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

FLEXI BURN CFB

2nd International Workshop on Oxyfuel FBC Technology
Antti Tourunen
VTT Technical Research Centre of Finland
Aim: to develop and demonstrate FLEXI BURN CFB concept enabling to reach the target of near zero emission power plants

The FLEXI BURN CFB concept:
High efficiency Circulating Fluidized Bed (CFB) power plant with CCS capable of air/oxy operation with a wide range of fuels including biomass

The FLEXI BURN CFB concept has a set of important advantages:

1. **fuel flexibility** in order to decrease dependency on imported coals and in order to improve power plant economics especially with CCS operation

2. **operational flexibility** in order to apply air-firing and oxygen-firing with CO$_2$ capture

3. lower NO$_x$ production due to reduced and more uniform furnace temperature profiles, and lower SO$_x$ concentration in flue gases due to in-furnace capture, thus reducing the need for downstream flue gas cleaning

4. overall concept for phased transition into CCS technology with minimised risks through high efficiency air-oxy flexible CFB combustion

5. lower specific CO$_2$ emissions from the reduced consumption of fuel due to the intrinsic high efficiency of the technology. In addition, by substituting e.g. 20% of coal input with renewable fuels, CO$_2$ emissions can further be reduced by 15-20%.

6. Provides utilities an attractive alternative to take into use the new technology and decommission old capacity with lower efficiency and poorer emission performance
The FLEXI BURN CFB concept:
High efficiency Circulating Fluidized Bed (CFB) power plant with CCS capable of air/oxy operation with a wide range of fuels including biomass.
Role of FLEXI BURN CFB Partners

Research institutes
- VTT, LUT, CzUT UNIZAR-LITEC, AICIA

Manufacturers
- FWEOY, FWESA, ADEX, Siemens, Praxair

Utilities
- Endesa, EDP, Tauron Generation

Development steps
1. Concept
2. Laboratory and small pilot scale test (0.1-1MWth)
3. Demonstration Pilot Plant 30 MWth, CIUDEN
4. 1st Commercial scale FLEXI BURN CFB Power Plant
5. FLEXI BURN CFB Power Plant

FLEXI BURN CFB project
2009 - 2012

Industrial applicability
Demonstration of FLEXI BURN CFB
CIUDEN 30MW\textsubscript{th}
- air-/ oxy-firing with fuel flexibility
- CO\textsubscript{2} separation

Field measurements at OTU CFB
Lagisza 460 MWe
- scale-up information from the world first and largest OTU CFB
- design model validation

FLEXI BURN CFB - General project structure

- WP1: R&D support
- WP2: Design tools
- WP3: Demonstration
- WP4: Boiler design
- WP5: Power plant concept
- WP6: Commercial Scale FLEXIBURN

Scale up criteria
Commercial scale FLEXI BURN CFB Technology
Air- / oxy-firing CCS expertise
Background for engineering
Development and **demonstration** in multiple scales

**EXPERIMENTAL SCALES**

**MODELS AND DESIGN TOOLS**

**MODELS FOR PHENOMENA**

1-D PROCESS MODELS

3-D PROCESS MODELS
Process scale-up

- 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)

<table>
<thead>
<tr>
<th></th>
<th>CFB800</th>
<th>Lagisza</th>
<th>Turow 4-6</th>
<th>JEA</th>
<th>Turow 1-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furnace</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Width</td>
<td>m</td>
<td>40</td>
<td>27.6</td>
<td>22.0</td>
<td>26.0</td>
</tr>
<tr>
<td>- Depth</td>
<td>m</td>
<td>12</td>
<td>10.6</td>
<td>10.1</td>
<td>6.7</td>
</tr>
<tr>
<td>- Height</td>
<td>m</td>
<td>50.0</td>
<td>48.0</td>
<td>42.0</td>
<td>35.1</td>
</tr>
</tbody>
</table>
Validation runs at a 460 MW<sub>e</sub> SC-OTU CFB boiler

EMISSION (at 6% O<sub>2</sub>, dry flue gas) (follows EU's LCP directive), mg/Nm<sup>3</sup>

- SO<sub>2</sub> 200
- NO<sub>x</sub> (as NO<sub>2</sub>) 200
- CO 200
- Dust 30

Typical measurements during the test runs:
- Temperature profiles
- Pressure profiles
- Gas profiles
- Process data (including emission data)
- Fuel and ash samples
FLEXI BURN CFB – Demonstration steps

Aim: to develop and demonstrate FLEXI BURN CFB concept enabling to reach the target of near zero emission power plants

Concept for 300 MWₑ

VTT 0.3kW

VTT 0.1MW

CANMET 1MW

CIUDEN 30MW

Completed

In progress
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.

