Integration of Oxygen-containing Exhaust Gas into the Air Separation Unit of an Oxyfuel Power Plant with Maximised CO₂ Capture Rate
- Process uses matured technologies
- Cryogenic air separation unit (ASU)
- CO₂ capture in gas processing unit (GPU)
- CO₂ capture rate 90%
Constraints of the basic process

- **Reference power plant**
  - Study: reference power plant North-Rhine Westphalia (bituminous coal)
  - Air-fired: $\eta_{\text{net}} = 45.8\%$
  - $P_{\text{el}} = 600 \text{ MW}_{\text{gross}}$

- **Oxyfuel modification**
  - Treated primary recycle by hot ESP and wet FGD
  - Treated secondary recycle by hot ESP
  - Adiabatic ASU with heat integration
  - Preheated $O_2$: 95 vol% (dry)
  - 2% (w/w) air ingress
  - GPU: partial condensation (externally cooled)
  - 90% $CO_2$ capture rate, 10% $CO_2$ leakage with the offgas
  - $CO_2$ purity: 97 vol% (dry)
  - $\eta_{\text{net}} = 36.9\%$
Process with maximised CO$_2$ capture rate

- PEO Membrane for additional capture
  - Selectivity CO$_2$/N$_2$ 50, O$_2$/N$_2$ 2.8, Ar/N$_2$ 2.8 (T=25°C)
  - CO$_2$ permeance 3 m$^3$(STP)/m$^2$hbar (T=25°C)
- CO$_2$ capture rate 99%, $\eta_{\text{net}} = 36.4\%$
- CO$_2$ from PM is recycled due to low purity and pressurisation
Motivation

- Additional capture process resolves in a net efficiency penalty of 0.5 %-pts.
- Exhaust gas to environment contains 4% of the oxygen supplied by the ASU
- Recycle to ASU can decrease its energy demand
- Increase of net efficiency possible

- Modelling of an exhaust gas recycle to the ASU
- Examine how much of the maximum 4% energy saving at the ASU can be realised
- Membrane and Adsorption not considered for separation, because of low separation selectivity of Ar/O₂
Potential of a O\textsubscript{2} recycle to the ASU

- Estimation of the potential to lower the energy demand of the ASU
- 4\% of the oxygen supplied by the ASU in the offgas

<table>
<thead>
<tr>
<th>Exhaust gas CO\textsubscript{2} in vol%</th>
<th>Exhaust gas N\textsubscript{2} in vol%</th>
<th>Exhaust gas O\textsubscript{2} in vol%</th>
<th>Exhaust gas Ar in vol%</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.3</td>
<td>52.3</td>
<td>22.7</td>
<td>19.7</td>
</tr>
</tbody>
</table>

99\% CO\textsubscript{2}
- Dual column
- Dual reboiler
- Lox boiler
- Adiabatic compression
- Energy demand
  - 229 kWh/t\textsubscript{O2} (w/o heat integration)
- O\textsubscript{2} capture rate 98.48%
Scenarios for exhaust gas integration into the ASU

- Recycle is on pressure (about 4.6 bar) => 2 MW higher power demand of the GPU
- Constant amount of O₂ and purity in product stream
- Scenario A with direct mixture upstream direct contact cooler
- Scenario B with separate feed to the cold box
## Results (dual column)

<table>
<thead>
<tr>
<th></th>
<th>Basic process</th>
<th>A (Dir. Mix with change)</th>
<th>B (sep. feed with change)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$O_2$ capture rate in %</strong></td>
<td>98.48</td>
<td>97.9</td>
<td>98.27</td>
</tr>
<tr>
<td><strong>Spec. energy demand in kWh/$t_{O_2}$ (w/o heat integration)</strong></td>
<td>229</td>
<td>226</td>
<td>223</td>
</tr>
<tr>
<td><strong>Ar in $O_2$ product</strong></td>
<td>0.024</td>
<td>0.043</td>
<td>0.029</td>
</tr>
</tbody>
</table>

- **Overall process evaluation (with adiabatic compression)**
  - Benefit for the ASU results in a net efficiency penalty for the overall process for the dual column
Results for dual column

• Integration into ASU
  ▶ Only small benefit for the ASU due to problems of the columns with the high amounts of Ar (increased about 70% compared to basic process)
  ▶ The capture rate is decreased in both scenarios, because the Ar leads to an increased slip of O₂ with the N₂

• Is there a benefit for the overall process with a triple column?
Triple column basic process

- Triple column
- Adiabatic compression
- Lox boiler
- Energy demand
  - 197 kWh/t\textsubscript{O2} (w/o heat integration)
- Expander power used with generator/compander
- O\textsubscript{2} capture rate 97.85%
  - \(\eta_{\text{net}} = 37.4\%\) (CCR 90%)
  - \(\eta_{\text{net}} = 36.9\%\) (CCR 99%)
• Energy demand
  184 kWh/t\(_{O_2}\) (w/o heat integration)
• \(O_2\) capture rate 97.85%
• Exhaust gas into HPC
• \(\eta_{\text{net}} = 37.15\%\) (CCR 99%)
• 0.25 \%-pts. benefit
## Overall process net efficiencies

<table>
<thead>
<tr>
<th>Process configuration</th>
<th>Dual Column ASU in %</th>
<th>Triple column ASU in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic process (CCR 90%)</td>
<td>36.9</td>
<td>37.4</td>
</tr>
<tr>
<td>Increased CCR 99%</td>
<td>36.4</td>
<td>36.9</td>
</tr>
<tr>
<td>Exhaust Gas Recycle</td>
<td>&lt; 36.4</td>
<td>37.15</td>
</tr>
</tbody>
</table>
Conclusion and next steps

- Dual column ASU has difficulties with the effective separation of the Ar from the O$_2$
- For the overall process the results show no benefit for a dual column ASU with an exhaust gas recycle
- The triple column benefits from the exhaust gas recycle and can lessen the efficiency decrease of an increased capture rate to 0.25 %-pts.

- Economical evaluation of the offgas treatment with PM and PSA