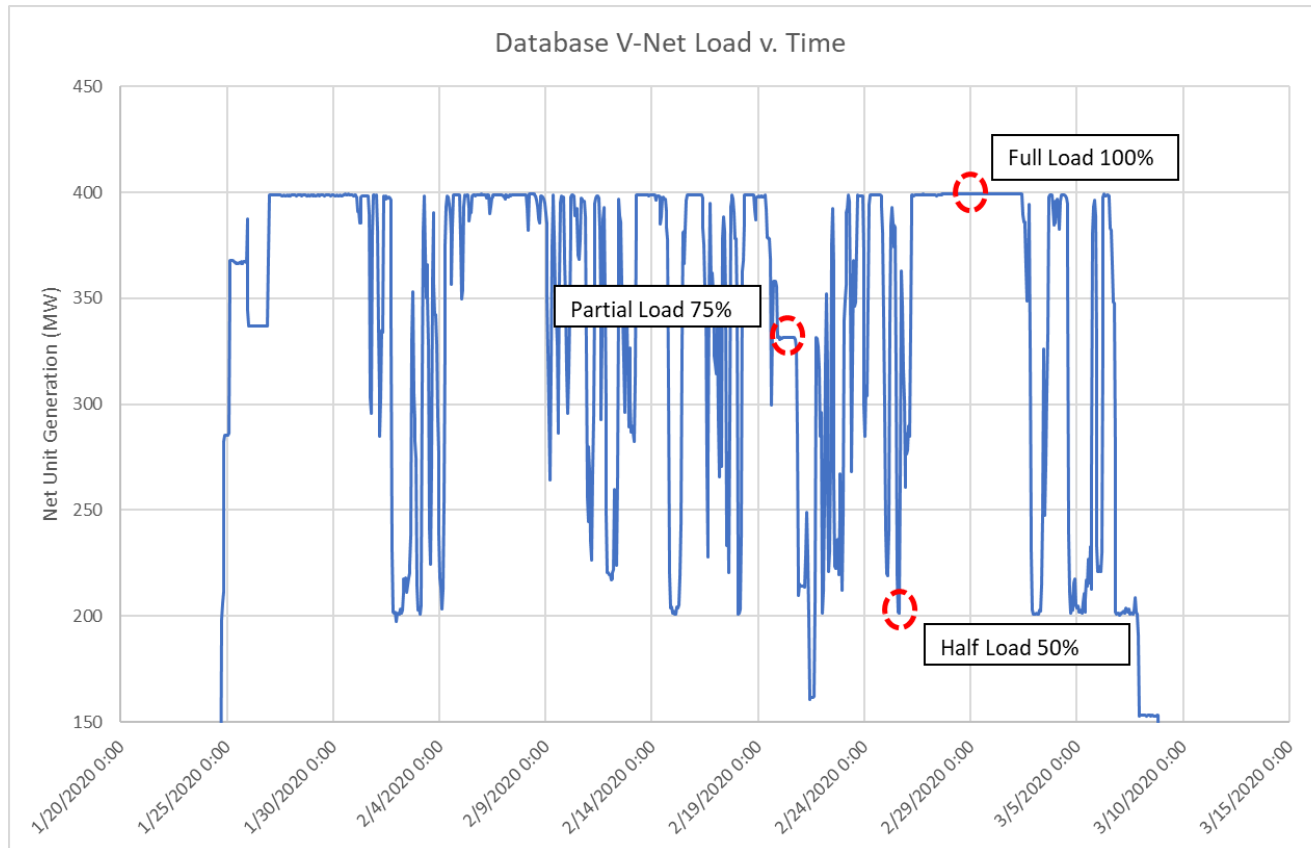
Fuel Ash and Supplementary Fuel Flow v. Time



