Feasibility Study on Carbonate Looping Process for Post Combustion CO$_2$-Capture from Coal fired Power Plants

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CO₂ Capture from Coal-Fired Power Plants
Overview of Processes

- Flue gas scrubbing (z.B. MEA scrubbing)
  - Very high energy demand (Δη ~ 14%), high costs
  - Environmental problems (toxic absorbents)
  - „Post-combustion“ technology -> retrofit possible
  - Far developed

- Oxyfuel combustion
  - High energy demand (air separation)
  - Need for further development (e.g. steam generator/burner)

- Gasification technology (IGCC)
  - „Pre-combustion“ technology
  - High energy demand, high costs, complex process
  - Need for further development (e.g. H₂ gas turbine)

- Membrane processes (z.B. AZEP, Oxycoal)
  - Oxyfuel technology
  - Low energy demand
  - High need for development (e.g. materials)

Alternatives: "Oxyfuel“ Chemical Looping
"Post-combustion“ Carbonate Looping
„Post Combustion“

Carbonate Looping
Carbonate-Looping Principle

- "Post-combustion" process
- Energy demand for O\textsubscript{2} supply to calciner (~1/3 of oxyfuel)
Carbonate Looping: Reaktivity of CaO

- Experiments in batch reactor with cyclic carbonisation/calcination (Abanades, 2002)
- Decrease of reactivity of CaO with number of cycles
- Reactivity converges against constant values of approx. 15 %

Application to continuous operation of two reactors

Active fraction of CaO (Formula of Abanades (2005)):

\[ X_{\text{carb}} = \frac{f_m \times (1 - f_w) \times F_0}{F_0 + F_R \times (1 - f_m)} + f_w \]
Process Scheme for Retrofit

Cold end of reference power plant 1052 MW_{el}

CO₂ reduced flue gas

Carbonator
- 650 °C
- Q₁
- CaCO₃ → CaO

Calciner
- 900 °C
- Q₂
- Q₄
- CaCO₃ → CaO

CO₂ compression

Source: Romeo et al.
Mod. by EST TU Darmstadt
Reference Power Plant 1052 MWel

<table>
<thead>
<tr>
<th>Power</th>
<th>( \text{MW}_{\text{th}} )</th>
<th>2308</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{MW}_{\text{el}} ) (net)</td>
<td>1052</td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>% (net)</td>
<td>45.6</td>
</tr>
<tr>
<td>Fuel</td>
<td>Hard coal</td>
<td></td>
</tr>
</tbody>
</table>
ASPEN-Modell: Assumptions

- Flue gas from reference plant after FGD
- Aim: 80 % CO₂ capture in carbonator
- Pressure increase by fan before carbonator: 200 mbar
- 99 % SO₂ capture in carbonator und calciner
- Coal burn-out in calciner: 99,5 %
- Oxygen excess in calciner: \( \lambda = 1,1 \)
- O₂ purity after ASU: 95 %
- Energy demand for ASU: 185 kWh/t O₂ (Source: IVD Stuttgart)
- Cooling of flue gases in steam generator down to 330 °C; below cooling for internal pre-heating down to ~100 °C
- Water/steam process according to reference plant
- 100 % CO₂ capture in calciner
- CO₂ compression treated separately (considered later)
High Makeup rate (at constant CO₂ capture rate in carbonator of 80 %):

→ High Active fraction of CaO → low circulating mass flow required

→ Low energy demand in calciner for heating CaCO₃ from 650 to 900 °C
High Makeup rate (at constant CO₂ capture rate in carbonator of 80 %):

→ Lower energy demand for heating solids, **but** higher energy demand for first calcination of fresh limestone

→ Less CO₂ from coal in calciner (i.e. captured by 100 %)
Heat Balance of Steam Generator

Boundary conditions:
Steam parameters as in reference plant:
- SH: 600 °C, 285 bar
- RH: 620 °C, 59 bar
\( \Delta T > 23 \) K
- Feed water before ECO: 307 °C
- Cooling of flue gas down to 330 °C

