267873 EDeMoTeC

Enabling technology for the Development of moving bed Temperature swing adsorption (MBTSA) process for post combustion CO2 capture

Final report

Main project results

The MBTSA process for post-combustion CO_2 capture was first suggested around 15 years ago by K. S. Knaebel at ARI (Patent US7594956 B2. Filed in 2005). Since then, to our knowledge MBTSA pilot plant development has been going on at SRI in US (around 2010-2012), in Kawasaki in Japan (Since 2014) and at SINTEF in Oslo (Since 2018, through the ECCSEL CCS RI project 245822). Other groups in Brazil and South Korea have contributed to the development with process modelling. The MBTSA concept is like state-of-art amine solvent-based processes in that the sorbent flows counter-current to the flue gas through an adsorber section (see Figure 1) before CO_2 is stripped off in the regenerator, then cooled down for a new cycle. Since the solid sorbent based MBTSA process concept is much younger than similar solvent-based processes, there are much more uncertainties in process design and how to handle the solid sorbent circulation.

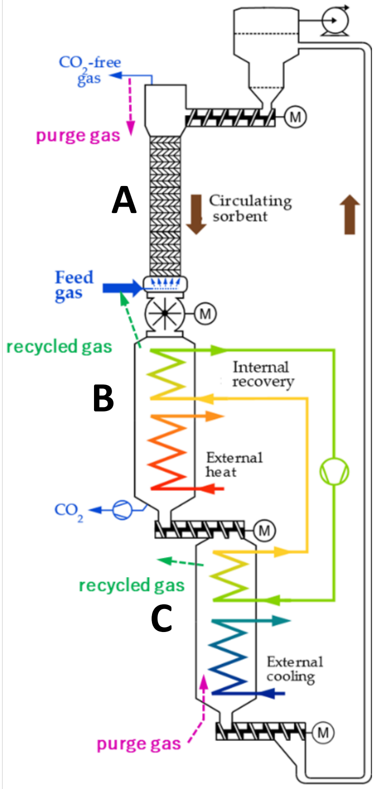

Figure 1: Schematic drawing of MBTSA pilot at SINTEF. **A**: Adsorption section, **B**: Regenerator, and **C**: Cooling section.

The EDeMoTeC project was established to get more insight on the most uncertain parts of the MBTSA process and thus drive the development one step further towards application:

- what kind of adsorbent and adsorbent shape that is optimal for the MBTSA process,
- carry out experiments to get better estimates of uncertain process parameters to improve the mathematical model of the process simulator, and
- understand better how to run such a process to achieve the target capture rate and CO_2 purity at the lowest possible energy requirement.

Our tools in the project have been both experimental and mathematical simulations. Typically, we have used experimental methods to derive parameters for the chosen adsorbents and our inhouse pilot setup so less more or less well-founded guessing is needed in the process simulation part of the project. In our pilot MBTSA rig we have chosen to have indirect heating and cooling in the regenerator and cooling sections. The alternative would have been to use direct heating with steam which would be much faster but would also require that the adsorbent was dried before a new cycle. Since many new adsorbent materials (especially metal-organic frameworks (MOFs) and Zeolites) either are not stable in water vapor at 130 °C or would require a lang drying step prior to a next cycle, we have chosen to use indirect heating and cooling, since then different adsorbent materials can be compared on a fair basis.

Overall, we believe the project has led to more reliable results on the performance of the MBTSA process in various post-combustion CO_2 capture contexts.

Throughout the project period (2018 to 2022) We can point at the following main findings:

1. We have evaluated activated carbon (AC), Zeolite 13X, amine-grafted silica and a chosen metal-organic framework (CPO-27-Ni) as adsorbents for the MBTSA process. All adsorbents can be used, but the size of the process (footprint) is largely dependent on the cyclic capacity of the adsorbent and the cycle time. Of these classes of adsorbent materials both Zeolite 13X and the MOF show good performance with energy requirements close to that of amine solvent-based processes, while amine-grafted silica adsorbents are thermally too unstable at the temperatures needed for regeneration (>150 °C) and AC have too low cyclic capacity leading to extremely large process footprint. Results with AC, MOF and Zeolite 13X have during the project been thoroughly published in NGCC and waste-to-energy contexts and earlier in a coal fired power plant context.
2. The residence time of the adsorbent spheres in the adsorber is short (< 1 min), but more time is needed in the regenerator since the indirect heat transfer from the heating fluid to the adsorbent is relatively slow. The time needed to heat the adsorbent in the regenerator will strongly determine the cycle time of the process and thus the footprint of the full process. We have estimated the heat transfer in our inhouse pilot to be 70-120 W/m^2 K, in-between typical heat transfer coefficients for fixed bed (10-50 W/m^2 K) and fluidized bed systems. To get a better estimate of the heat transfer coefficient has been very important to improve the reliability of the process simulation results.
3. A very important way to lower the energy requirement of the MBTSA process is to heat integrate the various parts of the process: Of special importance is to use the heat of the hot adsorbent powder leaving the regenerator to heat the cold adsorbent powder entering the regenerator. Other options is to use a heat pump to transfer heat from the adsorber to the preheating part of the regeneration section.
4. Gas recirculation, both from the top of the regenerator and from the cooling section is needed to reach the target CO_2 capture rate (>90%) and CO_2 purity (>97%). The recirculation possibility has also been implemented to the MBTSA pilot at SINTEF in the last part of the project.

