Development of High Efficiency CFB Technology to Provide Flexible Air/Oxy Operation for Power Plant with CCS

FLEXI BURN CFB

WP1: Oxygen-firing knowledge – Comparison of air- and oxygen-firing

1st Project Workshop, 24th March 2011, Brussels
WP1: Oxygen-firing knowledge – Comparison of air- and oxygen-firing

WP2: Development of design tools

WP3: Demonstration tests at large pilot unit and commercial scale air fired unit

WP4: Boiler design and performance

WP5: Power plant integration, optimization and economics

WP6: Feasibility and readiness for the utilization of the technology within different regions in EU

WP7: Coordination and dissemination

Supporting R&D work

Technology demonstration and background for the commercial scale design process

Viable boiler design

Viable power plant
Main objectives

The purpose is to extend the knowledge of oxygen-firing in a circulating fluidized bed (CFB) boiler that is in a CO₂ - H₂O rich atmosphere differing considerably from that of normal combustion with air.

1. Laboratory scale combustion tests under air- and oxygen-firing conditions with different fuels and blends
2. Effect of flue gas composition (air-firing versus oxygen-firing) on heat transfer
3. Effect of flue gas composition (air-firing versus oxygen-firing) and process scale-up on hydrodynamics
4. Submodels for combustion and emission formation
Laboratory scale combustion tests have been carried out with pilot scale and bench scale test rigs at VTT.

Tests provide a base for development and validation of the design tools needed in the concept development.

Totally seven different fuels were selected for the combustion tests.

The selected project fuels cover the whole range of coals from anthracite to lignite. Straw pellet represents a typical agrobiomass which is easily available whereas wood represents a typical good quality forest-based biomass which is also available in many locations of the Europe.

### Fuels

<table>
<thead>
<tr>
<th>Fuels</th>
<th>Mixture ratio as energy basis</th>
<th>Mixture ratio as mass basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthracite + Pet-coke</td>
<td>55/45</td>
<td>70/30</td>
</tr>
<tr>
<td>Anthracite</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Bituminous coal (Polish)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Lignite (Spanish) + South African coal</td>
<td>55/45</td>
<td>70/30</td>
</tr>
<tr>
<td>Anthracite + wood</td>
<td>90/10</td>
<td>85/15</td>
</tr>
<tr>
<td>Bituminous coal (Polish) + straw pellet</td>
<td>80/20</td>
<td>75/25</td>
</tr>
</tbody>
</table>
7 fuels and 2 limestones were applied in the small pilot scale combustion tests

