Process Integrated Carbon Capture (CC)

Field Tests And Further Perspectives In Industrial Processes

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Overview

- Carbon Capture (CC) in industrial processes
- Chemical absorption in amine solutions
- Mobile test plant
- Results of field-tests
- Gas and Liquid analyses
- Implementation strategies
CC in industrial processes

*basic concepts*

- Post combustion CC
- Oxyfuel CC
- Process integrated CC

Source: [www.energieblog24.de](http://www.energieblog24.de)
Schwarze Pumpe - Oxyfuel
CC in industrial processes

**Basic Concepts**

1. **Iron & Steel Production**
   - 45 - 230 kg CO₂/GJ (LHV)
2. **Integrated Gasification Combined Cycle**
   - 45 - 230 kg CO₂/GJ (LHV)
3. **Coal Fired Power Plant**
   - 79 kg CO₂/GJ (LHV)
4. **Syn Natural Gas, SNG**
   - 110 kg CO₂/kg product
5. **Methanol, MeOH**
   - 113 kg CO₂/kg product
6. **Dimethyl Ether, DME**
   - 78 kg CO₂/kg product
7. **Fischer-Tropsch Fuel**
   - 79 kg CO₂/kg product
8. **Synthesis Gas, SNG**
   - 45 - 230 kg CO₂/kg product

**Products:**
- CHP
- FT-fuels
- MeOH
- DME
- SNG

**Gasification**
- Coal, biomass
- CO₂-removal (90%)
- Process gas: CO, CO₂, H₂, CH₄, N₂, H₂O, H₂S, HCN, NH₃, dust
- Fermentation
  - Biomass, sewage
- Iron making, others...
  - Coal, biomass

**Conversion step**
- Products: CHP, FT-fuels, MeOH, DME, SNG

**Source:** www.energieblog24.de: Schwarze Pumpe - Oxyfuel
CC in industrial processes

**basics**

**Ecological benefits**
- Emission reduction and energy recovery
- Saving resources due to CO$_2$ recycling

**Procedural benefits**
- Increase of calorific value
- Volume flow reduction
- Decrease of CO$_2$ partial pressure

→ **Benefits in subsequent conversion steps**
  (e.g. Catalytic conversion including complete recovery of sulphur)
Chemical absorption in alkanolamine solutions

basics

• Dissociation and ionization of CO₂:
  \[
  \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{HCO}_3^- + \text{H}^+
  \]

• Protonation of alkanolamine:
  \[
  \text{RNH}_2 + \text{H}^+ \rightleftharpoons \text{RNH}_3^+
  \]

• Carbamate formation:
  \[
  \text{RNH}_2 + \text{CO}_2 \rightleftharpoons \text{RNHCOO}^- + \text{H}^+
  \]

![Absorber and desorber diagram](image)

<table>
<thead>
<tr>
<th>Specific Heat demand [kJ/kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ gas out Concentration [vol%]</td>
</tr>
</tbody>
</table>

- DEA 30%
- Abs. p: atm.
- Des. p: 1.8 bar
- Des. T: 116-118 °C
- Gas flowrate: 15 - 17 m³/h, usc
- L/G ratio: 7.0 - 12.2 l/m³, usc
- Test duration of point: 3-5 h

Diagram showing absorber and desorber processes with temperatures and CO₂ concentrations.
CO\textsubscript{2}-separation tests
\textit{technology & methods}

- Redesign of a mobile CO\textsubscript{2}-separation unit for process gas
- Reference and long term tests with different absorbent compositions
  Monoethanolamine (MEA), Diethanolamine (DEA), MDEA+MEA-solutions, Industrial CO\textsubscript{2}/H\textsubscript{2}S-removal solvents
- Chemical analysis of gas and liquids
  Online gas analysis (main gas components, CO\textsubscript{2} and H\textsubscript{2}S), additional gas measurement (periodically), CO\textsubscript{2}-loads (TIC), degradation products (HPLC)
- Evaluation of chemical effects
  Degradation products, capacity, corrosion, long-time behaviour
- Evaluation and analysis of CC process data
  Separation efficiency, energy demand, sorbent capacity, control strategy

Key-data of tests

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas flow</td>
<td>9 - 30 Nm\textsuperscript{3}/h</td>
</tr>
<tr>
<td>Sorbent flow</td>
<td>115 - 300 l/h</td>
</tr>
<tr>
<td>Test duration</td>
<td>à 200 - 400 h</td>
</tr>
</tbody>
</table>
CO₂-separation tests