<table>
<thead>
<tr>
<th>Fuels</th>
<th>Mixture ratio on energy basis (LHV wet)</th>
<th>Mixture ratio on mass basis (wet)</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>
Small pilot scale CFB experiments (0.1MW) under air- and oxygen-firing conditions

Fuel reactivity

Combustion process dynamics

Transition between air- and oxygen-firing

Air-firing

Oxygen-firing

Oxygen-firing

Air-firing
Ash characteristics: air/oxy

Oxygen-firing test with high temperature

Air-firing test

Measured calcium compounds in bottom ash

Bottom ash Air-firing (Test 19)

Bottom ash Oxygen-firing (Test 20)
Model based analysis of the CANMET test data

Test program at CanmetENERGY, Ottawa

- 15 test weeks
- Runs: 88 of which
  - 35 in air combustion
  - 53 in oxy combustion

- Detailed analysis of solids mass balance
- Furnace vertical temperature profile
- Combustion and energy release profile
- Solids density profile
- Heat flux profile

➡ Furnace heat transfer
Demonstration runs at a 30 MWth CFB pilot plant

Presentation on Thursday 28th June: Oxyfuel testing at 30MWth CIUDEN Oxy-CFB boiler
Specifications for a FLEXI BURN CFB demonstration plant

**Plant size:**

- Two cases considered:
  - Flexi Burn CFB demonstration plant:
    - 300-350 MWe gross. (Detailed technical scope, main focus)
  - Full Commercial plant - post-2020:
    - 800 MWe gross (techno-economical feasibility study)
Specifications for a FLEXI BURN CFB demonstration plant

- **Steam parameters:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main steam temperature</td>
<td>598 °C</td>
</tr>
<tr>
<td>Main steam pressure</td>
<td>270 bar</td>
</tr>
<tr>
<td>Reheated steam pressure</td>
<td>57 bar</td>
</tr>
<tr>
<td>Reheated steam temperature</td>
<td>600 °C</td>
</tr>
</tbody>
</table>

- **Operating parameters:**

<table>
<thead>
<tr>
<th>Dynamic requirements for the power plant</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational Mode</td>
<td>Base Load</td>
</tr>
<tr>
<td>Load change rate</td>
<td>Max ramping 4%/min</td>
</tr>
<tr>
<td>Minimum load</td>
<td>40%</td>
</tr>
<tr>
<td>Start-up time (cold)</td>
<td>&lt;24h</td>
</tr>
<tr>
<td>Start-up time (ASU cold)</td>
<td>&lt;8h</td>
</tr>
</tbody>
</table>

- **Annual equivalent operating hours**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxy mode</td>
<td>6500 h</td>
</tr>
<tr>
<td>Air mode</td>
<td>500 h</td>
</tr>
<tr>
<td>TOTAL</td>
<td>7000 h</td>
</tr>
</tbody>
</table>

- **CO₂ compressed to transport by pipeline**

<table>
<thead>
<tr>
<th>CONCENTRATION</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O</td>
<td>&lt; 500 ppm</td>
</tr>
<tr>
<td>CO</td>
<td>&lt; 2000 ppm</td>
</tr>
<tr>
<td>O₂ + N₂ + Ar</td>
<td>&lt; 4 vol%</td>
</tr>
<tr>
<td>SOₓ</td>
<td>&lt; 100 ppm</td>
</tr>
<tr>
<td>NOₓ</td>
<td>&lt; 100 ppm</td>
</tr>
<tr>
<td>CO₂</td>
<td>&gt;95.5 %</td>
</tr>
</tbody>
</table>

- **Other oxycombustion criteria:**

  - **Air inleakage:** Base case 1% (sensitivity analysis up to 3%)
  - **O₂/CO₂ ratio:** close to air concentration (24% O₂ wet)
  - **Oxygen purity:**

    | Oxygen purity | 96.6 % vol |
    | Pressure      | 1.2 bar    |
    | Temperature   | 20 °C      |
Current status (1/2)

- **A lot of experimental work** has been carried out in order to support the development of FLEXI BURN CFB concept

- Combustion tests in different scales and field measurements in a commercial scale power plant provide a base for **development and validation of the design tools** needed in the concept development

- Demonstration tests at different scales:
  - VTT 0.1MW, CANMET 1MW has been completed (totally over 100 oxyfuel test balances) with encouraging results
  - **Flexible operation under air- and oxygen-firing modes** have been successful demonstrated in the small scales 0.1MW-1MW
  - Validation test campaigns with the world first and the largest (460 MWe) OTSC-CFB has been successfully completed
The design parameters for a FLEXI BURN CFB plant, from a technical and operational point of view, have been determined:

- Two cases considered: 1) Flexi Burn CFB demonstration plant: 300-350 MWe gross
  2) Full Commercial plant - post-2020: 800 MWe gross

The conceptual design of the FLEXI BURN CFB boiler has been developed.

The conceptual design for the FLEXI BURN CFB plant has been implemented including a preliminary integration with the Air Separation Unit (ASU) and the Compression and Purification Unit (CPU).
Next steps

- Demonstration tests at CIUDEN are ongoing
- Final verification of the concept based on the test results from CIUDEN
- Concept optimisation for the boiler island and the integrated power plant unit including dynamic simulation of the plant
- Health and safety assessment related to oxygen-firing conditions
- Estimate economics for the new concept and evaluate their feasibility on a commercial scale range
- Identification of the key success factors of the FLEXI BURN CFB technology covering the process efficiency, operability, maintainability, environmental impact and responsiveness to the market requirements, all leading to the economic performance of this new approach for power generation
- Project completed by February 2013
FLEXI BURN CFB

• More information on the project
  http://www.vtt.fi/sites/flexiburncfb/

Acknowledgements:
The research leading to these results has received funding from the European Community’s Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 239188.