<table>
<thead>
<tr>
<th>Fuel analysis</th>
<th>Anthracite (Spanish)</th>
<th>Pet-coke</th>
<th>Polish bituminous coal</th>
<th>Spanish lignite</th>
<th>South-African coal</th>
<th>Wood chips</th>
<th>Straw pellet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (w-%)</td>
<td>12.1</td>
<td>3.1</td>
<td>20.4</td>
<td>19.7</td>
<td>4.0</td>
<td>35</td>
<td>15</td>
</tr>
<tr>
<td>Ash, dry basis, (w-%) +815 °C</td>
<td><strong>35.6</strong></td>
<td>0.4</td>
<td><strong>13.0</strong></td>
<td><strong>33.0</strong></td>
<td>15.9</td>
<td>0.63</td>
<td>5.2</td>
</tr>
<tr>
<td>Ash, dry basis, (w-%) +550 °C</td>
<td><strong>36.7</strong></td>
<td>0.6</td>
<td><strong>14.0</strong></td>
<td><strong>34.1</strong></td>
<td>------</td>
<td>0.71</td>
<td>5.8</td>
</tr>
<tr>
<td>Volatile content, dry basis (w-%)</td>
<td>10.2</td>
<td>12.8</td>
<td>35.9</td>
<td>32.2</td>
<td>25.6</td>
<td>83.22</td>
<td>76.5</td>
</tr>
<tr>
<td>Higher heating value, dry basis (kJ/kg)</td>
<td>20810</td>
<td>35370</td>
<td>26640</td>
<td>18180</td>
<td>27730</td>
<td>20051</td>
<td>18260</td>
</tr>
<tr>
<td>Lower heating value, dry basis (kJ/kg)</td>
<td>20330</td>
<td>34540</td>
<td>25700</td>
<td>17470</td>
<td>26880</td>
<td>18751</td>
<td>16980</td>
</tr>
<tr>
<td><strong>Element analysis, dry basis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-content (w-%)</td>
<td>55.2</td>
<td>86.4</td>
<td>65.6</td>
<td>45.1</td>
<td>69.5</td>
<td>50.1</td>
<td>46.2</td>
</tr>
<tr>
<td>H-content (w-%)</td>
<td>2.2</td>
<td>3.9</td>
<td>4.4</td>
<td>3.3</td>
<td>3.9</td>
<td>6.12</td>
<td>5.9</td>
</tr>
<tr>
<td>N-content (w-%)</td>
<td>0.84</td>
<td>1.74</td>
<td>1.09</td>
<td>0.60</td>
<td>1.72</td>
<td>0.06</td>
<td>0.66</td>
</tr>
<tr>
<td>S-content (w-%)</td>
<td>1.75</td>
<td>5.72</td>
<td>2.02</td>
<td><strong>6.28</strong></td>
<td>0.49</td>
<td>0.02</td>
<td>0.32</td>
</tr>
<tr>
<td>O-content (w-%)</td>
<td>4.41</td>
<td>1.84</td>
<td>13.89</td>
<td>11.72</td>
<td>8.49</td>
<td>43.07</td>
<td>41.1</td>
</tr>
</tbody>
</table>
Small pilot scale CFB experiments (0.1MW) under air- and oxygen-firing conditions

- Example of comparison of flue gas emissions in air- and oxygen-firing

<table>
<thead>
<tr>
<th>Emission</th>
<th>Unit</th>
<th>Test 1</th>
<th>Test 3</th>
<th>Test 5</th>
<th>Test 6</th>
<th>Test 7</th>
<th>Test 8</th>
<th>Test 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>[vol-%]</td>
<td>14.7</td>
<td>78.1</td>
<td>78.9</td>
<td>83.0</td>
<td>81.1</td>
<td>81.1</td>
<td>82.0</td>
</tr>
<tr>
<td>CO</td>
<td>[vol-ppm]</td>
<td>107</td>
<td>387</td>
<td>250</td>
<td>409</td>
<td>679</td>
<td>467</td>
<td>326</td>
</tr>
<tr>
<td>NO</td>
<td>[vol-ppm]</td>
<td>75</td>
<td>63</td>
<td>60</td>
<td>51</td>
<td>56</td>
<td>52</td>
<td>64</td>
</tr>
<tr>
<td>SO₂</td>
<td>[vol-ppm]</td>
<td>201</td>
<td>1171</td>
<td>471</td>
<td>1536</td>
<td>1224</td>
<td>720</td>
<td>372</td>
</tr>
</tbody>
</table>

<table>
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<th>Emission</th>
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<th>Test 7</th>
<th>Test 8</th>
<th>Test 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>[mg/MJ]</td>
<td>44</td>
<td>46</td>
<td>28</td>
<td>42</td>
<td>75</td>
<td>53</td>
<td>34</td>
</tr>
<tr>
<td>NO</td>
<td>[mg/MJ]</td>
<td>33</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>SO₂</td>
<td>[mg/MJ]</td>
<td>187</td>
<td>316</td>
<td>122</td>
<td>358</td>
<td>309</td>
<td>187</td>
<td>89</td>
</tr>
</tbody>
</table>

- The expression of the results in units of mg/MJ provides an equal base for the air- and oxygen-firing cases due to flue gas flow to stack is much lower in oxygen-firing compared to air-firing.
- When the combustion is carried out without air, the nitrogen from air does not dilute the emission concentrations in flue gases.
- Emission concentrations of the flue gases from combustion are typically higher in oxygen-firing compared to air-firing. However, the mass flow rates of emission compounds to atmosphere/carbon capture unit are lower than in the air-firing.
Operational point of views:
- Combustion process dynamics
- Transition between air- and oxygen firing
Small pilot scale CFB experiments (0.1MW) under air- and oxygen-firing conditions

- Small pilot scale CFB experiments (0.1MW) under air- and oxygen-firing conditions have been completed with totally 33 experiments.

