Are moving bed temperature swing adsorption (MBTSA) processes feasible for post-combustion CO_2 capture in a NGCC context?

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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 CO_2 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 CO_2, 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 CO_2 adsorption isotherms of the adsorbent at the temperatures of the adsorber and the recovery sections.

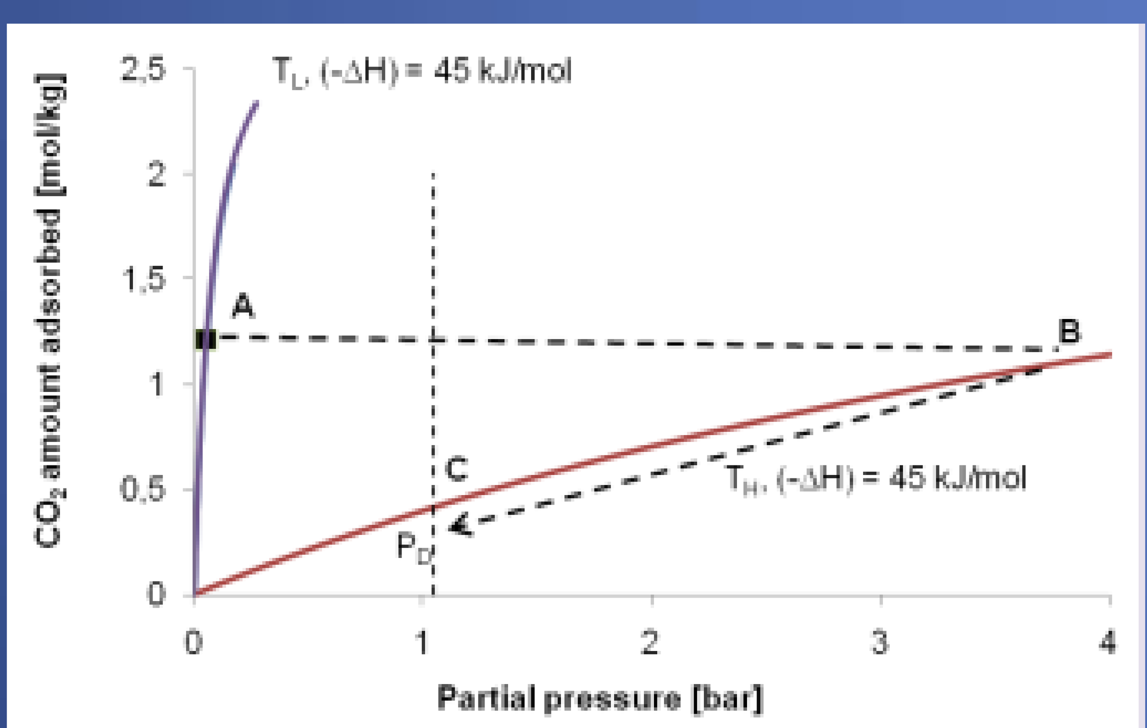

Figure 1: Principle of the temperature swing adsorption cycle; CO_2 is adsorbed at low temperature (LT) isotherm (point A). The adsorbed CO_2 is released by heating following the stippled lines (to B) then to C. The vertical distance between point C and A indicates the cyclic working capacity.

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

	Knaebel, 2005	Hornbostel et al., 2011	Kim et al., 2013	SINTEF (this study)
Feed section	Several horizontal perforated plates. That idea is from old patents but can generate high pressure drop.	Use of structured packing for solid distribution	Not specified but it is a fixed bed	Structured packing for distribution. Pressure drop assumed to be similar to liquids. Gas hold-up (porosity) equal to 0.8 (at least).
Pre-heater	Necessary for heat integration. Use of heat-transfer fluid. Design not specified.	Necessary for heat integration. Design not specified.	Not used.	Perpendicular tubes after the feed section. Utilization of heat-transfer fluid. Good contact between tubes and solid.
Recovery (regeneration)	Not specified	Not specified	High temperature + vacuum of 0.15 bar (two desorbing reactors). Heat exchangers in parallel plates.	Heat exchangers are parallel plates (gas-solid heat exchangers). Vacuum (0.95 bar) necessary to remove CO_2.
Pre-cooler	Heat-transfer fluid is used to cool-down the adsorbent. Design not specified.	Not specified	Not used.	Perpendicular tubes located after the heat exchanger. Use of closed circuit heat-transfer liquid. Can act to control solid velocity.
Cooler	Not used.	Existing but not specified.	Not necessary (regeneration with vacuum).	More perpendicular tubes across the adsorbent. Cold water is used to speed-up cooling.
Conveyor belt	Used for solid transport and to cool down adsorbent. Mechanical	Used for solid transport (air lift).	Not specified.	Not specified. Energy consumption calculated for mechanical belts.
Other	No details on adsorbent but it may be zeolite 4A. The adsorption bed is very tall (over 10 m).	Activated carbon. First work with relatively short adsorption bed.	Zeolite 13X. Confirm short bed for adsorption	Zeolite 13X. Short adsorption bed.

