Are moving bed temperature swing adsorption (MBTSA) processes feasible for post-combustion CO₂ capture in a NGCC context?

Carlos A. Grande, Hanne Kvamsdal, Giorgia Mondino and Richard Blom
SINTEF Materials & Chemistry, Oslo and Trondheim, Norway; E-mail address: richard.blom@sintef.no

The MBTSA concept
In the moving bed temperature swing adsorption (MBTSA) concept a solid adsorbent flows downwards through a construction involving the following sections:
1. An adsorption section in which CO₂ is adsorbed from a countercurrent flue gas stream,
2. A section in which the powder is preheated by heat exchange with the hot powder leaving the recovery section,
3. A recovery section in which the adsorbent is indirectly heated by steam (or hot flue gas) to recover the adsorbed CO₂ and
4. A cooling section where the powder is cooled by heat exchange with the cool powder leaving the adsorption section.
The cycle is closed by transferring the lean adsorbent powder back to the top of the construction – the entrance of the adsorber. The process is schematically drawn in Figure 2. Figure 1 shows the principle of the TSA process in terms of the CO₂ adsorption isotherms of the adsorbent at the temperatures of the adsorber and the recovery sections.

Table 1. Summary of process details of the different MBTSA approaches from literature and the present study:

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Literature</th>
<th>Present study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed section</td>
<td>2.2 m horizontal perforated plates. That idea is from old patents but can generate high pressure drop.</td>
<td>Not specified</td>
<td>Not specified</td>
</tr>
<tr>
<td>Recovery</td>
<td>Not specified</td>
<td>Not specified</td>
<td>Not used.</td>
</tr>
<tr>
<td>Pre-cooler</td>
<td>Heat transfer fluid is used to cool down the adsorbent. Design not specified.</td>
<td>Not specified</td>
<td>Not used.</td>
</tr>
<tr>
<td>Cooler</td>
<td>Not used.</td>
<td>Existing but not specified.; Not necessary (regeneration with vacuum).</td>
<td>Not necessary (regeneration with vacuum).</td>
</tr>
<tr>
<td>Preheater</td>
<td>Used for solid transport and to cool down adsorber.</td>
<td>Used for solid transport (air) to cool down adsorber. Mechanical</td>
<td>Not specified.</td>
</tr>
<tr>
<td>Recuperator</td>
<td>No details on absorber but</td>
<td>Used for solid transport (air) to cool down adsorber. Mechanical</td>
<td>Not specified.</td>
</tr>
</tbody>
</table>

Figure 1: Principle of the temperature swing adsorption cycle; CO₂ is adsorbed at low temperature (LT) isotherm (point A). The adsorbed CO₂ is released by heating following the stippled lines (to B) then to C. The vertical distance between point C and A indicates the cyclic working capacity.

Table 2: Comparison of heat requirement, MBTSA and reference MEA based processes for the 500 MW CCOT case (heat provided by steam from power plant cycle)

<table>
<thead>
<tr>
<th></th>
<th>Cost without capture</th>
<th>Cost MBTSA</th>
<th>EBT 410 MW MEA</th>
<th>MEA reference (this study)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net requirement (MWel)</td>
<td>114</td>
<td>149</td>
<td>146</td>
<td></td>
</tr>
<tr>
<td>Net boiler load (MWth)</td>
<td>3.3</td>
<td>4.0</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>CO₂ capture</td>
<td>36.5</td>
<td>31.5</td>
<td>32.0</td>
<td></td>
</tr>
<tr>
<td>EER</td>
<td>2.5</td>
<td>7.4</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>CO₂ compression (MWth)</td>
<td>4.6</td>
<td>13</td>
<td>13.1</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>3.6</td>
<td>3.6</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Integration</td>
<td>-</td>
<td>56.4</td>
<td>57.2</td>
<td></td>
</tr>
<tr>
<td>Total efficiency (%)</td>
<td>58.0</td>
<td>51.5</td>
<td>51.4</td>
<td></td>
</tr>
<tr>
<td>Additional capital cost (€/MW)</td>
<td>268.3</td>
<td>442.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusions:
In this study the MBTSA process comes out with a 25% lower energy penalty as compared to a base case MEA process (the European Benchmark Task Force (EBTF) case) and similar energy penalty as a further optimized and more complex MEA process including a lean vapor compression loop. The result is promising, but we should note that it is based on a number of more or less well funded assumptions:

- The main uncertainty in the initial design of the MBTSA concept relies in the heat transfer coefficients to be used in the heat-exchanger in the regeneration section: We have chosen indirect heating by steam at 495K – which we believe is a conservative assumption. If regeneration can be efficiently done using lower grade steam, this would lead to significant reduction in energy penalty.

- In the present study, Zeolite 13X having CO₂ adsorption energy of around 45 kJ/mole have been used. Indirect heating is necessary when using strongly water selective adsorbents, such as Zeolites. Activated carbon adsorbents, which are more relevant for flue gases with higher CO₂ content might be regenerated by direct heating in steam at significantly lower temperatures.

Acknowledgement: We acknowledge financial support from Gassnova and Statoil (grant no. 221137), from the EU FP7 project HiPerCap (grant no. 608555) and from the Polish-Norwegian Research Program through the Solsor project (grant no. 237761).