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

Gautham Krishnamoorthy

May 12th, 2022
DOE FE R&D Project Review Meeting
University Coal Research

Acknowledgement: This research is being funded by the University Coal Research Program which is administered by DOE-NETL (Award #: DE-FE0031741)
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

Coal Storage Building – Ash content

Burner Silo – Ash content
Load Definition Selection

Database V-Net Load v. Time

- Full Load 100%
- Partial Load 75%
- Half Load 50%
Temperature (in K)
Impaction and Capture Efficiencies

Ash deposition is a function of:

Impaction efficiency (Particle Stokes number)
- Particle size distribution
- Gas velocity
- Gas viscosity

Capture Efficiency
- Particle viscosity (temperature and composition)
- Particle KE (particle size distribution and velocity)

flue gas velocity of $u_\infty = 10 \text{ m/s}$ and a gas temperature of $T_g = 1000^\circ \text{C}$.
Methodology validation against well characterized lab-scale measurements
Methodology validation against well characterized lab-scale measurements

<table>
<thead>
<tr>
<th></th>
<th>Measured</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIR (g/m²-hr)</td>
<td>257</td>
<td>226</td>
</tr>
<tr>
<td>OXY70 (g/m²-hr)</td>
<td>569 +/- 38</td>
<td>701</td>
</tr>
<tr>
<td>Deposition rate</td>
<td>2.1 − 2.4</td>
<td>3.1</td>
</tr>
<tr>
<td>enhancement (OXY70/AIR)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Ensure methodology robustness with modeling uncertainties

Predicted deposition rate enhancement: 2.8 to 3.7
Measured deposition rate enhancement: 2.1 to 2.4
Microbeam’s gas-side fouling deposit probe is used to collect ash deposits from coal-fired boilers. The probe was successfully used to collect and extract ash deposits from a boiler during operation.

The probe is a 5 ft long, 1” T22 steel tube on which deposits develop.

The probe was inserted horizontally through a port in the boiler between the secondary superheater and reheater heat exchange sections (gas temperature roughly 1600 °F).
Deposition Rates During the Field Test – Full Load Conditions

Information gathered from the deposition probe was used to determine deposit growth rates and collect ash deposits for characterization to determine the processes involved in the formation of ash deposits.

The objective of the field test was to successfully extract ash deposits from a boiler during operation to gather information on deposit sample weight over time. The weights of collect deposits were then charted and compared (Day 4 results are shown above as examples).
Deposit Composition Variation

Deposit samples were collected from varying positions at the front and back sections of the ash deposition probe.

Major oxide ash composition (%) for the upstream and downstream a) 0-10” probe deposit samples and b) 10-20” probe deposit samples.
Deposit samples were collected from varying positions at the front and back sections of the ash deposition probe.

Major oxide ash composition (%) for the upstream and downstream c) 20” - wall probe deposit samples.
Deposition Rates During the Field Test – Reduced Load Conditions

Information gathered from the deposition probe was used to determine deposit growth rates and collect ash deposits for characterization to determine the processes involved in the formation of ash deposits.

Low load conditions decrease temperature and creates a growth and shedding process.
# Milestones completed

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Task/Subtask</th>
<th>Milestone Title and Description</th>
<th>Planned Completion Date</th>
<th>Verification Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Task 1</td>
<td>Project Management Planning</td>
<td>8/31/2019</td>
<td>PMP Updated</td>
</tr>
<tr>
<td>2</td>
<td>Task 1</td>
<td>Project Kick-off Meeting</td>
<td>10/31/19</td>
<td>Project kick-off meeting conducted</td>
</tr>
<tr>
<td>3</td>
<td>Task 2</td>
<td>Combustion simulations within cyclone barrels</td>
<td>1/31/2020</td>
<td>Completion of simulations within cyclone barrels encompassing 12 representative operational scenarios</td>
</tr>
<tr>
<td>4</td>
<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</td>
<td>Completion of simulations encompassing 12 representative operational scenarios</td>
</tr>
<tr>
<td>5</td>
<td>Task 3</td>
<td>Thermal modeling refinement with validation against data from plant</td>
<td>7/31/2021</td>
<td>Thermal modeling refinement and validation of the simulations encompassing the 12 representative scenarios selected in Task 2</td>
</tr>
<tr>
<td>6</td>
<td>Task 3</td>
<td>Deposition modeling refinement with validation against data from plant</td>
<td>1/31/2022</td>
<td>Deposition modeling refinement and validation of the simulations encompassing the 12 representative scenarios selected in Task 2</td>
</tr>
<tr>
<td>7</td>
<td>Task 4</td>
<td>CSPI-CT Tool Refinement</td>
<td>7/31/2022</td>
<td>Functional/parametric relationships relating to plant performance are developed and refined</td>
</tr>
<tr>
<td>8</td>
<td>Task 4</td>
<td>Installation, testing and performance assessment of the CSPI-CT tool</td>
<td>7/31/2022</td>
<td>The CFD augmented CSPI-CT tool is installed on site and its performance is assessed</td>
</tr>
</tbody>
</table>
Predicting ash deposition: This is almost as complicated as it gets...

- It's important to have high-fidelities in:
  - Ash PSD
  - Gas velocities
  - Particle/gas temperature
  - Ash composition

- First, focus on getting the impaction rates right! (highly resolved grids)
- Next, validate capture methodology against well resolved lab-scale measurements and access input parameter uncertainties
- Extend the methodology to larger scales (where measurements may not be available and uncertainties are greater)
- Close interactions between: boiler personnel, coal quality experts and CFD practitioners are necessary at all levels
Acknowledgements

• This research is being funded by the University Coal Research Program which is administered by DOE-NETL (Award #: DE-FE0031741) (1 student + 1 Post-Doc supported on the project)

• Otter Tail Power Company – Providing data on fuel properties and plant operations.

Disclaimer: "This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."
Questions?