Ash deposition formation from biomass oxyfuel combustion in a pilot-scale furnace

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1 Introduction: Oxy → Ash deposition

Recycled biomass Oxy Combustion

- Combustion / Radiation
- Fly ash formation
- Furnace operation

How will this change affect the ash deposition formation?

Low carbon emission

Reuse of indigenous waste energy

Temperature
Velocity
Gas atmosphere
Fly ash properties

Ash deposition formation
1 Introduction: Literature findings and purposes

<table>
<thead>
<tr>
<th>Furnace and fuel</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fryda et al. [1,2] Lab scale pulverized coal combustor; Russian and South African coals, Lignite; co-firing,</td>
<td>Oxy30, higher deposition rate (20%-110%), 1300 and 900 K; Mainly due to flue gas properties, flow conditions, and particle sizes, rather than the ash chemistry.</td>
</tr>
<tr>
<td>Yu et al. [3] 100 kW down-fired combustor; US coals,</td>
<td>Oxy 27 and Oxy 32, higher deposition rate (visual observation); 1300-1400 K; Mainly due to lower gas velocity; no obvious difference in ash chemistry and size distribution.</td>
</tr>
<tr>
<td>Li et al. [4] 25 kW down-fired combustor; Chinese bituminous coal.</td>
<td>Oxy 30, lower deposition rate (10%-50%); 1150 K; Mainly due to lower gas velocity and slightly coarser particle size; no obvious difference in ash chemistry.</td>
</tr>
<tr>
<td>Jurado et al. [5] 100 kW pulverised fuel combustor; El Cerrejon (EC) coal and cereal co-firing.</td>
<td>Flue gas recirculation, Oxy 27–35%, similar deposition formation (visual observation); Radiant zone;</td>
</tr>
<tr>
<td>Brink et al. [6] 300 kW pilot scale combustor; South African coal</td>
<td>Wet flue gas recirculation, similar deposition formation (deposit composition and SEM images); about 1500K;</td>
</tr>
</tbody>
</table>

Very different conclusions? What to expect for a new fuel in a new combustion environment?
1 Introduction: Literature findings and purposes

Experimental work

- Coal vs biomass.
- Biomass air vs Biomass Oxy.

✓ Overall ash deposition behaviour

Modelling analysis

- Build the new ash deposition models.
- Validate the models with experimental data.
- Investigate the detailed particle deposition behaviour.
- Predict the effect of the oxy condition.
- Predict the effect of the flue gas velocity.

✓ Particle based deposition behaviour.
✓ Fuel property-furnace operation condition interaction.
✓ Predictions in the new environments.
2 Experimental data: fuel properties and the PACT facilities

Fuel properties (El Cerrejon coal and Recycled wood) → Combustion furnace and deposition measurements.

<table>
<thead>
<tr>
<th></th>
<th>Coal</th>
<th>REC</th>
<th>AR</th>
<th>Moist.</th>
<th>Coal</th>
<th>REC</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>39.9</td>
<td>44.4</td>
<td></td>
<td></td>
<td>7.63</td>
<td>5.8</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>16.6</td>
<td>5.8</td>
<td>Vol.</td>
<td>35.5</td>
<td>73.9</td>
<td></td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>10.8</td>
<td>7.6</td>
<td>FC</td>
<td>54.0</td>
<td>17.1</td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>14.4</td>
<td>29.5</td>
<td>Ash</td>
<td>2.9</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>1.9</td>
<td>4.1</td>
<td>GCV (kJ/kg)</td>
<td>28.7</td>
<td>18.4</td>
<td></td>
</tr>
<tr>
<td>K₂O</td>
<td>1.6</td>
<td>2.6</td>
<td>DAF</td>
<td>Coal</td>
<td>REC</td>
<td></td>
</tr>
<tr>
<td>Na₂O</td>
<td>1.9</td>
<td>1.5</td>
<td>C</td>
<td>80.9</td>
<td>51.9</td>
<td></td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.6</td>
<td>0.9</td>
<td>H</td>
<td>5.12</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.8</td>
<td>0.6</td>
<td>N</td>
<td>1.65</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>SO₃</td>
<td>11.4</td>
<td>3.0</td>
<td>O</td>
<td>11.8</td>
<td>41.7</td>
<td></td>
</tr>
</tbody>
</table>

- Probe location: 2.8 m.
- Uncooled ceramic probe;
- 37 mm OD and 150 mm Length.
- Thermal input: 200 kW.

Schematic diagram of ash deposition measurement.
2 Models: Ash deposition models

3D CFD simulation of combustion (turbulence, combustion, and radiation)

Flow field, gas composition, temperature and ash flux.

