PILOT PLANT RESULTS FOR 5 M PIPERAZINE WITH THE ADVANCED FLASH STRIPPER

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UT PZ Pilot Plant Testing

2008
- 8 m PZ Absorber Mellapak 2X Simple Stripper

2010
- 8 m PZ AbsIntercooling RSP 250-hybrid Simple Stripper 120 °C

2010/2011
- 8 m PZ AbsIntercooling RSP 250-hybrid 2-Stage Flash 150 °C, 12 bar

2011
- 8 m PZ AbsIntercooling GTC-350Z, 70° 2-Stage Flash w/ Warm Rich Bypass 150 °C, 14 bar

2013
- 4 m PZ AbsIntercooling RSP-250 1-Stage Flash w/ Cold Rich Bypass 140 °C, 4.4 bar Aerosols, G2 PDI

2015
- 5 & 8 m PZ AbsIntercooling RSP-250 Adv Flash Stripper Cold/Warm Rich Bypass, 150 °C, 8 bar Aerosols, G3 PDI
Current Pilot Facilities & Equipment

- SRP - 0.1 MW, 16.8-inch ID
- 200-450 lb CO₂/hr removal
- Synthetic Flue Gas: Air/CO₂
  - Enthalpy, 1-2 % H₂O, 30-40 °C
  - 3-20% inlet CO₂
  - Air max. oxidative degradation
- 20 feet (6.1 m) absorber packing
- Absorber intercooling
- 0.1-0.2 MW AFS skid w/cold and warm rich bypass
## Concentrated PZ Benefits

8 m PZ → 5 m PZ

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Rate&lt;sup&gt;1&lt;/sup&gt;</th>
<th>CO&lt;sub&gt;2&lt;/sub&gt; Capacity&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Viscosity&lt;sup&gt;3&lt;/sup&gt; (cP)</th>
<th>T&lt;sub&gt;max&lt;/sub&gt; (°C)</th>
<th>P&lt;sub&gt;max&lt;/sub&gt; (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 m PZ</td>
<td>11.3</td>
<td>0.63</td>
<td>3</td>
<td>163</td>
<td>14.3</td>
</tr>
<tr>
<td>8 m PZ</td>
<td>8.5</td>
<td>0.79</td>
<td>10.8</td>
<td>163</td>
<td>14.3</td>
</tr>
<tr>
<td>7 m MEA</td>
<td>4.3</td>
<td>0.5</td>
<td>2.5</td>
<td>120</td>
<td>2.2</td>
</tr>
</tbody>
</table>

**Notes:**

1. $k'_g$ average @ 40 °C – (mol/Pa-s-m<sup>2</sup>)
2. mol CO<sub>2</sub>/mol alkalinity
3. @ 40 °C
Solubility of 5 m PZ and 8 m PZ

Transition Temperature (°C)

CO₂ loading (mol CO₂/mol alkalinity)

5 m PZ

8 m PZ

Solution

PZ·6H₂O
(solid)
**Advanced Flash Stripper Configuration**

**Trim condenser**
- CO₂
- H₂O

**Cold rich X**
- Cold Rich BPS 5-10%

**Warm Rich BPS 20-40%**

**Vented gas**
- Trim condenser
- Absorber

**Absorber**
- Flue gas 12% CO₂
- Lean solvent

**Cross exchanger**
- CRB:
  - Recover heat gas
  - Indirect contact
- WRB:
  - Non flashing feed
  - Optimal L/G
Adv. Flash Stripper Energy Performance

Heat duty (GJ/tonne CO₂)

Lean loading (mol CO₂/mol alkalinity)

Simple Stripper

Advanced flash stripper

-18%

5 m PZ
5 K CrossX LMTD
150 °C T_{Flash Tank}
0.40 rich loading
2015 AFS Campaign Configuration

- Flue gas 12% CO₂
- Rich pump
- Intercooler
- Absorber
- Condenser
- Cold rich bypass
- Cold rich exchanger
- Warm rich bypass
- Warm cross exchanger
- Hot cross exchanger
- Steam heater
- Stripper
- Flash
- Vented gas
- 5 and 8 m Piperazine
Absorber Conditions

- Flue gas: 12% CO₂
- Vented gas: 0.18-0.27 mol CO₂/mol alk
- Spray: 40°C
- Intercooler: RSP-250, 6.1 m
- ID = 0.43 m
- L/G: 3-5 kg/kg
- Rich pump: 9.9, 14.2 m³/min
- Absorber
- Condenser
- Cold rich exchanger
- Cold rich bypass
- Warm rich bypass
- Trim cooler
- Warm cross exchanger
- Hot cross exchanger
- Stripper
- Steam heater
- Flash
Stripper Conditions

- **Flue gas 12% CO₂**
- **Absorber**
- **Trim cooler**
- **Intercooler**
- **Rich pump**
- **Condenser** 50-70 °C
- **Cold rich exchanger**
- **Warm rich bypass 17 – 41%**
- **Delta T = 7°C**
- **Warm rich bypass 5 – 12%**
- **Hot cross exchanger**
- **Steam heater**
- **Flash** 145 – 150 °C

**Stripper**
- **RSR# 0.3**
- **ID = 0.16 m**
- **2 m**

**Vented gas**
AFS Energy Performance

$Q_{\text{stim}} - Q_{\text{loss}}$ (GJ/tonne CO$_2$)