- Transition between air- and oxygen firing conditions could be carried out smoothly and safely with the renovated automation system which included an automated transition mode between air- and oxygen-firing.

- **Combustion process could be operated in the both modes without any major drawbacks.**

- Based on the dynamic tests the reliable control of oxidant oxygen concentration is very important from the safety operation and process controllability point of view.

- If the inlet gas (oxidant) oxygen concentration is controlled effectively the combustion process stability seems to be comparable to corresponding air-firing conditions.

- If flue gas emissions are expressed in milligrams per megajoules the emission levels between air- and oxygen-firing have not remarkable differences.

![Bottom ash](image1.png)

**Bottom ash**
- **Air-firing (Test 19)**
  - CaCO3 [%]
  - CaO [%]
  - CaSO4 [%]

![Bottom ash](image2.png)

**Bottom ash**
- **Oxygen-firing (Test 20)**
  - CaCO3 [%]
  - CaO [%]
  - CaSO4 [%]
CFB technology is scaling up with the latest high-efficiency SC-OTU-references Lagisza (460 MWe). The Lagisza power plant (460 MWe), located in the southern Poland, is the world's largest CFB boiler, which is also the world's first supercritical CFB once-through unit (OTU).
Aim is to develop a dynamic similarity formula that will enable the analysis of boiler hydrodynamics in a laboratory scale based on the operation parameters.

The analysis will be performed on a 3D stand, with the geometric similarity being preserved.

Due to symmetry of combustion chamber the test stand is a half of the original Lagisza boiler in lateral direction.

The cold model was built with using a strong transparent plexiglass to get best possible visibility from every direction to the whole circulation process.

Effect of process scale-up on hydrodynamics has been studied with experiments in cold flow pilots.
Process scale-up and hydrodynamics

- Use of scale models allows the hydrodynamics of the Lagisza 460MWe supercritical CFB boiler to be satisfactorily reflected on a scaling model with a scale factor of k=1/20
- Next step is to solve the effect of flue gas composition on hydrodynamics i.e. air-firing vs oxygen-firing
Heat transfer (in back pass) convection and radiation

- 3D model of convective zone developed
- Based on Lagisza geometry
- Supercritical thermodynamics implemented, and checked
- Shell-side pressure-loss correlations investigated
- Radiation implemented
- Next step is to solve the effect of flue gas composition on heat transfer i.e. air-firing vs oxygen-firing
Development of submodels and modelling tools

- The modelling tools have been developed to support the development of the concept.
- The new 3D model frame is a major achievement and allows more detailed and realistic simulations of large CFB furnaces.
- The new developed 3D sorbent model allows simulation of various phenomena, which could not be done with the old 3D model, such as modelling of carbonation, direct sulfation and desulfation and flow modelling of each particle size fraction.
- The new features improve the prediction capability significantly.
- Based on the 3D modelling study, the sorbent reactions in oxygen-firing conditions may have a large impact on the furnace process. These reactions can have a large impact on local gas atmosphere, velocities and temperatures.

Oxygen concentration of Flexi-Burn CFB in air fired (left) and oxygen fired (right) mode.
WP1: Oxygen-firing knowledge –
Comparison of air- and oxygen-firing

Summary after the first half of the project M1-M18

The purpose is to extend the knowledge of oxygen-firing in a circulating fluidized bed (CFB) boiler that is in a CO$_2$ - H$_2$O rich atmosphere differing considerably from that of normal combustion with air.
WP1 Summary

• Experiments mainly completed
  – Encouraging results were obtained of the flexible operation under air- and oxygen-firing

• Submodel development is in progress
  – Phenomena differences between air- and oxygen firing has been identified (e.g. limestone behaviour, infurnace sulfur capture, heat transfer)

• Next steps
  – Validation of models
  – Scale up of results
  – Main results available by end of August 2011