Fuel Base to Acid Ratio and Supplementary Fuel Flow v. Time



Load Definition Selection

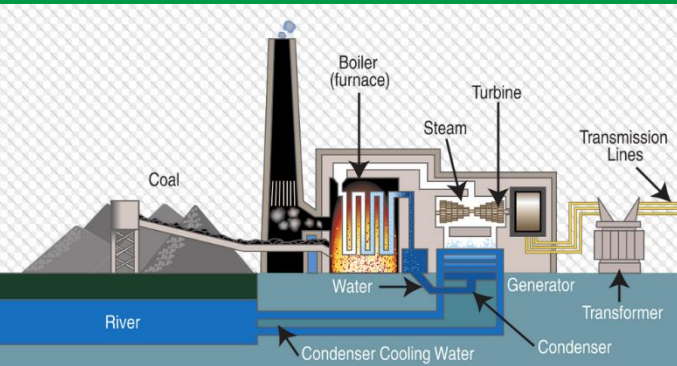


Boiler CFD Model Test Matrix

No.	Na content/ Na flowrate	Load	Time since last shutdown/cleaning outage
1	High	Full	30 Days after cleaning outage
2	Medium	Full	30 Days after cleaning outage
3	Low	Full	30 Days after cleaning outage
4	High	Medium	30 Days after cleaning outage
5	Medium	Medium	30 Days after cleaning outage
6	Low	Medium	30 Days after cleaning outage
7	High	Low	30 Days after cleaning outage
8	Medium	Low	30 Days after cleaning outage
9	Low	Low	30 Days after cleaning outage
10	Medium	Full	15 Days after cleaning outage
11	Medium	Full	30 Days after cleaning outage
12	Medium	Full	45 Days after cleaning outage

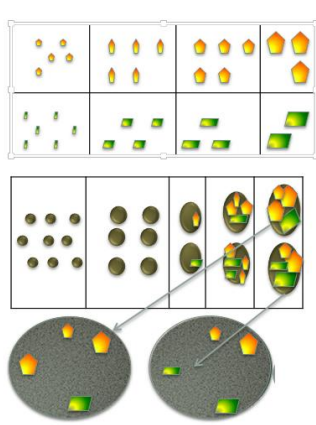
RED indicate cases that have been completed

Solution: Develop Functional Relationships for Incorporation into On-line Prediction Methods



Operational parameters from power plant

1. CCSEM and Ash Chemistry Analysis to generate mineral groupings and relative sizes
2. Mineral groups are placed in the coal particles to conform to the total ash analysis



CCSEM, PSD of parent fuels

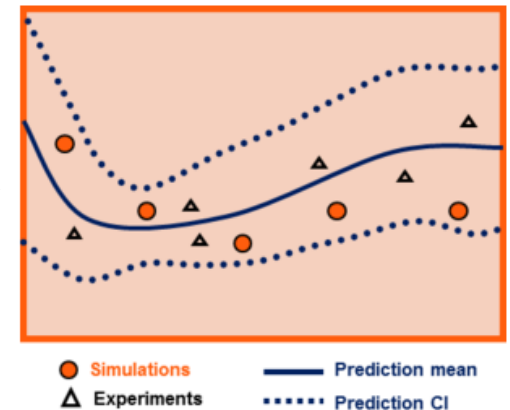
MICROBEAM
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Add-on modules:

High fidelity **gas radiative property models**
Composition dependent particle radiative properties
Slag/Deposition models to predict partitioning rates, composition
Conjugate heat transfer modeling of steam tubes

