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Characterization of fuel segregation in a fluidized bed by magnetic particle tracking

David Pallarès  
*Dept. of Energy and Environment, Chalmers University of Technology, Sweden*, david.pallares@chalmers.se

Anna Köhler  
*Dept. of Energy and Environment, Chalmers University of Technology, Sweden*

Alexander Rasch  
*Dept. of Energy and Environment, Chalmers University of Technology, Sweden*

Filip Johnsson  
*Dept. of Energy and Environment, Chalmers University of Technology, Sweden*

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Experimental characterization of axial fuel mixing in fluidized beds by magnetic particle tracking

Anna Köhler, Alexander Rasch, David Pallarès and Filip Johnsson

Department of Energy and Environment
Chalmers University of Technology, Sweden

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Background

• Mixing of large particles in FB

- Lateral mixing
- Axial mixing

Residence time
Mass/Heat Transfer

Process performance
Efficiency

• Combustion (incl. CLC, OCAC), gasification
• Industry (chemical, petrol, metal, pharma)
Background

- Mixing of large particles in FB
- Axial mixing
  - Bubbles in dense bed
  - Particle properties
  - Operational conditions
Aim

- Investigate axial mixing of single large tracer
  - Operational conditions \((H_0, u_0-u_{mf}, \Delta P_{Distributor})\)
  - 3 tracer densities

Method

- Magnetic particle tracking
  - 3-dimensional tracking
- Fluid-dynamical scaling
  - Relevant for industrial scale
  - Resembling hot conditions
Theory

• Axial mixing induced by bubbles
• Segregation

• Biomass fuel
  • Light particles
  • Large particles
### Experimental setup

- **Fluid-dynamic scaling**

\[
\frac{U_0^2}{gD} \quad \frac{\rho_p}{\rho_f} \quad \frac{\rho_p U_0 d_p}{\mu_f} \quad \frac{\rho_f U_0 D}{\mu_f} \quad \frac{L}{D}
\]

### Parameter Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Hot model</th>
<th>Cold model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>800</td>
<td>20</td>
</tr>
<tr>
<td>Bed dimensions</td>
<td>m × m</td>
<td>0.74 × 0.74</td>
<td>0.17 × 0.17</td>
</tr>
<tr>
<td>Bed height</td>
<td>m</td>
<td>0.18 / 0.305</td>
<td>0.04 / 0.07</td>
</tr>
<tr>
<td>Superficial velocity</td>
<td>m/s</td>
<td>0.01 – 0.5</td>
<td>0.006 – 0.236</td>
</tr>
<tr>
<td>Bed material density</td>
<td>kg/m³</td>
<td>2 600</td>
<td>8 900</td>
</tr>
<tr>
<td>Bed material size</td>
<td>µm</td>
<td>250</td>
<td>60</td>
</tr>
<tr>
<td>Tracer size</td>
<td>mm</td>
<td>44</td>
<td>10</td>
</tr>
<tr>
<td>Biochar density</td>
<td>kg/m³</td>
<td>350</td>
<td>1 470</td>
</tr>
<tr>
<td>Biomass density</td>
<td>kg/m³</td>
<td>800</td>
<td>2 980</td>
</tr>
<tr>
<td>Emulsion density</td>
<td>kg/m³</td>
<td>1 230</td>
<td>4 320</td>
</tr>
</tbody>
</table>
Experimental setup

- 3D magnetic particle tracking
  - Spatial resolution: \( \sim 1 \text{ mm} \)
  - Temporal accuracy: \( \sim 30 \text{ Hz} \)

- Tracer
  - Permanent magnet
  - Spherical, const. diameter
Results

- Axial tracer location
Results

Flotsam

Transient

Stationary

Time spent on and above dense bed surface $F_{fb} [%]$

Excess velocity, $u_0 - u_{mf} [m/s]$

- Biochar
- Biomass
- Emulsion
Results

- $u_{\text{rise}}$ for $u_0 - u_{mf} = 0.19$ m/s
- $|u_{\text{sink}}|$ for $u_0 - u_{mf} = 0.19$ m/s
- $u_{\text{rise}}$ for $u_0 - u_{mf} = 0.43$ m/s
- $|u_{\text{sink}}|$ for $u_0 - u_{mf} = 0.43$ m/s
Results

- This work (upscaled)
- Rees et al. (3D labscale)
- Nienow et al. (3D labscale)
- Soria-Verdugo et al. (2D labscale)
- Lim et al. (2D labscale)
- Fotovat et al. (3D labscale)
- Stein et al. (3D labscale)
Conclusions

• Enhanced axial mixing
  • Bed height ↑
  • Fluidization velocity ↑
  • Tracer density ↑
  • $\Delta P_{\text{Distributor}}$ –

• 3 mixing regimes with $u_0-u_{mf}$ ↑
  1) Flotsam. 2) Transient. 3) Stationary.

• Tracers up-/downward velocities
  • Cold lab-scale ↔ fluid-dynamically down-scaled