Knaebel, K. S. Patent application to Adsorption Res. Inc. (ARI), US7594956 B2. Filed in 2005.
Hornbostel, M. Development of novel carbon sorbents for CO_2 capture. NETL 2011 CO_2 Capture technology meeting.
Kim, K.; Son, Y.; Lee, W. B.; Lee, K. S. Moving Bed Adsorption Process with Internal Heat Integration for Carbon Dioxide Capture. *Int. J. Greenhouse Gas Control*, 2013, *17*, 13-24

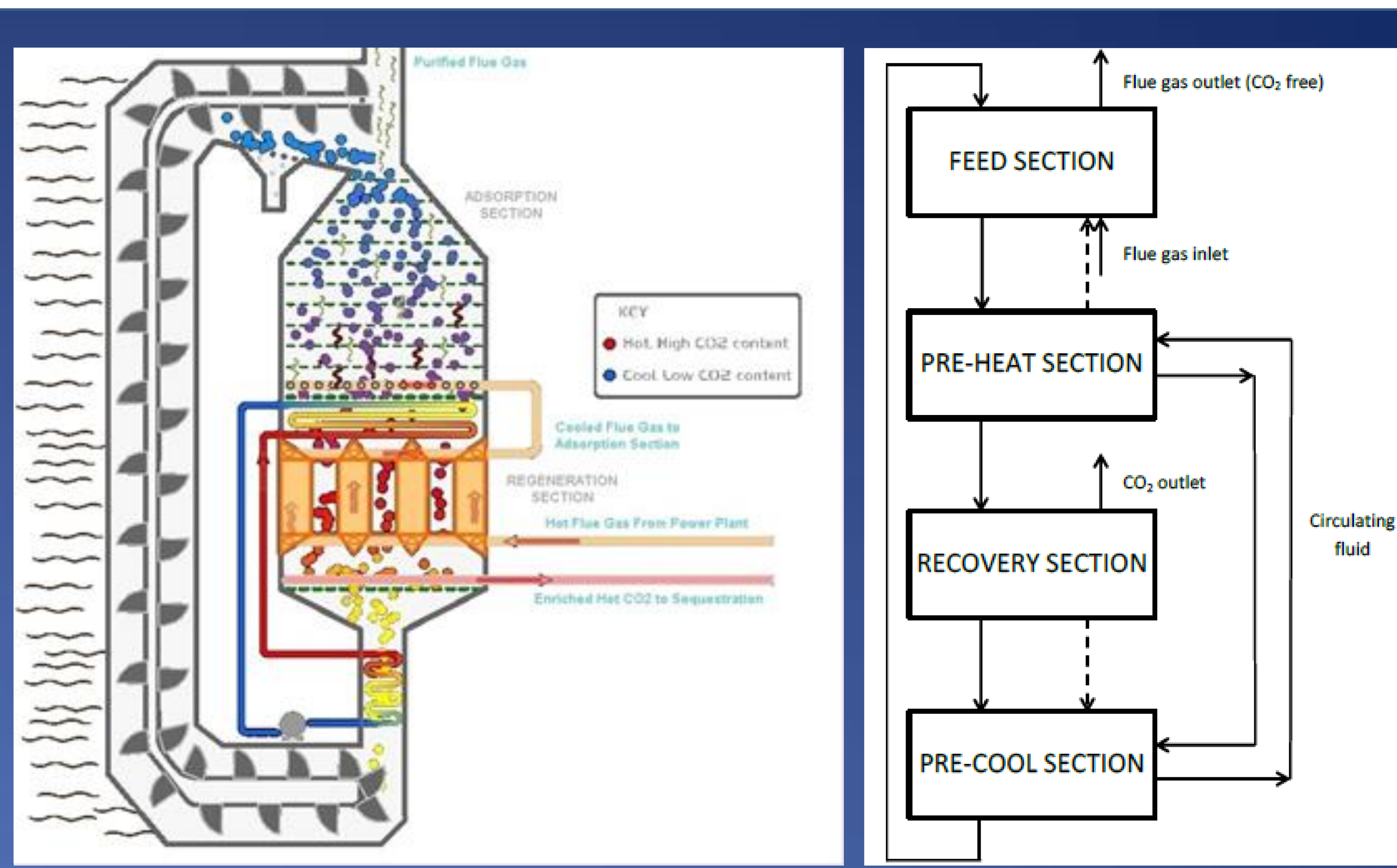

Figure 2: **Left**: Proposed scheme of the MBTSA technology for CO_2 capture from power plants (Knaebel, K.S. 2006. Temperature Swing Adsorption System. US Patent 7,594,956, September 29, 2009). **Right**: Schematic drawing of the different reactor sections considered in the modelling.