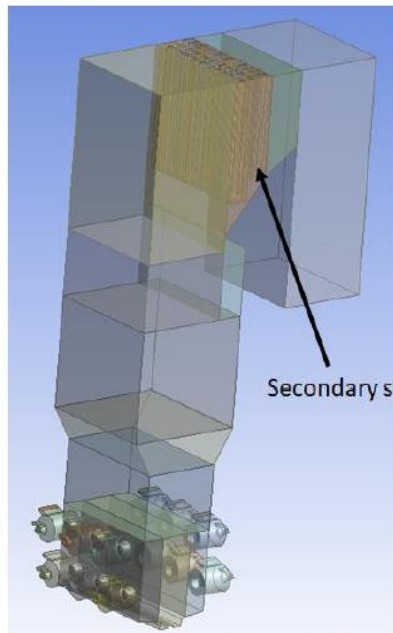
CFD

Operational Relationships

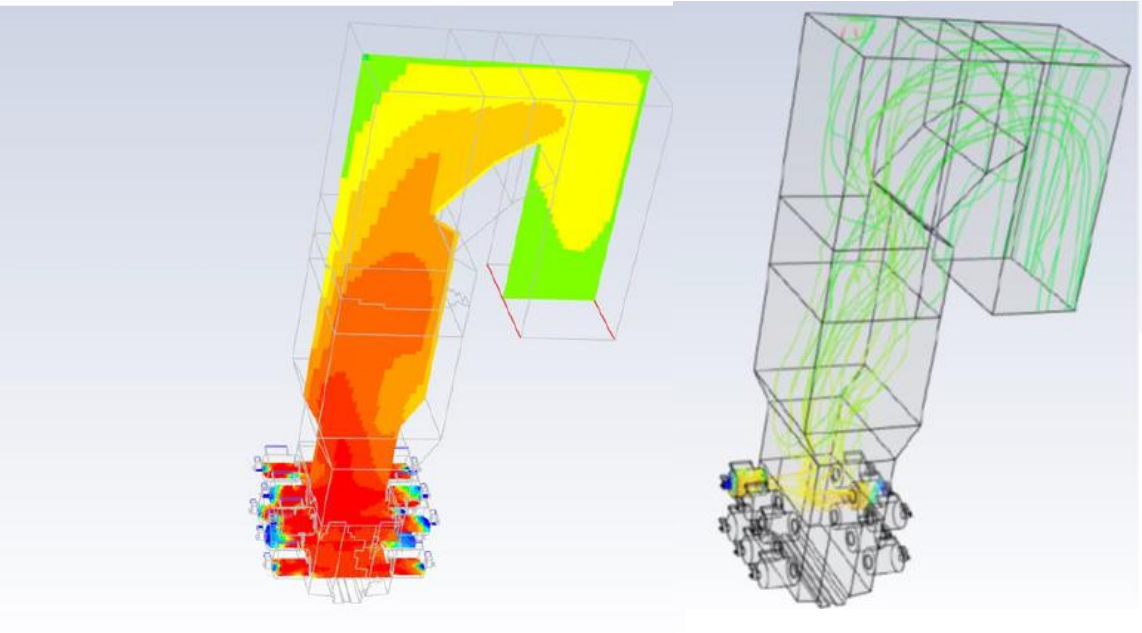
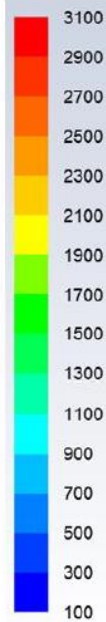


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Task 2. Full Scale Combustion Simulations



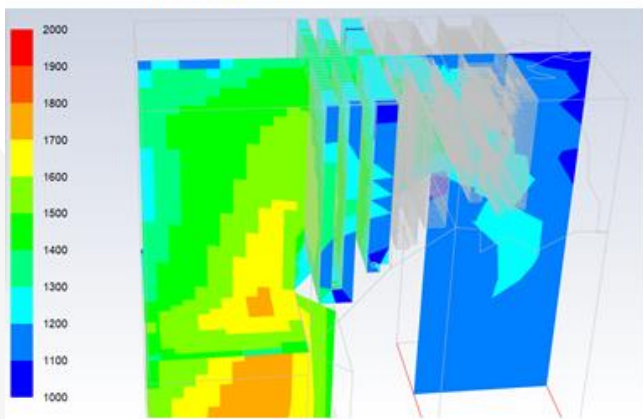
Modified Boiler Geometry



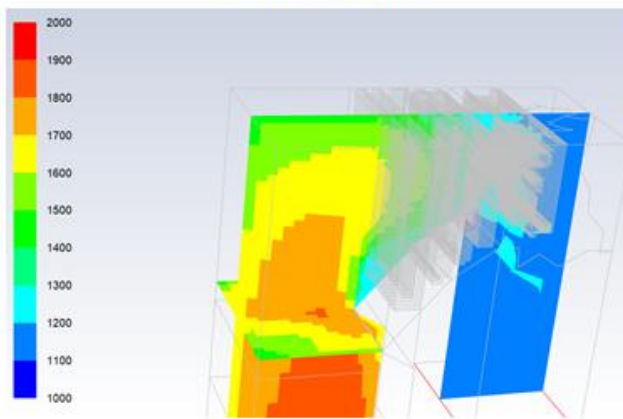
End-to-End boiler simulation of fuel combustion
(i.e., combustion within the cyclone barrel fully
integrated with that within the boiler)

