An advanced oxy-fuel process with CO2 capture based on elevated pressure combustion

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• Introduction
• Main process concept
  - elevated pressure combustion / advantages / disadvantages
  - heat integration
• PFBC boiler as main hardware component
• Simulation results
• DoE project (team, targets etc)
Main Idea
Elevated pressure

Pressurized combustion:
- GTI/Linde concept: 10-30 bar (Washington University, Korea Institute of Ind. Techn.)
- ITEA concept: approx. 5 bar
- other concepts > 80 bar (Hanno Tautz, Linde, …)
Main Idea
Heat integration and recycle

Heat integration:
Condensation heat, ASU compressor heat, CPU compressor heat?
Recycle options: warm recycle or cold recycle or combination of both
Bubbling fluidized bed. Within the bed there are two classes of particles: larger inert particles that make up the fluidized bed, and smaller pulverized coal and limestone particles that are elutriated, or carried up, through the bed by the gas flow that fluidizes the bed particles. The fluidizing gas is composed of oxygen mixed with recycled CO2

- Cooling: heat exchanger similar to HRSG
- Condensation: direct contact apparatus (similar to cooling tower)
- Candle filters for ash removal
- LICONOX® and DEOXO systems for NOx/SOx polishing and oxygen removal
Process Overview
• Air-fired PFBCs have been operating at commercial scale since the plant in Vartan, Sweden started in 1989 producing 135 MWe and 225 MWth for district heating.

• The 1990’s saw additional commercial scale PFBC’s become operational in Spain (Escatron), Japan (Wakamatsu and Karita), Germany (Cottbus) and the United States (Tidd).

**Information conc. this boiler**

• Visits to the PFBC plants in Cottbus and Vartan, information exchange

• published reports from others

• direct experience during the Atmospheric Fluidized Bed (AFB)6 program in the 1980s, where an AR heat exchanger and coal-fired fluidized bed combustor were developed and tested to demonstrate life.
## References for pressurized air-fired boilers

<table>
<thead>
<tr>
<th>Location</th>
<th>SIZE MW&lt;sub&gt;e&lt;/sub&gt;</th>
<th>FUEL</th>
<th>COMM. DATE</th>
<th>REMARKS</th>
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</thead>
<tbody>
<tr>
<td>Vartan, Stockholm, Sweden</td>
<td>135 (2x70)</td>
<td>Bituminous Coal</td>
<td>1990</td>
<td>ABB-Carbon, Power &amp; Heat</td>
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<td>Tidd, AEP, Ohio, USA</td>
<td>73</td>
<td>Bituminous Coal</td>
<td>1991</td>
<td>Asea-Babcock (ABB-Carbon and B&amp;W Joint Venture)</td>
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<td>Escatron, ENDESA, Spain</td>
<td>79.5</td>
<td>Black Lignite</td>
<td>1990</td>
<td>ABB Carbon, Babcock &amp; Wilcox Espanola, Demonstration plant</td>
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<tr>
<td>Wakamatsu, EPDC, Kyushu, Japan</td>
<td>71</td>
<td>Bituminous Coal</td>
<td>1994</td>
<td>Demonstration plant supplied by IHI, Licensee of ABB</td>
</tr>
<tr>
<td>Tomato-Atsuma, HEPCO, Japan</td>
<td>85</td>
<td>Coal</td>
<td>1995</td>
<td>MHI, Japan; began commercial operation in Feb 1998; tubular ceramic filters</td>
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<tr>
<td>Trebovice, Czech Republic</td>
<td>70</td>
<td>Hard Coal</td>
<td>1996</td>
<td>Power, Steam &amp; Heat</td>
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<tr>
<td>Karita, Kyushu, Japan</td>
<td>350</td>
<td>Hard Coal</td>
<td>1999</td>
<td></td>
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<tr>
<td>Osaki, Chugoku, Japan</td>
<td>250</td>
<td></td>
<td>1999</td>
<td>Hitachi</td>
</tr>
<tr>
<td>HKW Cottbus, Germany</td>
<td>71</td>
<td>brown coal</td>
<td>1999</td>
<td>ABB Kraftwerke AG</td>
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</tbody>
</table>
PFBC based power plant in Cottbus

Cutaway drawing of the Cottbus PFBC power plant with ABB T200 module:

1. PFBC pressure vessel
2. PFBC feed vessel
3. In-bed boiler tubes
4. Feedwater
5. Control deck
6. Cyclones
7. Closed coil and gas pipe
8. Interceptor valves
9. Gas turbine
10. Intercooler
11. Gas turbine generator
12. Gas turbine air intake
13. Economizer
14. Manganese filter
15. Bed ash removal
16. Peak load boilers
17. PFBC feedwater pumps
18. Peak load boiler feedwater pumps
19. Hot water pumps
20. HP steam turbine
21. HP steam turbine generator
22. IHLP steam turbine
23. IHLP steam turbine generator
24. Condenser
25. Feedwater tank
26. Distal heating hot water tank
27. Auxiliary condenser
28. Control room
250 MW plant
Hitachi

• Operating Pressure: 10 bar
• The fluidized-bed temperature is 865°C. The bed height varies from 2.5 to 4.0 m to enable changing the effective area of the heat-exchanger tubes laid out in the bed and adjusting the amount of steam generated by the boiler.