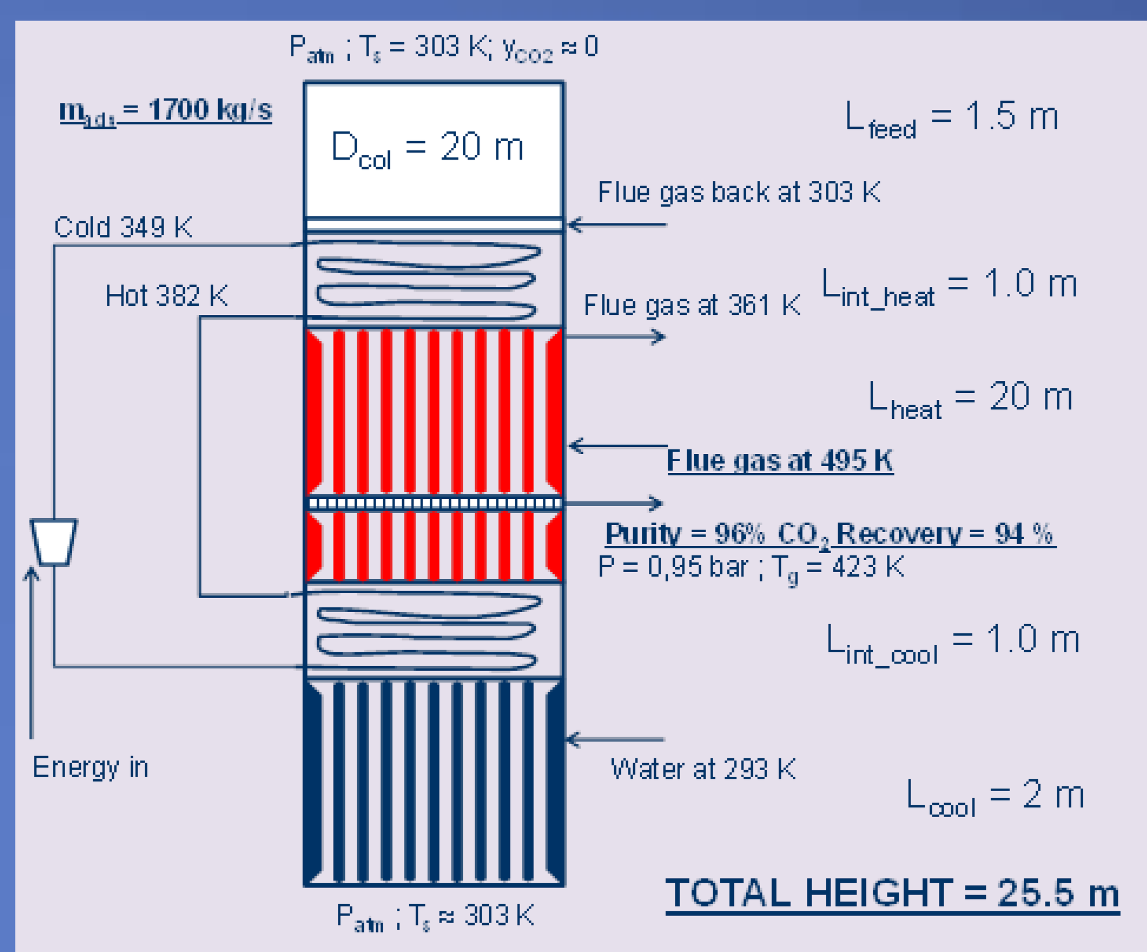

Figure 3: Estimated dimensions of the MBTSA process for CO_2 capture from gas-fired power plants. Also the temperatures in the different sections are shown. Regeneration is done by the use of hot flue gas/steam at 495K.

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

	CCGT without capture	CCGT MBTSA	CCGT EBTF 430 MW MEA reference [b]	CCGT MEA reference (this study) [c]
Heat requirement (MW_{th})	-	114	149	146
Specific Heat requirement (GJ_{th}/tonne CO_2 captured)	-	2.3	4.0	3.1
Loss in el. production due to heat (MW_{el})	-	36.5	31.5	32.0
Blower (MW_{el})	-	2.5	7.4	5.8
LVC compressor (MW_{el})	-			4.6
CO_2 compression (MW_{el})	-	16.4	13	13.1
Pumps (MW_{el})	-	1.0[a]	3.6	1.7
Total el. Requirement (MW_{el})	-	56.4		57.2
Total efficiency (%)	58.0	51.5	49.3	51.4
Net electrical output (MW_{el})	500.0	443.6	388.3	442.8

[a] Set arbitrary to 1.0, it should be low. [b] Can be downloaded at: http://www.co2cesar.eu/site/en/downloads.php
[c] An optimized MEA process including a lean vapor recompression loop that decreases the thermal heat requirement (Knudsen, J.N., Andersen, J., Jensen, J.N., and Biede, O., *Energy Procedia*, 2011, 4, 1558)

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 CO_2 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 CO_2 content might be regenerated by direct heating in steam at significantly lower temperatures.

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