**selected results**

<table>
<thead>
<tr>
<th>Key-data of tests</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂-conc., crude gas</td>
<td>21 - 23 vol%</td>
</tr>
<tr>
<td>Gas flow</td>
<td>9 - 30 Nm³/h</td>
</tr>
<tr>
<td>Sorbent flow</td>
<td>115 - 300 l/h</td>
</tr>
<tr>
<td>Test duration</td>
<td>175 - 300 h</td>
</tr>
<tr>
<td>Number of cycles</td>
<td>200 - 433</td>
</tr>
<tr>
<td>Desorber - pressure</td>
<td>1,8 - 2,5 bara</td>
</tr>
<tr>
<td>Separation rate, η&lt;sub&gt;CC&lt;/sub&gt;</td>
<td>75 - 95 %</td>
</tr>
</tbody>
</table>

Constant gas conditions:
- No oxygen
- Dust < 1 mg/m³, usc
- H₂S < 80 mg/m³, usc
- System overpressure 65 mbar

<table>
<thead>
<tr>
<th>Best results</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MEA 30%</td>
<td></td>
</tr>
<tr>
<td>Separation rate, η&lt;sub&gt;CC&lt;/sub&gt;</td>
<td>90%</td>
</tr>
<tr>
<td>Liq-gas-ratio</td>
<td>7 l/Nm³</td>
</tr>
<tr>
<td>Spec. heat duty, q&lt;sub&gt;Des&lt;/sub&gt;</td>
<td>3.300 kJ/kg CO₂</td>
</tr>
</tbody>
</table>

Desorption pressure: 1,8 bara
CO₂-concentration, crude gas: 21 - 23 vol%
Gas and liquid characterisation

**Sampling procedure**

**Gas-sampling**
- Heated tube
- Probe
- Heated filter
- Ball valve
- Impinger for inorganic parameters
- Control valve
- Safety flask
- Cooled double jacket flasks for organic parameters
- Cooling unit
- Flow rate measurement
- Collection drain

**Liquid-analysis**
- CO₂-Analyzer:
  - Total Inorganic Carbon (TIC)
  - Principle: stripping out CO₂ with phosphoric acid for infrared detection
- Conductivity:
  - via conductivity cell
- Degradation products:
  - HPLC
CO₂-separation tests
Absorption of H₂S/HCN

⇒ Complete removal of H₂S and HCN with all tested solvents (MEA, DEA and MEA+MDEA-solutions)
⇒ Complete stripping of H₂S in the desorption unit
CO₂-separation tests

**liquid analysis**

### CO₂ load in used solvent solution:

<table>
<thead>
<tr>
<th></th>
<th>CO₂-rich sorbent – CO₂-load</th>
<th>CO₂-lean sorbent – CO₂-load</th>
<th>Δc [g/l]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>c [g/l]</td>
<td>α [mol/mol Amin]</td>
<td>c [g/l]</td>
</tr>
<tr>
<td>MEA 20</td>
<td>80 - 89</td>
<td>0,55 – 0,61</td>
<td>52 - 57</td>
</tr>
<tr>
<td>MEA 30</td>
<td>115 - 132</td>
<td>0,53 – 0,62</td>
<td>59 – 81,5</td>
</tr>
<tr>
<td>DEA 30</td>
<td>34 – 44,2</td>
<td>0,27 – 0,35</td>
<td>8,5 – 18,7</td>
</tr>
<tr>
<td>MEA20/MDEA30</td>
<td>72 - 75</td>
<td>0,30 – 0,31</td>
<td>37,6 – 40,7</td>
</tr>
</tbody>
</table>

### Evaluation of degradation effects:

- **Up to 400 h of operation** → no depletion in performance (spec. heat duty, efficiency)
- Gas analyses via standardised methods
  - CO₂, CO, H₂, CH₄, impurities
- Liquid analysis via HPLC-UV
  - Oxazolidone, HEIA, HEEDA, DI-UREA
detection limit of 1 ppm → almost no degradation products found

**e.g.: oxazolidone**

sample (blue line); sample + standard (red line)
Appendix – Blast furnace + CC + GuD-// CC combined cycle

Example:
- Crude iron: 2,7 Mt/y
- CO₂ separated: 0,75 Mt/y
- CC steam demand 160 MW
Installation of the mobile plant
Looking for further collaborations………

- For initiatives of **plant manufacturers** to realised these technology in industrial scal for production and energy (IGCC)

- In general for **material testing** absorbent mixtures

- Specific interests of **gas characterisation** and degradive components; analyses can be performed

Thank You for Your kind attention!
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