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

Output Screen from CSPI-CT
Microbeam’s Existing on-line Technology
Background Information

• Inorganic transformations to form vapors, liquids and solids
• Partitioning in burner
• Vapor phase and particle transport mechanisms
• Ash sticking and deposit growth
• Sintering and strength development
• Heat transfer
Inorganic Transformations and Partitioning in Burner

Day 1 – B/A 1.18, Ash 8.08
- Coal particles – high B/A, low ash
- High coal/ash sticking coefficient
- Thin liquid slag layer
- Solid slag
- Cyclone wall
- T<sub>in</sub> = 1800°F
- Slag – low viscosity slag – low ash retention – 30%

Day 2 – B/A 0.72, Ash 8.81
- Coal particles – moderate B/A, low ash
- High coal/ash sticking coefficient – limited rebound
- Moderately thick liquid slag layer
- Solid slag
- Cyclone wall
- T<sub>in</sub> = 2040°F
- Slag – moderate viscosity slag – high ash retention – 70%

Day 3 – B/A 0.49, Ash 13.1
- Coal particles – low B/A, high ash
- High coal/ash sticking coefficient – higher rebound – freezing potential
- Moderately thick liquid slag layer
- Solid slag
- Cyclone wall
- T<sub>in</sub> = 2350°F
- Slag – moderate viscosity slag – high ash retention – 50%

Slag layer thickness as a function of fuel properties.
Ash formation during coal combustion
Cyclone Performance - Slag and Fly-Ash Partitioning

Fly Ash Composition

- Measured
- Predicted

Slag Composition

- Measured
- Predicted

\[ T_{cv} = 1385.44 + 74.1(A/B) \, (K) \]

\[ A/B = \frac{\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{TiO}_2}{\text{Fe}_2\text{O}_3 + \text{CaO} + \text{MgO} + \text{Na}_2\text{O} + \text{K}_2\text{O}} \]
Deposit Formation – particle transport to walls and convective surfaces

Layered Deposit Formation – Fouling Deposit

- **Layered Deposit**
  - Diffusion
  - Thermophoresis
  - Inertial Impaction

- **Transport Process**
  - Aerosols (0.02 – 0.2 µm)
  - Homogeneous Condensation
  - Vapor phase
  - Heterogeneous condensation
  - Coalescence
  - Fragmentation shedding

- **Ash Intermediates – gas liquid and solid**
  - Na, S, Cl, K, P, Fe, Ni, Zn
  - Quartz, Clay, Pyrite, Calcite, Organic Ca

- **Inorganic Component Feedstock and Flux from Gasification Process** – Vapors, liquids, and solids

- **Steel Tube**
  - Corrosion and bonding layer - Gas-solid reaction
  - Sulfate rich layer

- **Gas Flow**

- **Shedding**

**Microbeam Technologies, Inc.**
**University of North Dakota**
Slag formation – particle sticking growth – example – iron sulfide

Pyrite-Derived
FeS/Fe/FeO

<table>
<thead>
<tr>
<th>Fig</th>
<th>Pt/Area</th>
<th>Description</th>
<th>Na</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
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<th>K</th>
<th>Ca</th>
<th>Ti</th>
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<td>1.87</td>
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<td>0.00</td>
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<td>0.00</td>
<td>5.39</td>
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<td>1.66</td>
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<td>1.50</td>
<td>0.00</td>
<td>74.27</td>
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Solution: Develop Functional Relationships for Incorporation into On-line Prediction Methods

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

**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**
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
- 4 Quarterly Reports submitted to DOE.
- Milestone changes

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<tr>
<th>Milestone</th>
<th>Task/Subtask</th>
<th>Milestone Title and Description</th>
<th>Planned Completion Date</th>
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<td>Task 2</td>
<td>Combustion simulations within cyclone barrels</td>
<td>4/31/2020 10/31/2020</td>
<td>Completion of simulations within cyclone barrels encompassing 12 representative operational scenarios</td>
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<td>Task 2</td>
<td>Combustion simulations within a full-scale boiler employing the results from the cyclone barrel simulations</td>
<td>7/31/2020 1/31/2021</td>
<td>Completion of simulations encompassing 12 representative operational scenarios</td>
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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)
Load Definition Selection

Database V-Net Load v. Time

- Full Load 100%
- Partial Load 75%
- Half Load 50%
Task 2. Modifications to Cyclone Geometry
Cyclone Performance Comparison

Total Supplementary Fuel Flow

- Cyclone 1
- Cyclone 2
- Cyclone 3
- Cyclone 4
- Cyclone 5
- Cyclone 6
- Cyclone 7
- Cyclone 8
- Cyclone 9
- Cyclone 10
- Cyclone 11
- Cyclone 12
Fuel Ash and Supplementary Fuel Flow
• Worked with OtterTail Power’s Coyote Station to identify the plant operational data and as-delivered fuel properties associated with the time period during which Coyote faced slagging issues.
• As-delivered fuel properties data was used as input and predictions of as-fired fuel quality were made with the help of Microbeam’s CoalTracker program.
• Fuel properties hourly averages were calculated and compared for each cyclone.
• A cyclone with high amount of supplemental oil flow was selected for further testing.
Task 2. Modified Boiler Geometry

- Modified Boiler Geometry
- Secondary super heater

End-to-End boiler simulation of fuel combustion (i.e., combustion within the cyclone barrel fully integrated with that within the boiler)
Fuel Particle Trajectories
Net Radiative Flux
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
## Next Steps – Boiler CFD Model Test Matrix

<table>
<thead>
<tr>
<th>No.</th>
<th>Na content/ Na flowrate</th>
<th>Load</th>
<th>Time since last shutdown/cleaning outage</th>
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<td>1</td>
<td>High</td>
<td>Full</td>
<td>30 Days after cleaning outage</td>
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<td>2</td>
<td>Medium</td>
<td>Full</td>
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<td>7</td>
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<td>8</td>
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<td>10</td>
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<td>12</td>
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Task 4. Combustion System Performance Indices and Coal Tracker (CSPI-CT) Tool Refinement

Efforts focused on Wall Slagging and Convective Pass Indices – CFD Enhanced
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<td>Installation, testing, and performance assessment of the CSPI-CT Tool</td>
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Project Organization

PROJECT MANAGER
University of North Dakota
UND
Dr. Gautham Krishnamoorthy

MTI Principal Investigator
Dr. Steve Benson

MTI Personnel

Collaboration, exchanges

UND Principal Investigator
Dr. Gautham Krishnamoorthy

UND Graduate Student

OTPC Personnel
Take-Home Message(s)

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

- It's important to have high-fidelities in:
  - coal PSD
  - particle radiative properties
  - gas radiative properties
  - ash composition

- However, complexity in predicting ash deposition (capture criteria) depends on: fuel, boiler configuration, temperature zone (where the deposition occurs)

- Multiphase turbulent combustion + fuel properties and flow rates

- But our understanding of physical and chemical transformations associated with ash deposition is improving

- **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)
• Otter Tail Power Company – Providing data on fuel properties and plant operations.
Questions?