Capture of CO₂ in Pre-Combustion Processes by Pressure Swing Adsorption

Gongkui Xiao, Penny Xiao, Simon Wilson, Ranjeet Singh, Kaustubh Joshi, Alan Chaffee and Paul Webley

Cooperative Research Centre for Greenhouse Gas Technologies, Department of Chemical Engineering, Monash University, Wellington Road, Clayton, Victoria 3800, Australia

e-mail: paul.webley@eng.monash.edu.au

Abstract

There is considerable interest in identifying carbon dioxide capture processes that can be incorporated within Integrated Gasification and Combined Cycle (IGCC) systems. In this paper, we studied materials screening for adsorption at high temperatures and established that zeolite 13X can be used as an adsorbent in the temperature range of 30 to 250°C, and magnesium double salts from 350 to 400°C. Double salts [1] are very promising materials for adsorption technology at these high temperatures. They have relatively high CO₂ adsorption loading at 350°C (1.2mol/kg) with a rapid reduction in capacity to 0.2mol/kg when the temperature is increased above 400°C. In accordance with these materials’ characteristics, a PVSA (vacuum pressure swing adsorption) cycle was designed for zeolite 13X and a TPSA (temperature-pressure swing adsorption) cycle was designed for the double salt. These process configurations are proposed to operate in the temperature window (250-500°C) [2] suitable for an IGCC process downstream of the water gas shift reactor. These process configurations were numerically simulated with our in-house adsorption simulator MINSA (Monash Integrated Numerical Simulator for Adsorption) [3], and the simulation results indicate that good performance can be achieved. Carbon dioxide purity of greater than 95% and a carbon dioxide recovery of greater than 90% can be obtained.

Analysis of Adsorbents

Most IGCC process streams contain significant quantities of water [4]. The adsorption loading of water on 13X is much higher than that of CO₂ (Fig 1) and must therefore be removed when VPSA technology is used with 13X as the CO₂ adsorbent. Th effect of water on performance of double salts is as yet inconclusive but our preliminary data suggest that the double-salt is easily poisoned by water vapour. A pre-treatment stage would need to be added before CO₂ capture. From our TGA cycling experiments, the CO₂ adsorption/desorption on double-salt is not completely reversible when the CO₂ partial pressure is changed. However, the material can be easily regenerated at 400°C to restore its original capacity. VPSA technology can be used with this material at 350°C but periodic regeneration at 400°C may be needed. Alternatively, TSA technology may provide an option for use of this adsorbent.

VPSA cycle design and running condition
An eight step VPSA cycle with two-adsorption beds was designed for capture of CO₂ from IGCC process streams. The feed stream composition is 21.5% CO₂, 16.8% H₂O, with the remainder being H₂ and N₂ (both assumed to be non-adsorbing). The processing cycle includes adsorption, desorption, equalisation, compression and re-pressurisation steps. As discussed earlier, a PSA pre-treatment process is added to remove water when zeolite 13X and double-salt are used as CO₂ capture adsorbents which also increases capital and operating costs. Since 13X has a good working capacity for water at 250°C, we use 13X in the drying upstream PSA treatment process. The pressure swing profile for the CO₂ capture process and water removal is shown in Fig 2.

![Pressure profile with cycle time](image)

**Simulation Results**

<table>
<thead>
<tr>
<th>Adsorbent</th>
<th>CO₂ purity (%)</th>
<th>CO₂ recovery (%)</th>
<th>Energy consumption (kW/TPDcCO₂)</th>
<th>CO₂ productivity (TPDcCO₂)</th>
<th>CO₂ in cleaned gas (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13X (250°C)</td>
<td>97.2</td>
<td>94.8</td>
<td>8.7</td>
<td>30.62</td>
<td>2.6</td>
</tr>
<tr>
<td>Double-salt (400°C)</td>
<td>95.2</td>
<td>97.7</td>
<td>6.51</td>
<td>32.6</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Performance of current commercial adsorbents 13X as well as prepared double salt have been simulated and compared. Both of these materials can be integrated in the IGCC flow train and give required purity (95%) and recovery (80%) With the current cyclic design, double salt has lower energy consumption and higher CO₂ productivity. Further studies are needed to optimize the process with respect to temperature, type of cycle and step times.

**Reference**