Modeling of the bed inventory in CFB boilers

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In collaboration with Metso Power
Project: "An overall CFB model"
Modeling of the bed inventory in CFB boilers

- Background
- Solids inventory control
- Modeling
- Results
Overall CFB model - concept

Inputs

- Geometry of the circulating loop
- Operational conditions
  - Fuel flows (rate, location, composition, temperature, frag)
  - Air flows (rate, location, composition, temperature)
  - Furnace pressure drop
  - Steam data
- Solids properties (PSD, density, sphericity)

Outputs

- Design tool
- Knowledge source
- Training tool

Concentration fields (gases & solids)
Mass flux fields (gases & solids)
Temperature field
Heat flux field
Overall CFB model - modules

Background       Solids inventory control       Modeling       Results
Overall CFB model - inputs

- Geometry of the circulating loop
- Operational conditions
  - Fuel flows (rate, location, composition, temperature, fuel frag.)
  - Air flows (rate, location, composition, temperature)
  - Furnace pressure drop
  - Steam data
- Solids properties (\(\text{PSD}_{\text{unit}}\), density, sphericity)

Influences the fluid dynamics strongly
Often difficult to guess or measure

Needs to be modeled
The bed solids inventory (or at least a representative part of it) is usually meant to consist of fuel ash (+sorbent).

Without acting on the bed solids inventory, it would tend to zero or (most likely) to fill up the riser, depending on:

- PSD
- Operational conditions
- Cyclone performance
Control strategies

Usual measures to control the bed solids inventory

- High $\Delta p_{\text{riser}}$ → Removal of bottom bed material
- Low $\Delta p_{\text{riser}}$ → Addition of coarse makeup material

- High $\Delta p_{\text{bottom}}$ → Addition of fine makeup material
- Low $\Delta p_{\text{bottom}}$ → Addition of coarse makeup material
  - Removal of fine bed material
Control strategies

Background
Solids inventory control
Modeling
Results
Solids attrition

The graph shows the cumulative percentage of solids attrition over time, with different durations ranging from 1 minute to 120 minutes. The x-axis represents the particle size (dp, mm) and the y-axis represents the cumulative percentage. The graph illustrates how solids attrition affects the particle size distribution over time.
Control strategies

Background
- Solids inventory control
- Modeling
- Results
Transient modeling

Operational strategy is needed as input and influences the results.
Pseudo-steady state

With control strategies of *sudden* nature, a steady state is never reached. However, a pseudo-steady state is finally reached in which a pattern of countermeasures is repeated at a constant frequency. The main fluidodynamical parameters keep oscillating slightly around their time-averaged values.
Transient modeling

1. Solution for average ash
2. Calculate \( dt \)
3. Solution for modified mass
4. Countermeasures (op. strategy)
5. Pseudosteady state reached?
6. Aimed conditions reached?

Flowchart:
- t=0
- \( m_{out\,cyc} \)
- \( m_{in\,fuel\,ash} \)
- Solution for modified mass
- t\_j = t + dt
- No
- Yes
Solids mixing - furnace

Cluster & disperse phases (Johnsson and Leckner)

Backflow effect - Correlation

Chalmers 12 MWth CFBC

\[ u_0 = 2.7 \text{ m/s}, \quad d_s = 320 \text{ \(\mu\text{m}\)} \]

Background Solids inventory control Modeling Results
Solids mixing – return leg

Pressure balance on circulating loop

$P_{seal} - P_{dc}$

$H_{dc}$

$m_{dc}$

Population balance on circulating loop

Background | Solids inventory control | Modeling | Results
Results – 4 parameters studied

Chalmers CFB boiler (12 MWth)
16 cases studied

<table>
<thead>
<tr>
<th>No sorbent</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel ash content [1]</td>
<td>0.005 0.25</td>
</tr>
<tr>
<td>Attrition time (h)</td>
<td>1 10</td>
</tr>
<tr>
<td>Cyclone efficiency</td>
<td>high low</td>
</tr>
<tr>
<td>dp_bot control</td>
<td>on off</td>
</tr>
</tbody>
</table>
Results – Control strategies used

\( \Delta p_{\text{riser}} \)-related
Countermeasures applied if experimental value deviates >5% from nominal value

\[ \Delta p_{\text{riser,exp}} > \Delta p_{\text{riser,nom}} : \text{Bottom bed material removal} \]
\[ \Delta p_{\text{riser,exp}} < \Delta p_{\text{riser,nom}} : \text{Coarse worn-out material addition} \]