• Sulfur oxides (SOx) in the furnace gas are desulfurized by the limestone in the furnace and the limestone fed into the furnace together with coal.
Cost of Generation of PFBC compared with other Advanced Technologies*

* Source unreliable
Simulation Framework

- Simulation tool: Optisim for thermal calculations and optimization (equation based → therefore enhanced optimization is possible)
- Separate simulation tool (Unisim with Aspen electrolyte package) for chemistry
- Coal: Illinois #6
- Steam cycle: NETL, we assume that an appropriate steam turbine is available
- Real ASU with an external oxygen compressor
- No modelling for PFBC, we assume a fixed pressure drop and a fixed thermal efficiency
Simulation flowsheet
Heat integration

Boiler feedwater preheating

Condensat preheating

\(\dot{Q}_{\text{from flue gas cooling}}\)

\(\dot{Q}_{\text{heat from deoxidator}}\)

\(\dot{Q}_{\text{heat of condensation}}\)

HP Turbine

MP Turbine

LP Turbine

Condenser
• Warm recycle is more efficient
• Max efficiency at 20-25 bar
• Considerable increase in efficiency in 5-15 bar range
Oxygen purity study

• Max efficiency at oxygen purity of 95-96% for all pressures for all kinds of recycles
DoE -project
Technology Description: Oxy-PFBC\(^1\)

**Efficiency Enhancement**

- Staged combustion with elutriation reduces O\(_2\) consumption relative to low pressure oxyfuel, with high sulfur capture
- Pressurization reduces energy required for CO\(_2\) purification
- Flue gas heat recovery at higher temperature

**Cost Reductions**

- PFBC\(^1\) – Reduces combustor size by 2/3 and Capex cost by half
- Fluidized bed enhances heat transfer by factor of 3+, reducing HEX size and cost
- Simpler, lower-cost CPU\(^2\)
- Eliminates FGD\(^3\)

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Note: 1) Oxy-PFBC = Oxy-fired pressurized fluidized bed combustor  2) CPU = CO2 Purification Unit  3) FGD = Flue Gas Desulfurization
<table>
<thead>
<tr>
<th>Organization</th>
<th>Role/ responsibility</th>
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</table>
| **GTI** (former Aerojet Rocketdyne,  | • Project lead & PFBC technology  
| former Pratt Whitney Rocketdyne)    | • **Process & system engineering**  
|                                      | • Risk mitigation & pilot test planning                                                                                                                                 |
| **Linde Group**                      | • **Oxygen supply**  
|                                      | • Flue gas path after PFBC (cooling, condensation, drying, oxygen removal, heat integration)  
|                                      | • Support for heat exchanger design                                                                                                                                 |
| **Canmet ENERGY**                    | • **Pilot test facility**  
|                                      | • Procurement and construction  
|                                      | • Operation of PFBC facility                                                                                                                                 |
| **EPRI**                             | • Voice of end user  
|                                      | • Review of process and cost modelling                                                                                                                                 |
| **Jamestown bpu**                    | • Field demonstration unit site  
|                                      | • Support demo plant design and cost estimate                                                                                                                                 |
| **ALSTOM**                           | • PFBC design support  
|                                      | • Commercialization partner                                                                                                                                 |
| **PennState**                        | • Fluidized bed design support  
|                                      | • Sorbent reaction risk mitigation                                                                                                                                 |
The objectives of the Phase I effort, completed in 2013, were to perform design, bench scale testing and techno-economic analysis of an Oxy-PFBC system.

Techno-economic analysis indicates the Oxy-PFBC system exceeds the United States Department of Energy goals of less than 35% increase in the cost of electricity while capturing at least 90% of the CO2 emissions. Predictions show 90-98% capture with an 18-31% increase in cost of electricity compared to supercritical steam, pulverized coal (SCPC) plant without CO2 capture as defined in DOE Case 11.9.
Further information

Development of a Pilot Scale Coal Powered Oxy-fired Pressurized Fluidized Bed Combustor with CO₂ Capture

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Many thanks for your attention