ANALYSIS OF INFLUENCE OF MODEL INPUT PARAMETERS ON ASH FOULING RATE PREDICTED BY CFD

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Particulate matter fouling of combustion facilities

- One of the most severe problems of combustion of biomass or solid alternative fuels
- Little experience from combustion in industrial facilities
- Necessity for flexible models → CFD modelling

CFD simulations of fouling

- Fouling is a complex phenomenon
- Flue gas chemistry, contact mechanics, heat transfer, turbulent flow, boundary layer flow
- Strong dependence on empirical data
- Initial conditions – data from industrial boilers, laboratory experiments, combustion simulations
Models of particulate matter fouling

Critical viscosity models, molten fraction models
• Sticking criterion based on viscosity or fraction of molten mass of ash particle
• Empirically given dependence between viscosity/molten fraction, temperature and chemical composition

Critical velocity models
• Considering particle composition, temperature, impact velocity and forces acting on a particle
• Sticking criterion usually based on the energy or force balance
• More universally applicable
• Material properties of ash components are often required
Implemented fouling model

• Solid spherical particles + clean flat surfaces
• The sticking probability $P$ determined from the force balance

\[
P = \begin{cases} 
1, & F_{VW} + F_g \sin \theta \geq F_{el} \\
0, & \text{otherwise}
\end{cases}
\]

Gravitational force
\[
F_g = \frac{1}{6} \pi d_p^3 \rho_p
\]

Van der Waals force
\[
F_{VW} = B \frac{d_p}{6\delta^2}
\]

Elastic rebound force
\[
F_{el} = G \left( \frac{d_p}{d_{ref}} \right)^n d_p^2 |v_{i,n}|^{1.2}
\]

• No energy loss in case of particle rebound
• 5 parameters: $B, \delta, G, n, d_{ref}$
• Reference diameter $d_{ref}$ chosen as a tested parameter
Simulated facility

- Rotary kiln + flue gas system
Deposition chamber

• Passive mechanical part for retaining ash particles
Heat exchanger

Design parameters

- Inlet temperature: 450°C
- Outlet temperature: 950°C
- Flue gas mass flow: 0.231 kg/s
- Flue gas density: 0.288 kg/m³
- Transferred heat flow: 142 kW

Cold water inlet

Heated water outlet

filter

bypass

deposition chamber
Simulated case

- Only the deposition chamber and simplified kiln geometry considered
- Combustion experiments not conducted yet, we used the calculated data from the design calculations and from literature
- Initial simulations → largest size fraction unable to leave the kiln → not included in further simulations

<table>
<thead>
<tr>
<th>Flue gas inlet boundary conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature: 950°C</td>
</tr>
<tr>
<td>Mass flow: 0.231 kg/s</td>
</tr>
<tr>
<td>Density: 0.288 kg/m³</td>
</tr>
</tbody>
</table>

- ANSYS® Fluent®
- Steady-state
- Turbulence flow model: Realizable k-ε, Enhanced Wall Treatment
- Particle tracking: Discrete Phase Model (DPM), Discrete Random Walk Model (DRWM), Random Eddy Lifetime

Assumed particle size distribution

- Flue gas inlet boundary conditions
  - Temperature: 950°C
  - Mass flow: 0.231 kg/s
  - Density: 0.288 kg/m³
Geometry and tested meshes

• 5 tested meshes with differently resolved boundary layer

<table>
<thead>
<tr>
<th>Number of cells</th>
<th>393651</th>
<th>458310</th>
<th>490141</th>
<th>588677</th>
<th>667559</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average $y^+$</td>
<td>6.92</td>
<td>6.06</td>
<td>5.74</td>
<td>1.66</td>
<td>1.14</td>
</tr>
<tr>
<td>Cells with $y^+ &gt; 4$ [%]</td>
<td>39.77</td>
<td>21.37</td>
<td>14.23</td>
<td>0.75</td>
<td>0.08</td>
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<tr>
<td>Cells with $h &lt; 37.25 \mu m$ [%]</td>
<td>0</td>
<td>0</td>
<td>0.069</td>
<td>0.49</td>
<td>1.03</td>
</tr>
</tbody>
</table>

• Discrete Phase Model → particle can impact surface, if its center lies in a boundary cell → boundary cell height $h >$ maximum particle radius (37.25 $\mu m$)

Unrealistic submersion

Relative values of deposition mass flows
Test of influence of model parameter value

- reference diameter $d_{\text{ref}}$
Application of the implemented fouling model

- Fouling simulation on mesh with 588677 cells with $d_{\text{ref}} = 17.54 \, \mu m$

Application of the implemented fouling model

Chamber efficiency

Deposition efficiency [kg/kg]

Mass flow [mg/s] vs. particle diameter [μm]

Mass flows on chamber inlet

Mass flows on chamber outlet

Application of the implemented fouling model
Application of the implemented fouling model

Deposition mass flux

$d_p = 6.0 \mu m$

$d_p = 19.5 \mu m$

$d_p = 74.5 \mu m$
Proposed improvements of current fouling model

• Energy losses of the impacting particle
• Particle transport mechanisms – thermophoresis, turbophoresis, ...
• Heterogenous or homogenous gas species condensation

• Wall/deposit surface roughness
• Impaction on powdery deposit
• Time evolution of deposit properties

• Fly ash formation
• Time evolution of fly ash properties and composition
Practical use and possible simplifications

- Direct simulations of particle impact → necessity for sufficiently resolved mesh near walls
- Concept of deposition velocities – approximation of actual particulate matter mass flow by means of boundary layer flow theory
- Standalone simulations of geometrically complex parts → fouling characteristics (impaction efficiency)

In case of using two mentioned simplifications we need to approximate value of impact velocity.

- Eulerian approach for fine particles
- Long time scales of fouling process → quasi-steady simulations
Thank you for your attention

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