Design and modelling of a 330 MWe Flexi-Burn® CFB for oxygen-fired and air-fired combustion

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Design and Modelling of a 330 MWe Flexi-Burn® CFB for Oxygen-Fired and Air-Fired Combustion

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Introduction

- A Flexi-Burn® CFB is a concept, in which a circulating fluidized bed (CFB) boiler can be operated both in air-fired and oxygen-fired modes.

- A commercial CCS demonstration plant applying the Flexi-Burn concept is under development at Compostilla, Spain (OXYCFB300-project).

- The design is supported by one-dimensional and three-dimensional modelling.
Development path from small to large scale

- **Bench scale**
- **Pilot scale**
- **Demonstration/Commercial scale**

**EXPERIMENTAL SCALES**
- Models and design tools
- Models for phenomena
- 1-D process models
- 3-D process models

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Simplified schematic of a Flexi-Burn CFB power plant
## Main process data of studied cases

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Air-fired</th>
<th>Oxygen-fired</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler load</td>
<td>%</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>Boiler capacity</td>
<td>MWe</td>
<td>300</td>
<td>330</td>
</tr>
<tr>
<td>Fuel flow rate</td>
<td>kg/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anthracite</td>
<td></td>
<td>18.1 (70%)</td>
<td>22.0 (70%)</td>
</tr>
<tr>
<td>Petcoke</td>
<td></td>
<td>7.8 (30%)</td>
<td>9.4 (30%)</td>
</tr>
<tr>
<td>Limestone flow rate</td>
<td>kg/s</td>
<td>5.4</td>
<td>6.6</td>
</tr>
<tr>
<td>Inlet gas flow to furnace</td>
<td>kg/s</td>
<td>272.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Ambient air</td>
<td></td>
<td>0.0</td>
<td>63.8</td>
</tr>
<tr>
<td>Oxygen (95% $O_2$)</td>
<td></td>
<td>0.0</td>
<td>261.9</td>
</tr>
<tr>
<td>Recirculated gas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_2$ content of inlet gas</td>
<td>%-vol</td>
<td>20.7</td>
<td>23.6</td>
</tr>
<tr>
<td>Primary gas ratio</td>
<td>%</td>
<td>62</td>
<td>60</td>
</tr>
<tr>
<td>Fly ash recirc. share</td>
<td>%</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

### Proximate analysis (as rec.)

<table>
<thead>
<tr>
<th></th>
<th>Anthracite</th>
<th>Pet-coke</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>8.3</td>
<td>6.6</td>
</tr>
<tr>
<td>Ash</td>
<td>30.7</td>
<td>1.3</td>
</tr>
<tr>
<td>Volatiles</td>
<td>6.4</td>
<td>11.8</td>
</tr>
</tbody>
</table>

### Ultimate analysis (daf)

<table>
<thead>
<tr>
<th></th>
<th>Anthracite</th>
<th>Pet-coke</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>89.5</td>
<td>87.2</td>
</tr>
<tr>
<td>H</td>
<td>2.9</td>
<td>3.7</td>
</tr>
<tr>
<td>N</td>
<td>1.4</td>
<td>1.8</td>
</tr>
<tr>
<td>S</td>
<td>1.7</td>
<td>6.1</td>
</tr>
<tr>
<td>O</td>
<td>4.5</td>
<td>1.2</td>
</tr>
</tbody>
</table>
One-dimensional design model

- Foster Wheeler’s stationary 1D design model is a semi-empirical tool consisting of several sub-models, which describe the furnace processes.
- Very large validation base of air-fired combustion.
- Validation of oxygen-fired combustion based on bench-scale and pilot-scale tests.
One-dimensional model results

Heat rel. (kW/m3), Temp. (°C)

Air-fired:  
- Heat rel. (kW/m3)
- Temp. (°C)
- Oxygen (mol-%)

Oxygen-fired:  
- Heat rel. (kW/m3)
- Temp. (°C)
- Oxygen (mol-%)

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Three-dimensional model

- A steady-state, semi-empirical model, which describes the CFB furnace process.
- 3D-modelling of furnace based on control volume method.
- Validation based on field tests at pilot scale and full scale units.

- Calculation mesh of Compostilla CFB:
Oxygen profiles

Air-fired

Oxygen-fired

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Carbon monoxide profiles

Air-fired

Oxygen-fired

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Temperature profiles

Air-fired

Oxygen-fired

Carbonation (oxygen-fired)

Temperature [°C]
- 960
- 910
- 860
- 810
- 760

Carbonation [mol/m3s]
- 2
- 1.5
- 1
- 0.5
- 0
Sulphation and sulphur dioxide profiles

Air-fired

Oxygen-fired

SO₂ [mol-%]
0.3
0.25
0.2
0.15
0.1
0.05
0

Sulfation [mol/m³s]
0.05
0.04
0.03
0.02
0.01
0

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Molar balance of sulphur dioxide

Air-fired (sources)

Air-fired (sinks)

Oxygen-fired (sources)

Oxygen-fired (sinks)

Molar flow of SO$_2$ (mol/s)

0 10 20 30

Gas feed
Char combustion
H2S combustion
Desulphation
Sulphation
Direct sulphation
Recirc. gas
Flue gas

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Validation by CIUDEN TDP test data

Work in progress...

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Summary

- A Flexi-Burn CFB is a concept, in which a circulating fluidized bed boiler can be operated both in air-fired and oxygen-fired modes.

- 1D and 3D process models have been used to support the design of the OXYCFB300 Compostilla demonstration plant.

- Model analyses reveal phenomena, which need to be considered in the design.

- For future improvement, the different empirical correlations describing the furnace phenomena need to be further validated based on measurement data from CIUDEN TDP test facility.