Variants of process heat extraction for post-combustion CO\textsubscript{2}-capture plants in exergetic comparison

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Siemens AG - Energy Sector
Fossil Power Generation / Products / Steam Turbine
Agenda

- Post-Combustion Capture
  - Schematic diagram of a post-combustion plant
  - Choice of Desorber pressure for different solvents

- Provision of process steam
  - Bleeds respectively controlled extractions
  - Choice of separation pressure (between IP- and LP-Turbine)
  - Exergetic Contemplation
Agenda

- Calculation results of variants under examination
  - Overview of results
  - Breakdown of losses for selected variants

- Aspects of steam turbine
  - Position of steam extraction
  - Retrofit of Post-Capture Plants

- Integration of the Capture Plant

- Summary
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Principle Configuration of a plant for downstream CO₂-Capture by Flue Gas Scrubbing
Choice of pressures
→ Pressure at Desorber

Amino-Acid-Salt Solvent
(measured range)

Degradation increases with temperature

Monoethanolamin (MEA)

Reaction velocity decreases
→ heat consumption per ton CO₂ increases

Pressure at Desorber:
- 2.8 bar
- 1.6 bar
- 1 bar

Assigned Saturation Temperature
- ≈ 180 °C
- ≈ 170 °C
- ≈ 150 °C
- ≈ 130 °C
- ≈ 120 °C
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Provision of Process Steam
→ Bleeding vs. Controlled Extraction

For Post-Carbon-Capture between 30 and 50% of LP steam has to be extracted!

Thermal Consumer: \( \dot{Q}, \phi \)
→ \( p_{\text{Turbine}} > \text{Saturation Pressure (}\phi\text{)} \)
Choice of pressures

→ Separation Pressure (between IP- and LP-Turbine) and at Desorber

<table>
<thead>
<tr>
<th>Pressure at Extraction position respectively at Reboiler</th>
<th>Assigned Saturation Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 bar</td>
<td>≈ 180 °C</td>
</tr>
<tr>
<td>8 bar</td>
<td>≈ 170 °C</td>
</tr>
<tr>
<td>5 bar</td>
<td>≈ 150 °C</td>
</tr>
<tr>
<td>3 bar</td>
<td>≈ 130 °C</td>
</tr>
<tr>
<td>2 bar</td>
<td>≈ 120 °C</td>
</tr>
</tbody>
</table>

Common Separation Pressures (between IP- and LP-Turbine)

Amino-Acid-Salt Solvent (measured range)

Monoethanolamin (MEA)

Pressure at Desorber:
- 2.8 bar
- 1.6 bar
- 1 bar
Provision of process steam

→ Adjustment by Throttling

Throttling Device

8.0 bar
\((\varphi_{\text{Sat}} \approx 170^\circ \text{C})\)

CO\(_2\)

1.0 bar
Desorber

Condensation at \(\approx 2\) bar
\(\approx 120^\circ \text{C}\)

Injection Cooler

Temperature Terminal Difference (TTD) 10-20 K

spec. Exergetic loss:
\(e_V = T_U \cdot (s_2 - s_1)\)

Exergetic Loss

Dissipated Energy
Provision of process steam
→ Adjustment by increase Temperature Terminal Difference (TTD)

Throttling Device

8.0 bar
\( \vartheta_{\text{Sat}} \approx 170°C \)

Injection Cooler

TTD \( \approx 64 \, K \)

Process steam (condensation)

CO\(_2\)

1.0 bar

Desorber

condensation at 8 bar

170 °C

TTD \( \approx 64 \, K \)

Exergetic Loss

\[ \sigma \approx 64 \, K \]

\[ \sigma \approx 10-20 \, K \]
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Calculation results of variants

### Overview

Additional summarized exergetic losses of the variants:

<table>
<thead>
<tr>
<th>Pressure at desorber</th>
<th>1.0 bar</th>
<th>1.6 bar</th>
<th>2.8 bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 bar</td>
<td></td>
<td></td>
<td><strong>Base (#)</strong></td>
</tr>
<tr>
<td>3.6 bar</td>
<td></td>
<td>1.5 MW (#)</td>
<td></td>
</tr>
<tr>
<td>5.6 bar</td>
<td>24.5 MW</td>
<td>14.7 MW</td>
<td><strong>6.2 MW (#)</strong></td>
</tr>
<tr>
<td>8.0 bar</td>
<td>35.0 MW</td>
<td>25.1 MW</td>
<td>16.6 MW</td>
</tr>
</tbody>
</table>

( #): no throttling in process steam line or increased terminal temperature difference in the heat exchanger

Spec. heat consumption (in GJ/t_{CO2}) nearly constant for all investigated variants

