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Enabling Rapid Thermal Swing Adsorption of Carbon Dioxide using Water-Tolerant Sorbent Coatings

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Abstract

High-performance CO_2 sorbents were formulated as inks and coated onto aluminium fins for heat and mass exchangers, significantly reducing the thermal swing period. Water-tolerant sorbents, including functionalized silicas, Zn-based MOFs, and porous polymer remained effective in 25-75°C rapid thermal adsorption-desorption cycles under humid flue gas, minimizing the need for flue gas dehydration and steam.

Keywords: rapid thermal swing, solid sorbents, heat exchangers, MOF, coupled heat and mass transfer.

Post-combustion CO_2 capture using thermal swing adsorption on packed beds of zeolites, MOFs, activated carbons, and porous polymers has been rigorously investigated previously [1]. Most of the previous efforts focused on processes with high desorption temperatures and steam, as higher desorption temperature increases productivity. Exergy efficiency, however, quickly decreases with the increase of desorption temperature above 90ºC [2]. Although steam and hot feed gas effectively redistribute heat within the adsorption units and enhance efficiency, their high cost makes solid thermal swing capture less appealing [3]. To avoid thermal transfer problems of the packed beds, zeolite-based monoliths are being produced and are often considered as good alternatives to the static sorbent bed. At the same time, zeolites are fully saturated by small humidity levels in the flue gas and require dry flue gas for operation to maintain acceptable CO_2 cycling performance [4]. CALF-20, commercialized by Svante Carbon Capture and Removal and BASF SE, also loses significant CO_2 capacity at high humidity levels [5]. Therefore, water-tolerant sorbent coatings that can be rapidly cycled under humid conditions with low desorption temperatures could revolutionize post-combustion CO_2 capture and significantly lower the cost of captured CO_2 compared to existing technologies.

In this work, some of the best commercially available water-tolerant CO_2 sorbents were formulated in the form of inks, which were then used to apply coatings onto heat and mass exchangers. The state-of-the-art high precision vacuum system with an integrated heat and mass exchanger allowed us to perform rapid thermal swing cycles with these coated sorbents, including amino-functionalized silicas, Zn-based MOFs, and porous polymer. We demonstrated that corresponding heat and mass exchanger coatings with thicknesses of less than 1 mm were operable with 25-75ºC thermal cycles under a simulated wet flue gas with up to 40 g kg^{-1} (14 g CO_2 m^{-2}) cycled mass even at 10-20 mbar water partial pressure (30-60% Relative humidity at 25ºC). As a result, these sorbents have the potential to make rapid thermal & pressure swing technology significantly more effective than any existing market alternatives, minimizing the need for flue gas dehydration and steam usage.

Each cycling experiment was additionally validated using a coupled heat-and-mass transfer model, which allowed to calculate effective CO_2-H_2O diffusivities and demonstrate that water does not significantly influence CO_2 cycled mass for the majority of the studied materials. The results of the model validation are shown in Figure 1 together with the experimental cycling curves. As shown in Figure 1, we can reproduce both surface temperature of the coatings monitored with the infrared sensor and the pressure inside the vacuum chamber with the simulated flue gas. This model can be utilized to describe coatings with other materials and confirms that water does not significantly affect CO_2 diffusivity and thermal efficiency for selected microporous sorbent coatings. As can be seen in the Figure 1, coatings can even be cycled with the periods of less than 2 minutes, making it possible to reach rapid cycling speeds when using sorbent-coated heat exchangers.

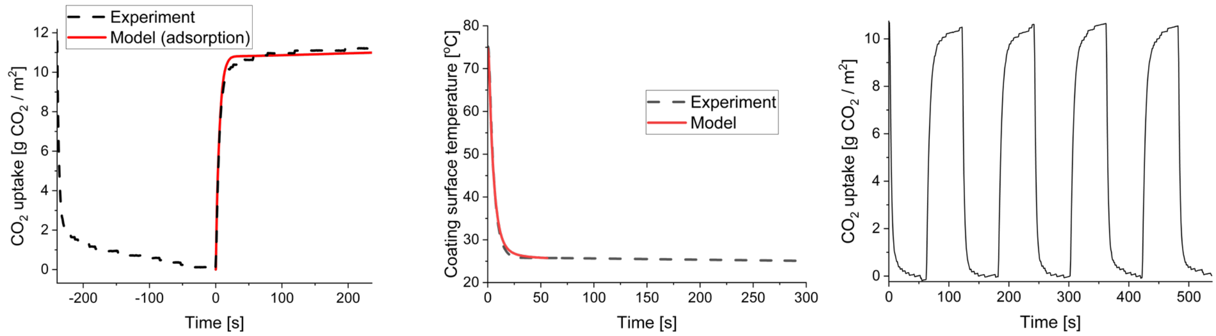

Figure 1. Rapid thermal swing of the functionalized Zn-based MOF coating: CO_2 uptake per m^2 of the coating surface during the entire temperature cycle; temperature during adsorption step; rapid cycles.

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