Are the results in accordance with the goals?

The primary objective of the project is to perform proof-of-concept study of the moving-bed temperature swing adsorption (MBTSA) process.

- ✓ *Status July 2022: We have been able to carry out continuous testing of AC sorbent in the pilot MBTSA with >90% capture rate, but maximum CO_2 purities of around 30%. As such these tests show that the basic principle is working (proof-of-concept), but more work must be put on finding ways to improve the CO_2 purity.*

Secondary objectives were:

1. Find best adsorbent for the process.
   => *There is now "best adsorbent" so far, but our experience indicates that several adsorbents can be used giving similar performance*.
2. Develop an improved reactor model of the continuous process.
   => *The MBTSA process model has been further developed and improved throughout the project by including experimentally derived heat transfer parameters as well as better characterized adsorbent spheres. This reduces the uncertainties in the simulation results*.
3. Test the most promising sorbents in a continuous lab-scale MBTSA unit - proof-of-concept!
   => *Still only a limited number of adsorbents have been evaluated for MBTSA. So far, there is*

no clear winner, but several adsorbents can be used giving performance and energy requirements close to amine-based processes.

4. Based on reactor testing and modelling, carry out proper integration and benchmarking of the process for the said sorbents in selected power plant, industrial and waste combustion contexts.
   => *We have made full integration for NGCC and waste-to-power plants*.
5. Educate one PhD candidate
   => *Our PhD student, Giorgia Mondino, defended her degree in April 2022*.
6. Publish at least 8 papers in international peer review journals.
   => *We have published 3 peer review papers and 2 full proceeding papers (linked to the GHGT conference series). The main reason for the somewhat low number of papers coming from the project is mainly due to delays in the building of the MBTSA pilot (partly due to Covid 19), and the fact that supported amine-based adsorbents didn't work as we hoped they should, and negative results are not easy to publish alone.*
7. Further develop the cooperation with the USA partner towards a common demonstration project.
   => *SRI was part of the project as advisor in the beginning of the project since they have been working on a direct heating MBTSA system using an activated carbon adsorbent. That activity was stopped in SRI in 2018 and the two scientists working in the field left SRI for other activities in other companies. We therefore ended the contract with SRI in 2019. Since there now is no corresponding activity in SRI the plans to work together on a joint project on upscaling and further development of the MBTSA concept was then also cancelled.*

Effects of the project

- When can we expect results from EDeMoTec to be implemented on a full scale?
- How much cheaper has CO_2 capture become with EDeMoTec?
- According to international climate goals, the whole world should be climate neutral by 2050 and CCS will be an important technology to achieve this goal. What is EDeMoTec's contribution in this context?

We are still developing our MBTSA rig within the ongoing H2020 MOF4AIR project (https://www.mof4air.eu/?lang=no). In that project we are now about to upscale one (and maybe two) shaped MOF adsorbents to 10 L scale to be tested in the MBTSA pilot. As part of the project we will also make modification to the rig to improve the process. This work will go on during the second half of 2022 and in 2023.

In addition, we are presently working with a big oil and gas company to evaluate one of their adsorbents for use in an MBTSA process in both NGCC and DAC (direct air capture) contexts.

At presently we also work in a project with TotalEnergies E&P NORGE partly funded by Gassnova named "Disruptive CO_2 capture" where the aim is to evaluate various adsorbent/process concepts on a comparable basis for use to capture CO_2 in a NGCC context. There are several KPIs to be compared with the most important being cost, energy requirement, environmental issues and LCA. In this project also the MBTSA process for NGCC will be further evaluated. We believe the future further development of the MBTSA process will be strongly dependent on the outcome of this study.

So, answering the question of the three bullet points is not possible today. But, after the thorough examination of the different available adsorbent-based technologies done in the "Disruptive" project mentioned in the former paragraph, I am certain that we in 2-3 years are able to answer.