\( \Delta p_{\text{bottom}} \)-related (\( \Delta p_{\text{bottom}} \) measured between \( h=0.135 \) and \( h=1.635 \) m)
Countermeasures applied if experimental \( \alpha = \Delta p_{\text{bottom}} / \Delta p_{\text{riser}} \) is outside range 0.40-0.82

\[ \alpha < 0.40 : \text{Coarse worn-out material addition and bottom bed material removal} \]
\[ \alpha > 0.82 : \text{Fine worn-out material addition and bottom bed material removal} \]

\[ \text{(no removal from seal available at Chalmers boiler)} \]
Bed material modeling

High-efficiency cyclone (slow attrition, $x_{\text{ash, fuel}}$)
Bed material modeling

High-efficiency cyclone (slow attrition, $x_{ash,fuel}$↑)
Conclusions ($\eta_{\text{cycl}} \uparrow$)

- In all runs, relatively similar pseudo-steady state values for:
  \[ \text{PSD}_{\text{unit}}, H_b, F_{s,\text{net}} \]
- Limited influence of the attrition rate also on all other variables
- \[ F_{\text{stack}}, F_{\text{class}} \propto x_{\text{ash,fuel}} \rightarrow \frac{F_{\text{stack}}}{F_{\text{class}}} \sim \text{constant} \]
- High \( x_{\text{ash,fuel}} \) leads to sooner pseudosteady states
Bed material modeling

Low-efficiency cyclone, no $\Delta p_{\text{bot}}$ control (slow attrition, $x_{\text{ash,fuel}}$)
Bed material modeling

Low-efficiency cyclone, $\Delta p_{\text{bot}}$ control (slow attrition, $x_{\text{ash,fuel}} \uparrow$)
Bed material modeling

Low-efficiency cyclone, $\Delta p_{\text{bot}}$ control (slow attrition, $x_{\text{ash,fuel}}$↑)
Conclusions ($\eta_{\text{cycl}} \downarrow$)

- For all cases

  Higher attrition rates imply increased need of makeup material (and thereby changes in the fluiddynamics).

- Without $\Delta p_{\text{bot}}$ control

  The unit tends very slowly to a pseudo-steady state in which all bed material is formed by coarse, non-circulating ash. Only fines from attriting ash are entrained and go to stack.

- With $\Delta p_{\text{bot}}$ control

  The PSDs of added materials govern the pseudo-steady state. This influence increases as $x_{\text{ash,fuel}}$ decreases.
Conclusions

- A model for the solids bed inventory is built. It has a dynamical approach and provides \( PSD_{\text{unit}} \) as well as solids flows within the CFB loop and in/out from the CFB unit (bottom/seal removal, stack, makeup).

- Cyclone performance is the most influential parameter and governs how other parameters influence the results.

- Attrition rate influence increases as cyclone separation efficiency decreases.

- Resolution and accuracy for finest sizes (i.e., \( \eta_{\text{cycl}} \), \( PSD_{\text{plateau}} \)) is crucial.
Further work

- The model will be within short tested against experimental data from large-scales CFB boilers

Thank you for your attention!
Questions?
Bed material modeling

Inputs needed

- $\dot{m}_{\text{fuel}}$, $x_{\text{ash,fuel}}$
- Ash attrition pattern
- PSD of coarse and fine material
- $\eta_{\text{cyclone}}(d)$, $\eta_{\text{classifier}}(d)$
- Control strategy
Bed material modeling

Inputs needed

• \( \dot{m}_{\text{fuel}}, x_{\text{ash,fuel}} \)
• Ash attrition pattern
• PSD of coarse and fine material
• \( \eta_{\text{cyclone}}(d), \eta_{\text{classifier}}(d) \)
• Control strategy

![Graph showing data points with x-axis from 0 to 500 and y-axis from 0 to 1.2.](image)
Bed material modeling

Inputs needed

• $\dot{m}_{\text{fuel}}$, $x_{\text{ash,fuel}}$

• Ash attrition pattern

• PSD of coarse and fine material

• $\eta_{\text{cyclone}} (d)$, $\eta_{\text{classifier}} (d)$

• Control strategy
Bed material modeling

Inputs needed

- $\dot{m}_{\text{fuel}} \cdot x_{\text{ash,fuel}}$
- Ash attrition pattern
- PSD of coarse and fine material
- $\eta_{\text{cyclone}}(d)$, $\eta_{\text{classifier}}(d)$
- Control strategy

\[ \Delta p_{\text{riser,exp}} \text{ 5\% deviation tolerance} \]
\[ \alpha [0.40,0.82] \]