2D CFD case for deposition.

Inertia impaction

Particle sticking model based on excess energy [7]

Overall deposition

Particle impaction

Particle ash deposition

Schematic diagram of ash deposition prediction

3 Results: Experimental results of ash deposition

<table>
<thead>
<tr>
<th>g/(m²*hr)</th>
<th>Exp.</th>
<th>Predictions</th>
</tr>
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<tr>
<td>Coal-air</td>
<td>6.92</td>
<td>7.50</td>
</tr>
<tr>
<td>Recy-air</td>
<td>24.22</td>
<td>30.56</td>
</tr>
<tr>
<td>Recy-o27</td>
<td>22.49</td>
<td>24.22</td>
</tr>
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</table>

a) For all cases, the deposits are mainly formed at the windward section and the leeward section of the probe is clean.
b) Recycled > coal.
c) For Recy., Air slightly > Oxy27.
d) Predictions are close to measurements.
3 Results: Predicted particle size based deposition behaviour

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Overall impaction and sticking:

a) For impaction efficiency, biomass > coal
b) For sticking efficiency, coal > biomass
c) For impaction efficiency, bio-Air > bio-Oxy27.
d) For sticking efficiency, bio-Air ≈ bio-Oxy27.

Particle size based impaction, sticking and deposition:

- For the pilot-scale furnace, deposition formation favours coarse particles.

(1) Overall impaction and sticking behaviour; (2-4) Particle size based impaction, sticking and deposition behaviour.
3 Results: Effect of Oxy conditions (numerical results)

<table>
<thead>
<tr>
<th></th>
<th>Temperature, K</th>
<th>Velocity, m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>air</td>
<td>1531</td>
<td>0.47</td>
</tr>
<tr>
<td>O24</td>
<td>1440</td>
<td>0.54</td>
</tr>
<tr>
<td>O27</td>
<td>1497</td>
<td>0.36</td>
</tr>
<tr>
<td>O30</td>
<td>1563</td>
<td>0.33</td>
</tr>
</tbody>
</table>

**Oxy effect:**

a) Change in velocity and temperature.
b) Affect particle impaction and sticking behaviour.

<table>
<thead>
<tr>
<th></th>
<th>deposition rate g/(m²*hr)</th>
<th>impaction efficiency</th>
<th>sticking efficiency</th>
<th>deposition efficiency</th>
</tr>
</thead>
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<tr>
<td>air</td>
<td>30.56</td>
<td>0.14</td>
<td>0.39</td>
<td>0.055</td>
</tr>
<tr>
<td>O24</td>
<td>27.68</td>
<td>0.18</td>
<td>0.27</td>
<td>0.05</td>
</tr>
<tr>
<td>O27</td>
<td>24.22</td>
<td>0.11</td>
<td>0.39</td>
<td>0.043</td>
</tr>
<tr>
<td>O30</td>
<td>23.07</td>
<td>0.1</td>
<td>0.42</td>
<td>0.041</td>
</tr>
</tbody>
</table>

**Air vs Oxy**

a) For deposition rate, Air slightly > Oxy.

**Oxy 24, 27 and 30**

a) Oxy↑, deposition rate slightly ↓.
b) Overall effect of impaction and sticking.
3 Results: Effect of flue gas velocity (numerical results)

Effect on deposition rate:

a) The difference between air and oxy27 is small, although air slightly > oxy27.

b) Interestingly, with increasing the flue gas velocity, Coal > biomass, different from the PACT results.

Effect on the particle size based deposition efficiency:

a) Very different selective deposition behaviour.

b) PACT furnace, low furnace velocity, deposition favours the coarse particles. This makes biomass to have a higher overall deposition efficiency than the coal.

c) With velocity ↑, deposition gradually favours medium to small particle. This can make the coal to have a much higher deposition rate than biomass.
4 Conclusions

i. In the pilot-scale furnace, Recy. > Coal and Recy.-Air slightly > Recy.-Oxy 27.

ii. An ash deposition model has been developed and validated.

iii. By using the model, deposition efficiency of coal > biomass with same size. However, in pilot-scale furnace, low velocity conditions favour coarse particle deposition. In addition, the recycled wood has a much higher ash concentration. Both make the biomass have a higher deposition rate than coal.

iv. Change in the oxy condition can affect the velocity and temperature, which affects the deposition formation.

v. The transfer of the deposition observations in the pilot-scale furnace to full-scale boiler should be performed very cautious. Furnace velocity condition has a significant effect.
Acknowledgments

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Many thanks for your kind attention.
Reference