Run

- **2011 Jan.**
  - Two-stage flash
  - (8 m PZ)

- **2011 Oct.**
  - Two-stage flash
  - w/ cold rich BPS
  - (8 m PZ)

- **2015**
  - AFS
  - (5 m and 8 m PZ)
# 5 m vs 8 m PZ - AFS Performance

14 gpm, 145 °C, 0.24 loading

<table>
<thead>
<tr>
<th></th>
<th>Comparison 1</th>
<th>Comparison 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>5 m PZ concentration (m)</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>8 m PZ concentration (m)</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Solvent Capacity (lb CO₂/lb solution)</td>
<td>0.036</td>
<td>0.037</td>
</tr>
<tr>
<td></td>
<td>0.041</td>
<td>0.042</td>
</tr>
<tr>
<td>Total BPS ratio</td>
<td>25%</td>
<td>24%</td>
</tr>
<tr>
<td></td>
<td>26%</td>
<td>24%</td>
</tr>
<tr>
<td>Heat Duty (GJ/tonne CO₂)</td>
<td>2.36</td>
<td>2.51</td>
</tr>
<tr>
<td></td>
<td>2.21</td>
<td>2.41</td>
</tr>
<tr>
<td>Cross X cold side DT (°F)</td>
<td>11.7</td>
<td>15.2</td>
</tr>
<tr>
<td></td>
<td>11.5</td>
<td>15.7</td>
</tr>
</tbody>
</table>
Effect of Lean Loading – 5 m PZ

Lean loading (mol CO\textsubscript{2}/mol alkalinity)

Process heat duty (GJ/tonne CO\textsubscript{2})

Δ Ldg (mol CO\textsubscript{2}/mol alkalinity)

Aspen AFS heat duty

Pilot heat duty

Δ Loading
5 m PZ vs. 8 m PZ - Absorber Performance

12% Inlet CO₂, Full Spray Intercooling

<table>
<thead>
<tr>
<th>Solvent Rate</th>
<th>Gas Rate</th>
<th>Titration LLDG</th>
<th>Measured Removal</th>
<th>Heat Duty</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPM</td>
<td>ACFM</td>
<td>mol CO₂/mol alk</td>
<td></td>
<td>GJ/tonne CO₂</td>
</tr>
<tr>
<td>5 m</td>
<td>14</td>
<td>350</td>
<td>0.24</td>
<td>96%</td>
</tr>
<tr>
<td>8 m</td>
<td>14</td>
<td>500</td>
<td>0.24</td>
<td>80%</td>
</tr>
</tbody>
</table>

- 5 m PZ higher absorption rates due to viscosity reduction
- Better energy performance
## PZ Absorber with Intercooling

### 12% Inlet CO₂, Lean Solvent Rate 14 GPM

<table>
<thead>
<tr>
<th>Solvent Gas Rate</th>
<th>Titration LLDG</th>
<th>Intercooler Spray Nozzle</th>
<th>Measured Removal</th>
<th>Heat Duty GJ/tonne CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACFM</td>
<td>mol CO₂ /mol alk</td>
<td>N</td>
<td>N</td>
<td>80%</td>
</tr>
<tr>
<td>5 m 350</td>
<td>0.25</td>
<td>Y</td>
<td>Y</td>
<td>96%</td>
</tr>
<tr>
<td>8 m 500</td>
<td>0.24</td>
<td>Y</td>
<td>Y</td>
<td>68%</td>
</tr>
</tbody>
</table>

- Intercooling is essential
- Mass transfer enhancement by Spray Nozzle
- Better energy performance
PZ Over-Stripping without Intercooling

5 m PZ, 12% Inlet CO₂, Gas Rate 350 ACFM

- First time running over-stripping LLDG in Pilot Plant
- No solid precipitation observed
- Able to achieve adequate removal with comparable energy performance

<table>
<thead>
<tr>
<th>Solvent Rate</th>
<th>Titration LLDG</th>
<th>Intercooler</th>
<th>Spray Nozzle</th>
<th>Measured Removal</th>
<th>Heat Duty</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPM</td>
<td>mol CO₂/mol alk</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>GJ/tonne CO₂</td>
</tr>
<tr>
<td>8.6</td>
<td>0.18</td>
<td>N</td>
<td>N</td>
<td>84%</td>
<td>2.48</td>
</tr>
<tr>
<td>14</td>
<td>0.25</td>
<td>N</td>
<td>N</td>
<td>80%</td>
<td>2.48</td>
</tr>
</tbody>
</table>
Conclusions

- **Advanced Flash Stripper**
  - 17 run: 2.1-2.5 GJ/ton CO$_2$ (5 m PZ)
  - 4 runs: 2.5-2.9 GJ/ton CO$_2$ (8 m PZ)
  - 25% heat duty reduction vs past campaigns (2SF)
  - Optimized rich solvent bypass reduced heat duty by 15%
  - 5 m PZ reduced duty because better heat transfer performance than 8 m PZ (viscosity)

- **Absorber**
  - 5 m vs 8 m PZ ~ 5% higher CO$_2$ removal
  - IC = 90 – 98% CO$_2$ removal
  - No IC = 68 – 84% CO$_2$ removal
Acknowledgements

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