Results (APROS):
- Live steam: 476.6 kg/s
- El. gross power: 636.2 MW (as in ASPEN results)
<table>
<thead>
<tr>
<th>Customer</th>
<th>Power plant</th>
<th>Country</th>
<th>Gross $[\text{MW}_{\text{el}}]$</th>
<th>Year of commissioning</th>
<th>Fuel</th>
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<tbody>
<tr>
<td>China Guodian Corp.</td>
<td>Xialongtan</td>
<td>China</td>
<td>300</td>
<td>2007</td>
<td>Bituminous coal</td>
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<tr>
<td>China Guodian Corp.</td>
<td>Xialongtan</td>
<td>China</td>
<td>300</td>
<td>2007</td>
<td>Bituminous coal</td>
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<td>2007</td>
<td>Brown coal</td>
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<td>Yunnan Datang Honghe</td>
<td>Kaiyuan 1</td>
<td>China</td>
<td>300</td>
<td>2006</td>
<td>Anthracite</td>
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<td>China</td>
<td>300</td>
<td>2006</td>
<td>Bituminous coal</td>
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<td>290</td>
<td>2004</td>
<td>Waste coal</td>
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<tr>
<td>Reliant</td>
<td>Seward #1</td>
<td>USA</td>
<td>290</td>
<td>2004</td>
<td>Waste coal</td>
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<tr>
<td>AES Puerto Rico</td>
<td>Guayama 1</td>
<td>Puerto Rico</td>
<td>250</td>
<td>2002</td>
<td>Bituminous coal</td>
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<tr>
<td>AES Puerto Rico</td>
<td>Guayama 2</td>
<td>Puerto Rico</td>
<td>250</td>
<td>2002</td>
<td>Bituminous coal</td>
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<tr>
<td>Choctaw Generation</td>
<td>Red Hills 1</td>
<td>USA</td>
<td>250</td>
<td>2001</td>
<td>Brown coal</td>
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<tr>
<td>Choctaw Generation</td>
<td>Red Hills 2</td>
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<td>2001</td>
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<td>Warrior Run</td>
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<td>2000</td>
<td>Bituminous coal</td>
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<td>Korea Electric Power</td>
<td>Tonghae 1</td>
<td>South Korea</td>
<td>220</td>
<td>1998</td>
<td>Anthracite</td>
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<tr>
<td>Korea Electric Power</td>
<td>Tonghae 2</td>
<td>South Korea</td>
<td>220</td>
<td>1998</td>
<td>Anthracite</td>
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<tr>
<td>EdF/Soprolif</td>
<td>Provence IV</td>
<td>France</td>
<td>250</td>
<td>1995</td>
<td>Lignite</td>
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</tbody>
</table>
Largest CFB Boiler

kg/s  361 / 306
Bar   275 / 55
°C    560 / 580

Furnace
10.6 m * 27.6 m
Height 48 m

Lagisza/PL  460 MWe CFB , Commissioning 2008

Quelle: Foster Wheeler
Conclusions

Chemical Looping:

• potentially lowest efficiency drop (< 1% without CO₂ compression)
• restricted suitability for retrofit of existing power plants (CFB)
• promising option for new power plants with CO₂ capture

Carbonate Looping:

• efficiency drop (less than 3%*) mainly due to supply of O₂,
  but significantly lower than oxyfuel combustion or MEA scrubbing
  *plus CO₂ compression = in total 6% efficiency drop
• well suited for retrofit of existing power plants (repowering)

For further investigation regarding in 1 MWₜh scale at TU Darmstadt
Combustion chamber for exhaust gas generation

Main items for modifications:
- ignition device
- chamber (combustion volume)
- bottom ash separation
- fly-ashes (blower, filter)
**Carbonator**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Thermal duty</td>
<td>up to 1MW</td>
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<tr>
<td>height</td>
<td>10 m</td>
</tr>
<tr>
<td>Pressure</td>
<td>200mbar</td>
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<tr>
<td>External diameter</td>
<td>1.3 m</td>
</tr>
<tr>
<td>Internal diameter</td>
<td>0.6 m</td>
</tr>
<tr>
<td>Baghouse working T</td>
<td>140-180 °C</td>
</tr>
</tbody>
</table>

**CFB600 as Carbonator**
- primary air and flue gas source
- connection with the calciner
- dust separation and extraction
### Calciner (or Gasifier)

**ACFBG**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Thermal duty</td>
<td>1500 kW</td>
</tr>
<tr>
<td>Flue gas T</td>
<td>700 - 1000 °C</td>
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<tr>
<td>height</td>
<td>10,5 m</td>
</tr>
<tr>
<td>External diameter</td>
<td>1000 mm</td>
</tr>
<tr>
<td>Internal diameter</td>
<td>400 mm</td>
</tr>
<tr>
<td>Baghouse working T</td>
<td>300-400 °C</td>
</tr>
<tr>
<td>Reactor pressure</td>
<td>0-100MBAR (G)</td>
</tr>
</tbody>
</table>

**ACFBG as Calciner**
- pipe connections
- gasification mode
CO₂-Abscheidung in kohlebefeuerten Kraftwerken mittels Kalkstein
CO₂-Abscheidung in Kohlebefeuerten Kraftwerken mittels Kalkstein
• The financial support by the German Ministry of Economics and Technology (BMWi) und the Utility Companies (EON; EnBW; Evonik; RWE)
„OXYFUEL“

Chemical Looping
Chemical-Looping Principle

(1) **Air reactor**

\[ 2 \text{Me}_x\text{O}_{y-1} + \text{O}_2 \rightarrow 2 \text{Me}_x\text{O}_y \]

(2) **Fuel reactor**

\[ \text{Me}_x\text{O}_y + \text{Fuel} \rightarrow \text{Me}_x\text{O}_{y-1} + \text{CO}_2 + \text{H}_2\text{O} \]

- "Oxyfuel process"
- No energy demand for separation of N\textsubscript{2}/O\textsubscript{2}
END