Vacuum Pressure Swing Adsorption using MIL-160(Al) for CO_2 capture from flue gases

Arnaud HENROTIN [a], *Nicolas HEYMANS* [a], *Shyamapada NANDI* [b], *Farid NOUAR* [b], *Georges MOUCHAHAM* [b], *Christian SERRE* [b] *and Guy DE WEIRELD* [a]

[a] *Service de Thermodynamique et Physique Mathématique, Faculté Polytechnique, Université de Mons, 7000 Mons, Belgique, guy.deweireld@umons.ac.be*

[b] *Institut des Matériaux Poreux de Paris, UMR 8004, Ecole Normale Supérieure, ESPCI Paris, CNRS, PSL University, 75005 Paris, France*

Nowadays, power generation and carbon-intensive industries (cement plants, steel plants…) are responsible for around 50% of anthropogenic CO_2 emissions to our atmosphere that mainly contributes to global warming. So, the reduction of CO_2 emissions from industries is crucial. Since several decades, CO_2 capture techniques were investigated to envisage CO_2 storage and chemical reuse. Absorption-regeneration amine-based process, the benchmark solution, suffers from high energy penalties that leads adsorption process a promising alternative thanks to improvement of process design and development of new materials. Among these materials, MOFs appears as very promising materials for both gas separation and purification. However, the performances of these hybrid materials in carbon capture technologies have not been fully evaluated and fine-tuning is still needed for adsorption processes at large scale in real industrial conditions which is the purpose of H2020-MOF4AIR project (https://www.mof4air.eu/).

Several MOFs have been studied to be used in a Vacuum Pressure Swing Adsorption (VPSA) process. MIL-160 (Al)[1,2] ($Al(OH)(O_2C–C_4H_2O–CO_2)$) which is an easily scalable 3D Al-based MOF showing pore size between 4 to 6 Å, has been selected after several experimental measurements at small scale proving their capacity to keep CO_2 capture properties in real conditions (presence of impurities as water, NO_x, SO_2). It was upscaled at 200g-scale and shaped in 2mm-pellets with 3% of PVB by wet granulation. The adsorption performances have been evaluated by pure component adsorption isotherms and breakthrough curves measurements. From these data, a complete simulation of VPSA process using the Linear Driving Force (LDF) model and IAST was performed on Aspen Adsorption® software to evaluate the performances of a VPSA process with MIL-160(Al). Three different configurations were simulated for this study: (i) a 2-stage VPSA process with 2 columns (Skarstrom cycle with 5 steps including pressure equalization)[3] and a 1-stage VPSA process with 3 columns with (ii) 5 steps[4] or (iii) 6 steps[5] including rinse and purge. These configurations have been investigated with a VPSA lab scale pilot able to treat a CO_2/N_2 (15/85) flow of 1m³/h with column of 1.1 liters (L/D ratio of 4.3) in order to reach the targets of such a process: CO_2 purity of 95% and recovery of 90% with the lowest energy consumption. After an optimization of theses processes based on a design of experiments (adsorption time, purge time, purge flowrate, rinse time, rinse flowrate, pressure levels…), the best results were obtained with the 1-stage VPSA process with 6 steps for which the targets were reached (purity of 95.8 % and recovery of 97.8 %) with an energy consumption of around 800 kJ/kg_{CO2}.

References:
[1] A. Cadiau et al., Adv. Mater. 27, 4775 (2015).
[2] D. Damasceno Borges et al., J. Phys. Chem. C 121, 26822 (2017).
[3] C. A. Grande, ISRN Chem. Eng. 2012, 1 (2012).
[4] L. Wang et al., Adsorption 18, 445 (2012).
[5] S. Krishnamurthy et al., Chem. Eng. J. 406, 127121 (2021).

Acknowledgement:

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 831975 (MOF4AIR project).