Task 2. Temperature Contours

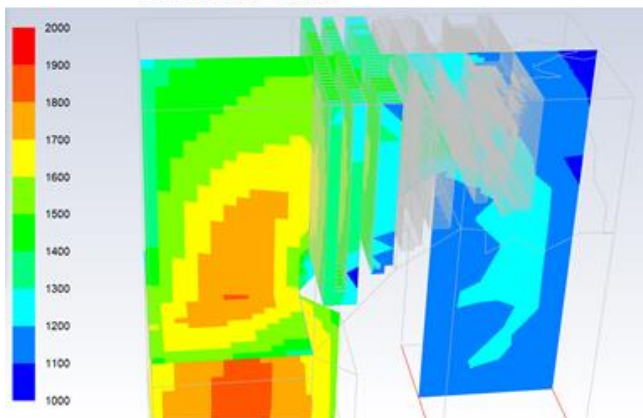
75% Load Coal 1



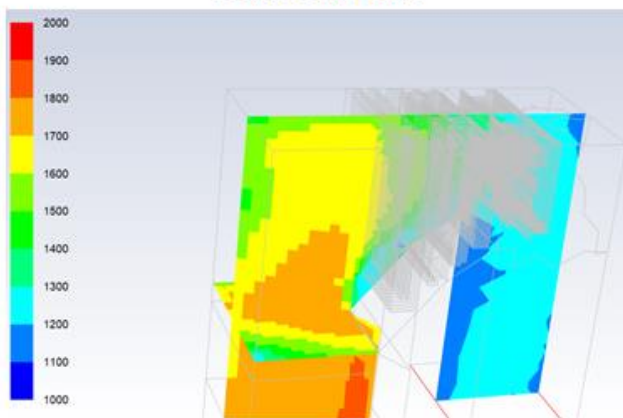
100% Load Coal 1



75% Load Coal 2



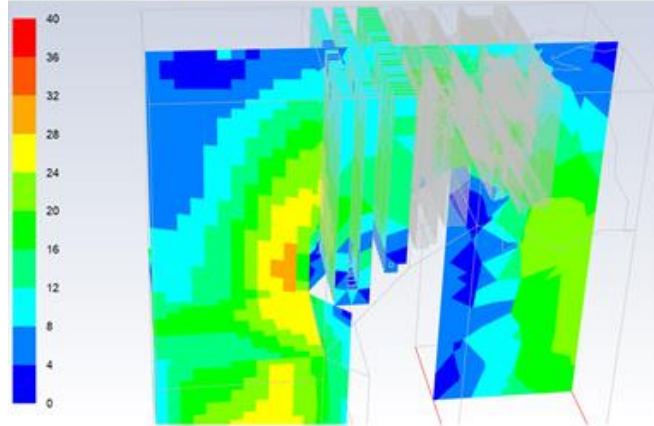
100% Load Coal 2



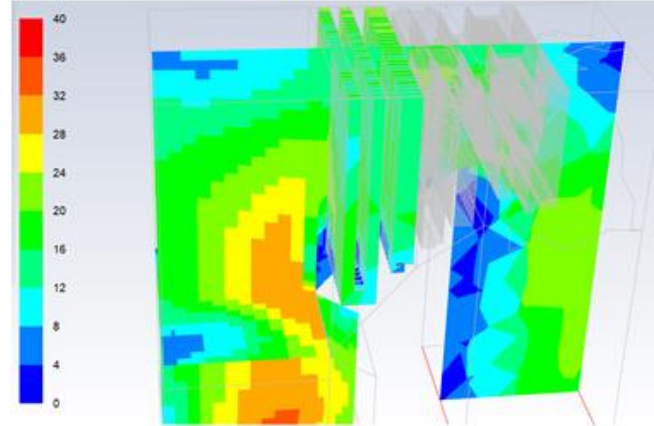
Temperature predictions at different sections in agreement with plant data