Basis: Amino-Acid-Salt solution as solvent
Calculation results of variants

→ Variants without throttling / increased TTD

- Variants without throttling
- Increased TTD

<table>
<thead>
<tr>
<th>Power Level (MW)</th>
<th>p Des = 1.0 bar</th>
<th>p Des = 1.6 bar</th>
<th>p Des = 2.8 bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 MW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120 MW</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>140 MW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>160 MW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>180 MW</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Auxiliary power (incl. CO2-compressor)
- Exergetic loss Desuperheating
- Exergetic losses of process steam
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Aspects of steam turbine
→ Position of steam extraction

Realized IP-Turbine
(with controlled process steam extraction up to 40%)

Outer casing of state-of-the-art IP-Turbine
with three uncontrolled extractions (bleedings) from blade path (plus A5 from IP exhaust)
Aspects of steam turbine

→ Position of steam extraction

Crane hook height determines the height of turbine house!

Volumetric flow determines the size of pipes and connections!

Upper part of outer casing with extraction connections (IP-Turbine)
Aspects of steam turbine

→ Retrofit of Post-Carbon-Capture for SPPs

Large throttling losses...

3.4 bara

≈ 60%

5.6 bara

≈ 40%

Necessity of smaller exhaust area depending on cooling capacity
Aspects of steam turbine
→ Retrofit of Post-Carbon-Capture for SPPs

Modification of IP-turbine required (due to low backpressure) → at least new rotor and inner casing

≈ 60%

3.4 bara

3.3 bara

≈ 40%
Aspects of steam turbine

→ Retrofit of Post-Carbon-Capture for SPPs

...can be avoided by adjustment of “swallowing capacity” → new guide blade carriers

5.6 bara
≈ 60%
5.5 bara
≈ 40%
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Summary
Integration of the Capture Plant
→ Optimization of the overall system

Overall economic optimization

Integration of heat to preheater line

Cleaned flue gas

Flue gas

Absorber

Rich Solvent

Poor Solvent

Heat Exchanger

Cooler

Throttling Device

Rich Solvent

Poor Solvent

Desorber

Reboiler

Process steam

Condensate

Definistion of
- Separation Pressure
- Desorber Pressure

Integration to preheater line

Integration of heat to preheater line

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Summary
Summary

- Low separation pressures are beneficial for the provision of process steam. Limitations may result from the design of the IP-turbine, or from high volumetric flows.

- To retrofit a power plant with post-carbon capture without modifying the IP steam turbine, exergetic losses can be avoided by increasing the desorber pressure. Most often this is more economic than to adapt the steam turbine to lower separation pressures.

- The pressure in the desorber represents an additional degree of freedom. However it can only be applied if the thermal stability of the solvent is sufficiently stable at increased temperatures.
Summary

- Siemens uses an amino acid salt as solvent, which is characterized by very high temperature stability. This has the advantage that the pressure in the desorber can be used as an additional degree of freedom.

- Siemens is in the position to evaluate all components along the process chain (from fossil fired boiler to water/steam cycle, including the steam turbine, up to the processes of capturing and compressing the CO$_2$) as well as their interaction, and to optimize the overall system.

- Siemens develops appropriate concepts with the aim of minimising the decrease in efficiency for the application of Carbon Dioxide Capture and Storage (CCS).
Thank you for your attention...
Backup
Carbon Capture & Storage (CCS) → Thematic Demarcation

**Power Plant**

- "IGCC": CO₂-Separation before combustion (after gasification)
- "Oxyfuel": Combustion with pure oxygen (CO₂/H₂O recirculates)
- "Post-Combustion Capture": downstream CO₂-flue gas scrubbing (Ab-/Desorption)

**Transport**

- Direct injection in situ
- Transport by truck / ship
- Pipeline (100 – 200 bar)

**Storage/Usage**

- Injection into salt-water conducting geological formations (Saline Aquifers)
- Injection into exploited gas- or oil-fields
- Injection in unminable coal deposits
- Injection into deep sea
- Usage for Enhanced oil (or gas) recovery
Carbon Capture & Storage (CCS)
→ Possible Processes for Power Plants

Post-Combustion Capture

- Fuel
- Air
- Flue Gas
- CO₂ Separation
  - N₂, O₂, H₂O

Pre-Combustion Capture

- Fuel → Gasification of Initial Oxidation, SPP Process
- Air → Air Separation Unit
- Reaction in Gasifier: CHₓ + O₂ ⇌ CO + H₂O
- Shift-Reaktion: CO + H₂O ⇌ CO₂ + H₂

Classical SPP-Process, Retrofit possible

Process with modified Gas Turbine

O₂/CO₂ Recycle Combustion Capture (Oxyfuel)

- Fuel
- Air
- O₂
- Air Separation Unit
- SPP-Process, modified boiler (fluidized bed)

Quelle: Siemens-Bericht „CO₂ – Reduktion und Abtrennung in Kraftwerken“ (Baumgärtel/Lezuo)

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Exergy & Anergy

→ Exergetic Loss: Exergy transformed to Anergy