Task 2. Velocity Contours

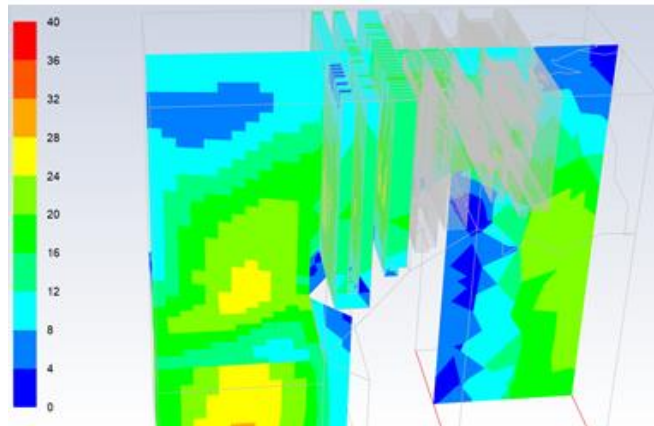
75% Load Coal 1



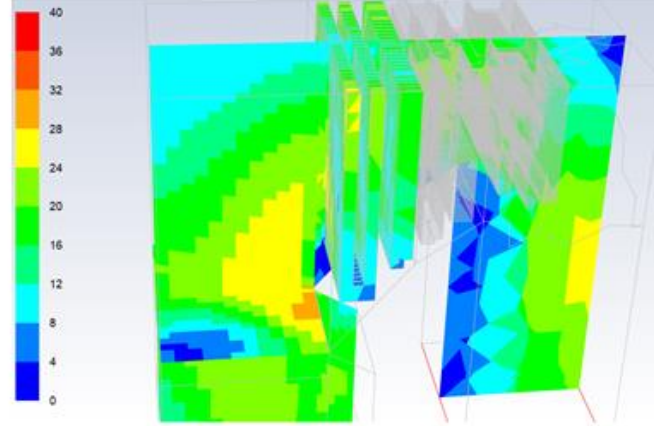
100% Load Coal 1



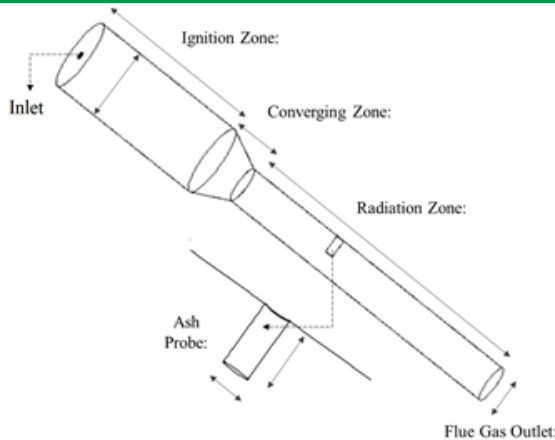
75% Load Coal 2



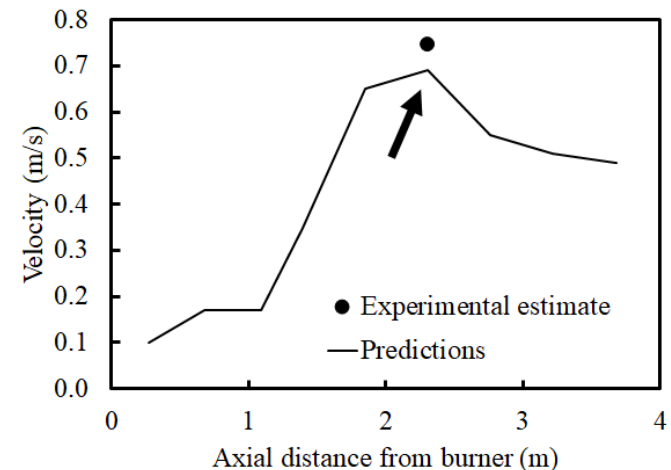
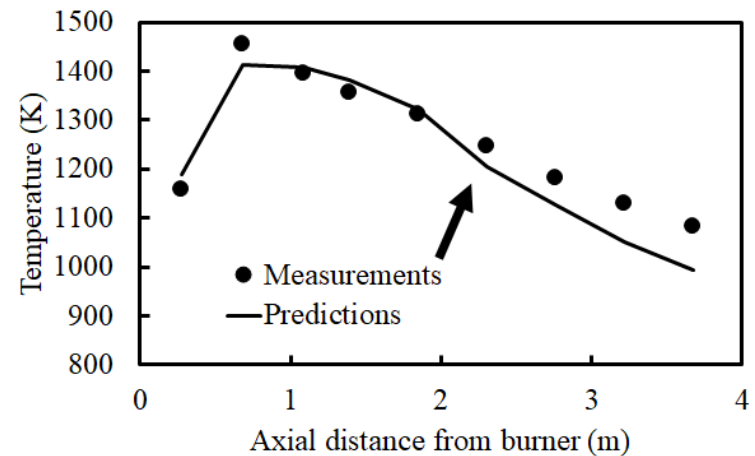
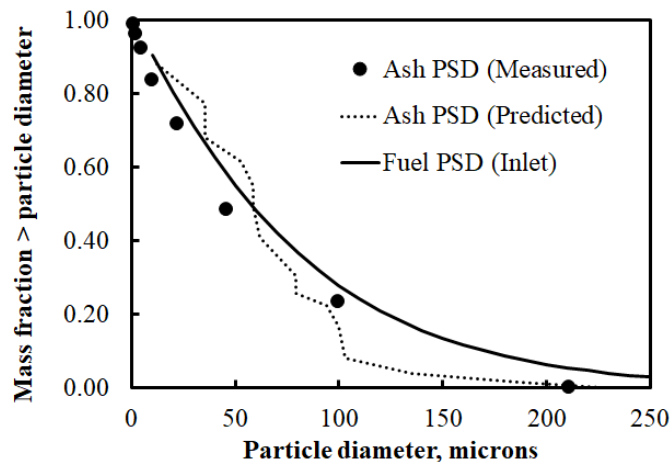
100% Load Coal 2



Task 2. Methodology validation against published lab scale data



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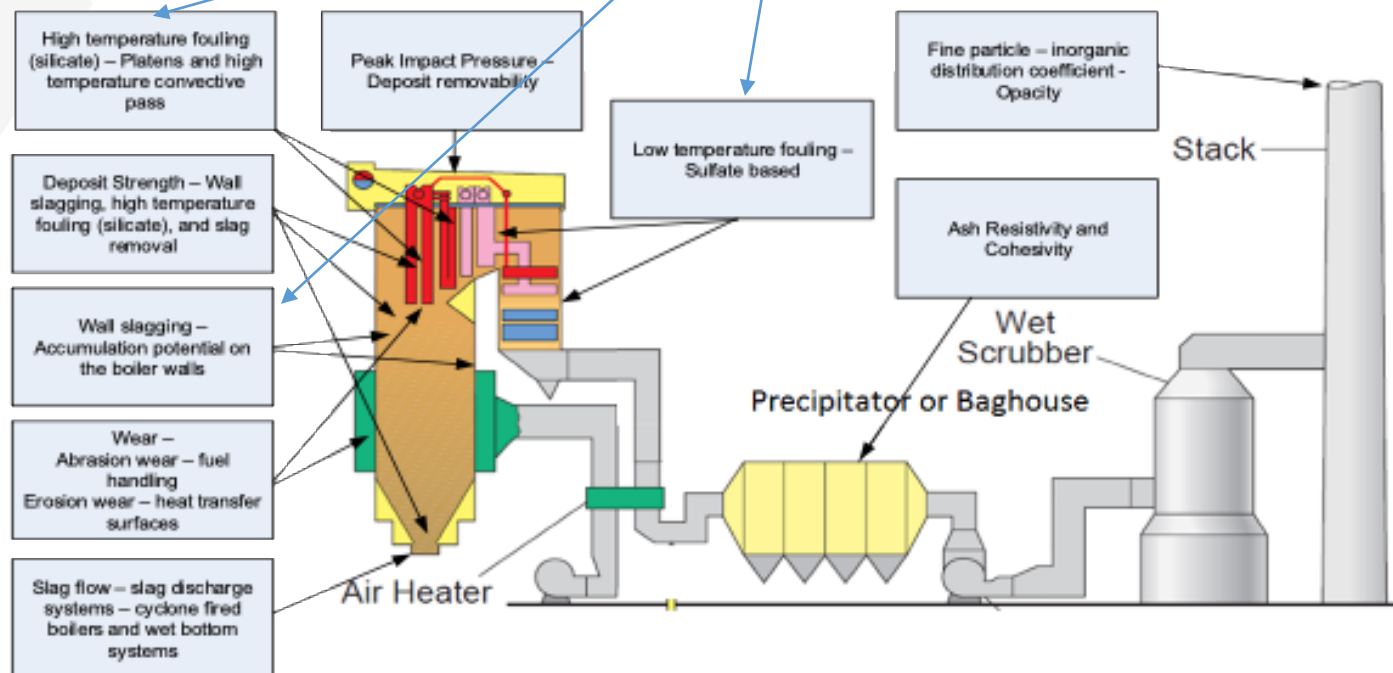


Task 2 Accomplishments

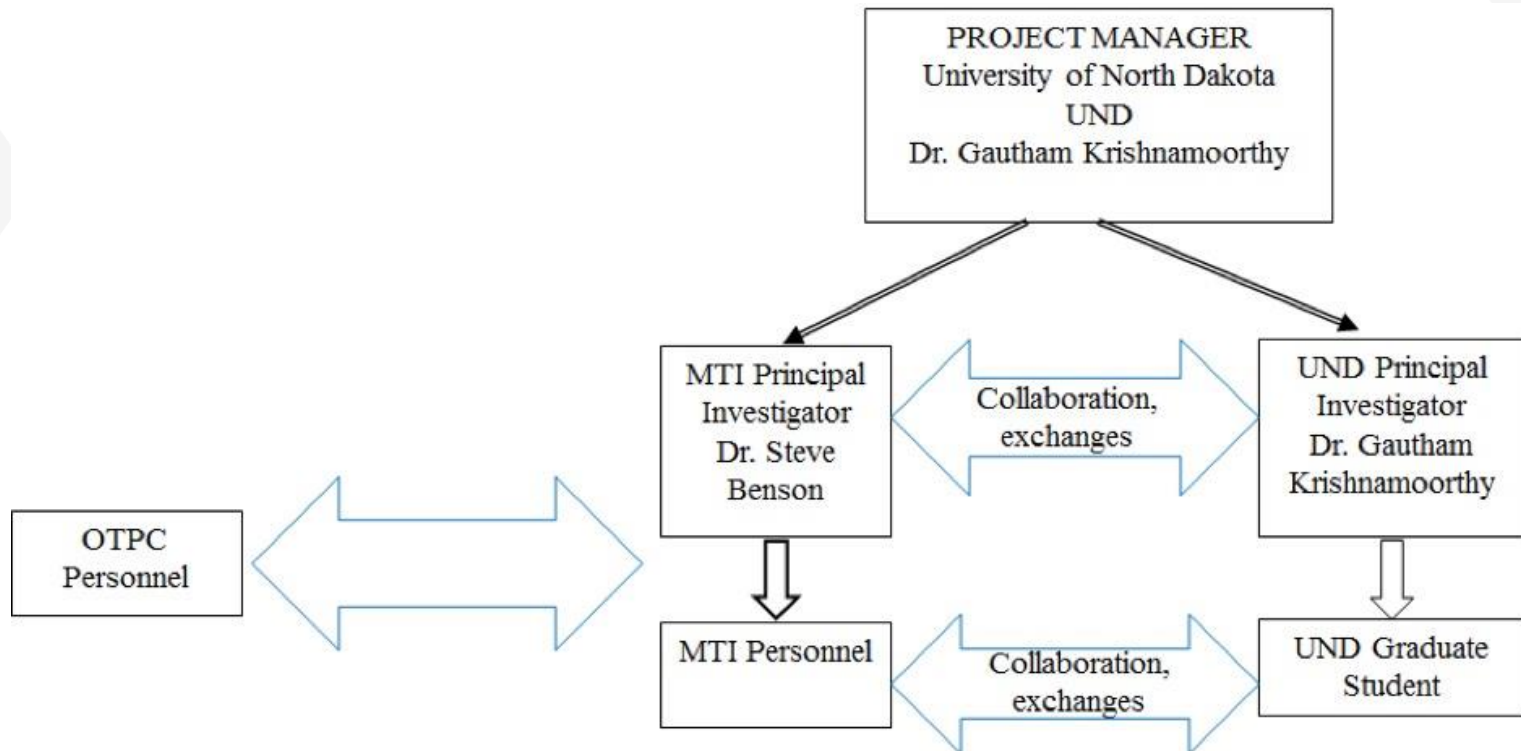
- Construction of geometries of full-scale utility boilers
- Slagging and fouling event specific database development and data analysis
- Simulations of coal combustion the boiler units
- Methodology validation against lab scale data

Task 4. Combustion System Performance Indices and Coal Tracker (CSPI-CT) Tool Refinement

Efforts focused on Wall Slagging and Convective Pass Indices – CFD Enhanced



Project Organization



Take-Home Message(s)

Predicting ash deposition: This is almost as complicated as it gets...

- Its important to have high-fidelities in:
 - ash PSD
 - Gas velocities
 - Particle/gas temperature
 - ash composition
- First, focus on getting the impaction rates right! (flow over cylindrical rows, highly resolved grids)
- Complex (capture criterion) for predicting deposition can be implemented easily
- Close interactions between: boiler personnel, coal quality experts and CFD practitioners are necessary

Acknowledgements

- This research is being funded by the University Coal Research Program which is administered by DOE-NETL (Award #: DE-FE0031741) (2 students supported on the project)
- Otter Tail Power Company – Providing data on fuel properties and plant operations.

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Questions?